nationalgrid

Karla M. Corpus
Senior Counsel
NY Regulatory

June 28, 2017

VIA ELECTRONIC MAIL

Honorable Kathleen Burgess
Secretary to the Commission
New York State Public Service Commission
Three Empire State Plaza
Albany, New York 12223-1350

Re: Case 07-M-0548 – Proceeding on Motion of the Commission Regarding an Energy Efficiency Portfolio Standard

Evaluation Status Report – 1st Quarter 2017

Dear Secretary Burgess:

Pursuant to the New York State Department of Public Service Office of Energy Efficiency & the Environment - Energy Efficiency Guidance Document, *EE-10: Reporting Requirements Guidance*, issued June 9, 2016, Niagara Mohawk Power Corporation d/b/a National Grid, The Brooklyn Union Gas Company d/b/a National Grid NY and KeySpan Gas East Corporation d/b/a National Grid (collectively "National Grid"), hereby files its Quarterly Evaluation Status Report ("Status Report") for the period ending March 31, 2017.

Included in this filing is the corresponding Niagara Mohawk Power Corporation d/b/a National Grid March 2017 Custom Compressed Air Impact Evaluation Study ("Compressed Air Study") cited within the Status Report, as well as a separate summary of the Compressed Air Study.

Please direct any questions to:

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Respectfully submitted,

/s/ Karla M. Corpus

Karla M. Corpus
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Enclosure

cc: Christina Palmero, DPS Staff, w/enclosure (via electronic mail)
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Angela Turner, w/enclosure (via electronic mail)
Ann Clark, w/enclosure (via electronic mail)

A. COMPLETED EEPS EVALUATIONS

Evaluations Finalized this Quarter	1
Total Number of Recommendations Made to Date	75
Total Number of Recommendations Implemented to Date	59
Total Number of Recommendations Rejected to Date	1
Total Number of Recommendations Currently in Progress	15

Niagara Mohawk Power Corporation d/b/a National Grid, The Brooklyn Union Gas Company d/b/a National Grid NY and KeySpan Gas East Corporation d/b/a National Grid

B. EEPS Program Evaluation Status Update Table

Evaluation Name	Evaluation Type	Project Kick-Off	Draft Work Plan Submitted to DPS	Workplan Approved by DPS	% of Data Collection Compete	Initial Draft Report Submitted to DPS	Report Approved by DPS	Final Report Filed with the Secretary
Energy Initiative - Electric - Lighting (custom and prescriptive, mid-sized and large)	Impact	Jan-13	Sep-12	Yes	Jul-14	Nov-15	Dec-15	03/31/17
Energy Initiative - Electric - Non Lighting (custom, mid-sized and large) - Custom Compressed Air	Impact	Feb-13	Jan-13	Yes	Mar-15	Dec-16	Q1 2017	Q1 2017
Energy Initiative - Electric - Non Lighting (custom, mid-sized and large) - Custom HVAC	Impact	Feb-13	Jan-13	Yes	Mar-15	Dec-16		
Energy Initiative - Electric - Lighting Controls (custom, mid-sized and large)	Impact	postponed	Jan-13	Yes	postponed	postponed	postponed	
Energy*Wise* Electric Program	Impact	Sep-12	Sep-12	Yes	Mar-13	Sep-13	Mar-15	06/30/15
Electric Enhanced Home Sealing Incentives Program	Impact	None	None	None	None	None	None	
Residential Building Practices and Demonstration Program (Electric)	Impact	2012	2012	Yes	Mar-13	Oct-13	Jan-14	06/30/15
Residential ENERGY STAR® Electric Products and Recycling Program (Thermostats)	Impact	Sep-13	Sep-12	Yes	Jul-13	Sep-13	Mar-15	06/30/15
Residential ENERGY STAR® Electric Products and Recycling Program (Refrigerators and Freezers)	Impact	Sep-10	Jun-10	Yes	Jul-11	Aug-11	Feb-13	02/21/13
Residential High Efficiency Central Air Conditioning Program	Impact	None	None	None	None	None	None	
Small Business Services Energy Efficiency Program - Lighting	Impact	2010	2010	Yes	Summer 2013	Dec-13	Nov-14	06/30/15
Small Business Services Energy Efficiency Program - Lighting with Controls	Impact	2013	2012	Yes	Summer 2014	postponed	postponed	
Energy Initiative - Multifamily, and Commercial & Industrial Gas Energy Efficiency Programs - Prescriptive	Impact	Jan-13	Sep-12	Yes	Summer 2014	3Q 2014	Jul-15	12/31/15
Energy Initiative - Multifamily, and Commercial & Industrial Gas Energy Efficiency Programs - Custom	Impact	Jan-13	Sep-12	Yes	Dec-15	Dec-16		
Energy*Wise* Gas Program	Impact	Sep-12	Sep-12	Yes	Mar-13	Sep-13	Mar-15	06/30/15
Gas Enhanced Home Sealing Incentives Program	Impact	None	None	None	None	None	None	
Residential Building Practices and Demonstration Program (Gas)	Impact	2012	2012	Yes	Mar-13	Oct-13	Jan-14	06/30/15
Residential ENERGY STAR® Gas Products Program	Impact	Sep-13	Sep-12	Yes	Jul-13	Sep-13	Mar-15	06/30/15
Residential High-Efficiency Heating and Water Heating and Controls Program	Impact	Oct-12	Statewide	Yes	[Feb-14]	Apr-14	Aug-14	Joint Statewide Study filed by lead Con Ed on 8/5/2014

Completed EEPS Evaluations

For each program, update the status of the process and impact evaluation recommendations for completed evaluations.

Program Name	Evaluations Finalized this Quarter	Total Number of Recommendations Made to Date	Total Number of Recommendations Implemented to Date	Total Number of Recommendations Rejected to Date	Total Number of Recommendations Currently in Progress
Impact Evaluations					
Residential Building Practices and Demonstration Program (Electric & Gas)		7	4	0	3
Small Business Services Energy Efficiency Program - Lighting		7	7	0	3
Energy*Wise* Electric Program, Energy*Wise* Gas Program, Residential ENERGY STAR® Gas Products Program		4	2	0	2
Prescriptive Gas Program Impact Evaluation	1	10	3	1	5 dependent on TRM MC/DPS modifications- 1 requires future evaluation
Energy Initiative - Electric - Lighting (custom and prescriptive, mid-sized and large)		9	9	0	0
Energy Initiative - Electric - Custom Compressed Air Impact Evaluation Study	1	8	8	0	

Program Name	Evaluations Finalized this Quarter	Total Number of Recommendations Made to Date	Total Number of Recommendations Implemented to Date	Total Number of Recommendations Rejected to Date	Total Number of Recommendations Currently in Progress
Process Evaluations					

Niagara Mohawk Power Corporation
d/b/a National Grid ("National Grid")

Energy Initiative - Commercial & Industrial Electric Program: Impact Evaluation of Custom Compressed Air Installations

Final Approval Date: March 2017

PROGRAM SUMMARY

The Energy Initiative - Commercial & Industrial Electric Program ("EI") provides rebates for the installation of energy-efficient measures for large commercial and industrial ("C&I") customers. Key measure types installed through the program include air compressors and dryers.

EVALUATION OBJECTIVE AND KEY FINDINGS

The primary objective of this evaluation is to quantify the gross annual energy and summer demand impacts of custom compressed air measures installed through the EI program. Key results include the peak summer kW demand reduction and realization rate and the kWh savings and realization rate. The study was designed to utilize on-site verification and monitoring to assess gross impacts. The evaluation was designed to achieve ±10.0% at the 90% confidence level for gross energy (kWh) savings.

The saving values in Table 1 below are for custom compressed air and are based on the metering & verification ("M&V") site results discussed below. The custom compressed air realization rate was 71% for the 2011/12 program years.

Table 1. Custom Compressed Air Gross Program Impact

Parameter	Electric Energy (MWh/yr)	Electric Demand (MW)	Natural Gas (MMBtu/yr)
Ex Ante Tracked Savings	12,119,073	1,567	N/A
Evaluation Realization Rate (RR)	70.8%	69.6%	N/A
Ex Post Gross Impact	8,583,362	1,090	N/A

DETAILED FINDINGS: REALIZATION RATES

Realization Rate:

- The energy savings realization rate for custom compressed air from the on-site M&V work is 70.8% with a precision of +/- 6.9% at the 90% confidence interval.
- The summer peak demand realization rate for custom compressed air from the on-site M&V work is 69.6% with a precision of +/- 13.1% at the 80% confidence interval.

EVALUATION METHODS AND SAMPLING

DNV GL performed onsite assessments of equipment installed at the facilities of 25 customers that participated in the program in 2011 or 2012. These on-site visits were statistically selected, and included comprehensive inventories and on-site metering performed for a duration of one to six months depending on the specific site needs. The method for the on-sites with metering adheres to the International Performance Measurement and Verification Protocol ("IPMVP") Option A. Spreadsheet engineering calculations were used to develop all savings estimates of interest for each sampled site. This analysis was performed in a manner that allowed the determination of impacts at each site and the primary reason for discrepancies observed between the gross and tracking savings estimates. These site level results were analyzed to represent the impacts of the custom compressed air population, along with all accompanying precisions.

RECOMMENDATIONS AND PROGRAM ADMINISTRATOR RESPONSE

The following recommendations were made by the evaluators conducting this study. National Grid's response to these recommendations is also summarized below.

Recommendation 1: This recommendation applies mostly to compressed air, but should be considered for all custom measures. The technical assistance ("TA") firm or equipment vendor savings estimate reports seemed to have used pre-implementation meter data for many projects. Having the data available would provide valuable information for use in the post analysis and would also be helpful for assessing and understanding any discrepancies. Some of the TA reports were very well documented while other calculations could have been more thorough. Asking the vendors/TA firms to provide the raw data with the reports would not be that difficult, but would require some way to transfer large files (e.g., big Excel files). For compressed air projects, "Raw" data includes the compressor "performance curves" used, whether that is Compressed Air & Gas Institute (CAGI) data sheets, AirMaster+, manufacturer performance specifications, or actual power/flow data. Having the data available will help evaluators specifically target reasons for discrepancy. In some cases, additional information was available and provided to the evaluation team throughout the study by the Evaluation Study Manager.

Response to Recommendation 1:

National Grid agrees with this recommendation and has already asked implementers to better document and store detailed project data and files.

Recommendation 2:

A general theme observed in the discrepancy between tracking and evaluated air demand (average CFM or average kW, average operating hours) was that the evaluated method tended to have greater (observable) resolution in the air demand profile. The TA/vendor reports mostly reported using a high level average method, using a single average CFM and single value for operating hours, or sometimes a few average CFM bins with accompanying operating hours for each bin. A lack of resolution can sometimes over/underestimate air demand by large amounts when the facility's air demand is not static or consistent. There were several sites where this was the case. We also note that other sites had very consistent air demand and, as such, the discrepancy between tracking and evaluated savings due to air demand profile differences was small.

Consider developing a program savings input tool for the TA/vendors to use as opposed to having them submit their own savings calculations. A uniform site data input tool would minimize the variety in data "quality" and would allow for calculations and submissions to be more consistent.

Response to Recommendation 2:

This recommendation is part of ongoing process improvements that are occurring within National Grid when discussing program improvements. An input tool may not be the best or only solution but will be discussed. The length of time for M&V is also part of the discussions with the understanding for balancing length of M&V versus cost of the M&V.

Recommendation 3

Some measures, such as compressed air storage, are difficult to evaluate separately and must be handled as a "whole system" evaluation. This occurs when pre-implementation data is not available at the measure level or tracking savings methodologies do not assess the measures separately (e.g., project is a compressor replacement and a tank expansion but the tracking savings appear to only estimate savings (and incentivize savings) for the compressor retrofit).

We recommend that the program clearly document what measures are being incentivized, and how those measures are being assessed in the savings calculations. Clearly stating the project boundaries will help ensure consistency between the tracking and evaluated savings estimates. The challenges with these measures are that savings are difficult to assess individually and should be incorporated into the compressed air system design savings estimates.

Response to Recommendation 3:

We agree. This recommendation is part of ongoing process improvements that are occurring within National Grid when discussing program improvements.

Recommendation 4: Energy savings typically decrease as compressed air flow increases. This is because at higher flow, the baseline and installed air compressor performance (efficiency) begin to converge. In some cases, at very high loads, the baseline compressor could be more efficient than the installed compressor. In these situations, energy and demand savings are reduced. It is recommended that compressed air demand profiles and corresponding compressor performance be reviewed closely during the implementation period. Ideally, pre and post-installation measurement should be done over a period of two to three weeks to develop a more accurate load profile.

Response to Recommendation 4:

We agree. This recommendation is part of ongoing process improvements that are occurring within National Grid when discussing program improvements. The length of time for M&V is also part of the discussions with the understanding for balancing length of M&V versus cost of the M&V and customers agreeing.

Recommendation 5: Peak demand reduction assumptions need to be clearly stated by the TA/vendor as part of the engineering analysis. In some cases, the evaluation team was not able to determine how tracking peak demand reduction was calculated. Other times the peak demand reduction was accepted as annual energy savings divided by operating hours. The evaluation consistently used the New York Technical Manual definition of hottest, non-holiday weekday between 4-5 pm. The use of different peak savings calculations between the tracking and evaluation estimates could result in larger discrepancies in this savings estimate.

Response to Recommendation 5:

We agree. This recommendation is part of ongoing process improvements that are occurring within National Grid when discussing program improvements.

Recommendation 6: Compressed air flow is a key variable used to determine compressor power . Unfortunately, flow metering is difficult to do during an evaluation due to the intrusive nature of connecting a flow meter in line with the compressor distribution system. The best time to install a flow meter is at the time of the compressor installation. It is recommended that the program investigate the installation of a flow meter, or include it as part of the incentive, when new systems are being installed. This does add cost to the program, but the benefits would be more accurate data on the air demand of the system, which can be used for evaluation as well as customer real time feedback on operational performance.

Response to Recommendation 6:

This recommendation is part of ongoing process improvements that are occurring within National Grid when discussing program improvements. Changes to the implementation phase of projects can be challenging with regard to getting customer and vendor agreement.

Recommendation 7: Throughout the evaluation, it was found that the original documentation provided from the tracking system was not always sufficient to understand exactly how the tracking energy savings were estimated. The Evaluation Study Manager was extremely helpful with obtaining additional documentation from technical representatives and vendors, which provided much more detail on the savings calculations in some cases. Future evaluation teams should be sure to reach out to all parties, including vendors, to be able to collect as much information on these projects early in the process. This may not always be possible, but the additional information will help evaluators better determine why savings estimates may be different between the tracking and evaluated estimates.

Response to Recommendation 7:

Agree.

Recommendation 8: The evaluation estimated annual energy savings based on observed operating conditions at the time of the evaluation site visits. This period was typically between 1 and 2 years after the implementation of the projects. Future evaluations in New York should consider the impact that this has on savings realization rates since New York is most interested in first year savings resulting from energy efficiency projects. Although it is standard evaluation practice to use observed operating conditions at the time of the evaluation to adjust the baseline, it’s possible that some facilities may experience radical changes in production and/or operating schedules between the time of the measure being installed and the time of evaluation. It is recommended that future program and evaluation planners consider this as a key indicator in how and when evaluation studies are planned.

Response to Recommendation 8:

Agree. This should be discussed as a statewide evaluation item so that there is consistency.

Impact Evaluation of Custom Compressed Air

Niagara Mohawk Power Corporation
d/b/a National Grid

Final Approval Date: March 2017

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Tables and Figures

1 EXECUTIVE SUMMARY

This document summarizes the work performed by DNV GL between 2013 and 2015 to quantify the actual energy and demand savings due to the installation of custom compressed air measures installed through Niagara Mohawk Power Corporation d/b/a National Grid ("National Grid")'s Energy Initiative - Commercial & Industrial Electric Program ("EI").

The scope of work of this impact evaluation covered the 2011 and 2012 custom compressed air end uses, which includes air compressors and refrigerated air dryers.

Methods

The evaluation of custom compressed air installations used an approach similar to those of previous evaluations. The primary objective of determining realization rates for energy and summer peak demand savings by conducting on-site Metering and Verification ("M&V") at a statistically selected sample of participant sites from the 2011 and 2012 program year. This impact study consists of the following five tasks:

1. Develop sample design.
2. Develop site measurement and evaluation plans.
3. On-site data gathering and site analysis.
4. Site report writing and follow-up.
5. Expansion analysis and evaluation report.

1.1 Sampling Strategy

The goal of the sample design was to monitor enough sites to produce aggregated realization rates by end use with reasonable precision. The target was 10% precision at the 90% confidence level for energy savings at the end use level. The sample design employed was a stratified ratio estimate approach, which is particularly efficient for programs with a wide variation in site-to-site savings and where a good predictor of site savings exists (the tracking savings).

DNV GL presented several preliminary sample designs stratified by annual kWh for custom compressed air end uses. The parameters considered in the sample design are the number of sample observations planned and the anticipated error ratio of quantity being estimated. The error ratio is a measure of the strength of the relationship between the known characteristic (i.e., tracking system savings) and the quantity being estimated (i.e., evaluated savings). Samples for this study were designed using an error ratio of 0.5 for compressed air.

Table 1 lists the calculated precision estimates for the proposed sample design, following stratification. A precision of ±10.0% was estimated for compressed air at the 90% confidence level. A total of 25 sites were selected for the evaluation.

The final sample required the selection of three back-up sample points. Back-up sample points, were chosen following refusal or unresponsiveness on the part of the customer.

Table 1: Proposed Sample Design

End Use	Projects	Total Gross Savings (kWh)	Error Ratio	Planned Sample Size	Expected Relative Precision
Custom Compressed Air	62	12,119,073	0.5	25	±10.0%

1.2 Findings and Results

The site level evaluation results were aggregated using the final adjusted case weights. The custom compressed air realization rates were estimated and then applied to the total tracking savings to determine their total measured savings. The resulting end use level realization rate is the ratio of the total measured savings to the total tracking savings. Table 2 summarizes the results of this analysis. The table shows the results for annual energy savings and peak demand savings. Since the New York Technical Manual defines the peak as occurring on the hottest summer day, the evaluation refers to peak demand savings as the Summer Peak kW savings in this report.

Table 2: Custom Compressed Air Results

End Use	Statistic	Gross kWh Savings (90% Confidence)	Summer Peak kW (80% Confidence)
Custom Compressed Air n=25	Tracking Savings	12,119,073	1,567
	Evaluated Savings	8,583,362	1,090
	Realization Ratio (Evaluated to Tracking)	70.8%	69.6%
	Relative Precision	±6.9%	±13.1%
	Error Ratio	0.33	0.61

The Gross kWh Savings realization rate for custom compressed air measures was found to be 71%. The relative precision for this estimate was found to be ±6.9% at the 90% level of confidence. The error ratio was found to be 0.33, which is better than the estimate of 0.6 used in the sample design for this study. For the on-peak summer kW, the overall realization rate was 70%, with a relative precision of ±13.1% at an 80% confidence level.

1.3 Recommendations

1.3.1 Realization Rates

The custom compressed air end use resulted in an energy realization rate of 71% with a precision of ±6.9%. This resulted in less than expected energy savings of 8,600 MWh for the 2011 and 2012 installations. There are several reasons for the discrepancies including differences in operating profiles and compressor performance differences.

The following sections present some recommendations for continued improvement in the performance of these custom end uses.

1.3.2 Program Improvement Recommendations

Provide Raw Pre-Installation Data if Available

This recommendation applies mostly to compressed air, but should be considered for all custom measures. The technical assistance (“TA”) reports or vendor savings estimate reports seemed to have used pre-implementation meter data for many projects. Having the data available would provide valuable information for use in the post analysis and would also be helpful for assessing and understanding any discrepancies. Some of the TA reports were very well documented while other calculations could have been more thorough. Asking the equipment vendors/TA firms to provide the raw data with the reports would not be that difficult, but would require some way to transfer large files (e.g., big Excel files). For compressed air projects, “Raw” data includes the compressor “performance curves” used, whether that is Compressed Air & Gas Institute (“CAGI”) data sheets, AirMaster+, manufacturer performance specifications, or actual power/flow data. Having the data available will help evaluators specifically target reasons for discrepancy. In some cases, additional information was available and provided to the evaluation team throughout the study by the Study Manager.

Encourage the use of Higher Resolution Air Demand Profiles when Estimating Savings for non-Static Air Compressor Usage

A general theme observed in the discrepancy between tracking and evaluated air demand (average CFM or average kW, average operating hours) was that the evaluated method tended to have greater (observable) resolution in the air demand profile. The TA/vendor reports mostly reported using a high level average method, using a single average CFM and single value for operating hours, or sometimes a few average CFM bins with accompanying operating hours for each bin. A lack of resolution can sometimes over/underestimate air demand by large amounts when the facility's air demand is not static or consistent. There were several sites where this was the case. We also note that other sites had very consistent air demand and, as such, the discrepancy between tracking and evaluated savings due to air demand profile differences was small.

Consider developing a program savings input tool for the TA/vendors to use as opposed to having them submit their own savings calculations. A uniform site data input tool would minimize the variety in data "quality" and would allow for calculations and submissions to be more consistent.

Provide more Documentation on all Measures being Incentivized

Some measures, such as compressed air storage, are difficult to evaluate separately and must be handled as a "whole system" evaluation. This occurs when pre-implementation data is not available at the measure level or tracking savings methodologies do not assess the measures separately (e.g., project is a compressor replacement and a tank expansion but the tracking savings appear to only estimate savings (and incentivize savings) for the compressor retrofit).

We recommend that the program clearly document what measures are being incentivized, and how those measures are being assessed in the savings calculations. Clearly stating the project boundaries will help ensure consistency between the tracking and evaluated savings estimates. The challenges with these measures are that savings are difficult to assess individually and should be incorporated into the compressed air system design savings estimates.

Consider the Impact of Compressed Air Demand Profiles on Energy Savings

Energy savings typically decrease as compressed air flow increases. This is because at higher flow, the baseline and installed air compressor performance (efficiency) begin to converge. In some cases, at very high loads, the baseline compressor could be more efficient than the installed compressor. In these situations, energy and demand savings are reduced. It is recommended that compressed air demand profiles and corresponding compressor performance be reviewed closely during the implementation period. Ideally, pre and post-installation measurement should be done over a period of two to three weeks to develop a more accurate load profile.

Require that TA/Vendors Document the Methodology for Calculating Peak Demand Savings

Peak demand reduction assumptions need to be clearly stated by the TA/vendor as part of the engineering analysis. In some cases, the evaluation team was not able to determine how tracking peak demand reduction was calculated. Other times the peak demand reduction was accepted as annual energy savings divided by operating hours. The evaluation consistently used the New York Technical Manual definition of hottest, non-holiday weekday between 4-5 pm. The use of different peak savings calculations between the tracking and evaluation estimates could result in larger discrepancies in this savings estimate.

1.3.3 Evaluation Recommendations

Flow Metering to be Installed with any New Air Compressor

Compressed air flow is a key variable used to determine compressor power. Unfortunately, flow metering is difficult to do during an evaluation due to the intrusive nature of connecting a flow meter in line with the compressor distribution system. The best time to install a flow meter is at the time of the compressor installation. It is recommended that the program investigate the installation of a flow meter, or include it as part of the incentive, when new systems are being installed. This does add cost to the program, but the benefits would be more accurate data on the air demand of the system, which can be used for evaluation as well as customer real time feedback on operational performance.

Use Error Ratio from this Study for Future Sample Design Planning

The use of the 0.50 for compressed air in the sample design was found to be higher than the actual resulting error ratio of 0.35 for each end use. Future custom compressed air sample designs could use a lower error ratio estimate or 0.4 or 0.5, which would have the effect of reduced sample sizes. If peak demand savings are important, evaluation should consider designing a sample using an error ratio of 0.6.

Collect Available Data from Vendors

Throughout the evaluation, it was found that the original documentation provided from the tracking system was not always sufficient to understand exactly how the tracking energy savings were estimated. The Evaluation Study Manager was extremely helpful with obtaining additional documentation from technical representatives and vendors, which provided much more detail on the savings calculations in some cases. Future evaluation teams should be sure to reach out to all parties, including vendors, to be able to collect as much information on these projects early in the process. This may not always be possible, but the additional information will help evaluators better determine why savings estimates may be different between the tracking and evaluated estimates.

Consider how Future Impact Evaluations are Planned

The evaluation estimated annual energy savings based on observed operating conditions at the time of the evaluation site visits. This period was typically between 1 and 2 years after the implementation of the projects. Future evaluations in New York should consider the impact that this has on savings realization rates since New York is most interested in first year savings resulting from energy efficiency projects. Although it is standard evaluation practice[1] to use observed operating conditions at the time of the evaluation to adjust the baseline, it’s possible that some facilities may experience radical changes in production and/or operating schedules between the time of the measure being installed and the time of evaluation. It is recommended that future program and evaluation planners consider this as a key indicator in how and when evaluation studies are planned.

[1] State & Local Energy Efficiency Action Network. Energy Efficiency Program Evaluation Guide. Section 4: Calculating Energy Savings.https://www4.eere.energy.gov/seeaction/sites/default/files/pdfs/emv_ee_program_impact_guide_1.pdf

2 INTRODUCTION

This document summarizes the results of an evaluation of National Grid's EI Program in Niagara Mohawk's electric service territory. The EI Program provides rebates for the installation of energy-efficient measures for large commercial and industrial ("C&I") customers through prescriptive and custom tracks. Key measure types installed through the program include lighting, lighting controls, energy management systems ("EMS"), economizer controls and air-compressors. This impact evaluation study is focused only on the Custom track for compressed air measures.

2.1 Study Objectives

The primary objective of this evaluation is to quantify the gross annual energy and summer demand impacts of custom compressed air measures installed through the EI program. The savings and factors of interest to the study include the kWh savings and realization rate, and summer peak demand savings and realization rate. The study was designed to utilize on-site verification and monitoring to assess gross impacts. The evaluation was designed to achieve ±10.0% at the 90% confidence level for gross energy (kWh) savings.

2.2 Scope

The scope of work of this impact evaluation covered the 2011 and 2012 custom compressed air end uses. This impact evaluation includes only measures which primarily reduce electricity consumption.

This impact study consists of the following five tasks:

1. Develop sample design.
2. Develop site measurement and evaluation plans.
3. On-site data gathering and site analysis.
4. Site report writing and follow-up.
5. Expansion analysis and evaluation report.

2.3 Evaluation Methods

To estimate gross savings for custom compressed air, we performed M&V work including power monitoring and time of use metering at a statistically selected sample of EI program participants. The New York Evaluation Plan Guidance for EEPS Program Administrators provides guidelines for statistical based evaluation work in New York and advises estimating gross energy savings at ±10% at 90% confidence. DNV GL used Model-Based Statistical Sampling ("MBSS") methodologies to inform a sample design that met these targets.

2.3.1 Description of Sample Design

The primary focus of the sample design was to examine various precision scenarios for the custom compressed air end uses in the EI program. The initial design approach was to support the estimation of annual kWh savings realization. The study population is summarized in Table 3.

Table 3: Population Summary

End Use	Projects	Total Gross Savings (kWh)	Average Savings (kWh)	Minimum (kWh)	Maximum (kWh)
Custom Compressed Air	62	12,119,073	195,469	6,075	1,775,240

The goal of the study was to design a sample that will allow DNV GL to estimate realization rates for annual kWh and summer peak demand savings with a relative precision of ±10% at the end use level. The target for annual kWh was set at the traditional ±10% at 90% confidence, while the target for summer kW was set at ±10% precision at 80% confidence during the design. The evaluation guidelines do not specify confidence interval specifically for kW thus 80% was used based on typical practice.

2.3.1.1 Annual kWh Sample Design

The parameters considered in the sample design are the number of sample observations planned and the anticipated error ratio of quantity being estimated. The error ratio is a measure of the strength of the relationship between the known characteristic (i.e., tracking system savings) and the quantity being estimated (i.e., evaluated savings). Samples for this study were designed using an error ratio of 0.5 for compressed air.

Table 4 shows the stratum cut points and distribution of sampled projects for the selected sample design.

Table 4: Sample Design Selected with Stratum Cut Points

End Use	Stratum	Maximum Total Gross Savings (kWh)	Projects	Total Gross Savings (kWh)	Planned Sample Size
Custom Compressed Air	1	98,438	26	1,148,949	5
Custom Compressed Air	2	148,603	12	1,558,103	4
Custom Compressed Air	3	215,006	8	1,627,715	4
Custom Compressed Air	4	331,735	7	1,823,488	4
Custom Compressed Air	5	534,330	5	2,201,177	4
Custom Compressed Air	6	1,775,240	4	3,759,641	4

Table 5 lists the calculated precision estimates for this scenario, following stratification. A precision of ±10.0% was estimated for compressed air at the 90% confidence level.

Table 5: Estimated kWh Precision for Selected Sample Design

End Use	Projects	Total Gross Savings (kWh)	Error Ratio	Planned Sample Size	Expected Relative Precision
Custom Compressed Air	62	12,119,073	0.5	25	±10.0%

2.3.1.2 Final Sample

Table 6 presents the list of 25 projects selected as the final sample for custom compressed air sites. The final sample required the selection of three back-up sample points. Back-up sample points, which are indicated in bold in the table, were chosen following refusal or unresponsiveness on the part of the customer.

Table 6: Final Sample Selection

Project Description	DNV GL Site ID	Stratum	Tracking Savings (kWh)	Tracking Savings (Summer kW)
Replace 2 rotary screw compressors with one VFD compressor	DNVCA01	1	53,910	16.5
Replace an air cooled and water cooled air comp with VFD rotary screw compressor	DNVCA02	1	109,376	15.2
Replace one load/unload and one start/stop with VFD compressor	DNVCA03	1	32,986	7.0
Install 3,000 Gallon Compressed Air Tank	DNVCA04	1	35,095	11.1
Replaced 2 air cooled recip compressors with 25-hp rotary screw compressor with VFD controls , integrated air dryer and air storage tank	DNVCA05	1	14,135	4.4
Replaced 1 rotary screw comp with air cooled rotary w/ VFD flow controls, added storage tank, added pressure / flow / compressor sequence controller	DNVCA06	2	122,975	15.3
Repair Approximately 200 Air Leaks	DNVCA07	2	165,114	19.4
Replaced 2 load/unload oil rotary screw comp with 1 VFD compressors	DNVCA08	2	153,159	17.7
Replace oil rotary screw comp w/ inlet modulation and blowdown flow control with rotary screw VFD comp and flow controller	**DNVCA09**	**2**	**181,038**	**64.2**
Redesign air system. Add 3 compressors and 2 pressure regulators. Retired existing compressors.	DNVCA10	3	238,896	29.3
Replace rotary screw modulating with VFD compressor and add air storage tank	DNVCA11	3	204,651	23.4
Replaced rotary screw load/unload with single stage rotary screw VFD compressor	DNVCA12	3	223,463	27.7
Replace air cooled oil rotary screw load/unload with air cooled oil VFD rotary screw and additional air storage tank	DNVCA13	3	237,276	38.0
Replace 3 fixed speed rotary with 1 VFD compressor	DNVCA14	4	256,061	24.3
Replace 2 fixed speed rotary screw compressors with 2 VFD compressors.	DNVCA15	4	262,800	30.0
Replace fixed speed rotary screw compressor with a VFD compressor and add dryer and storage tank.	**DNVCA16**	**4**	**251,410**	**0.0**
Replace two inlet modulating air compressors with water cooled VFD comp and add storage tank and pressure / flow controls.	DNVCA17	4	270,315	31.0
Replace 2 rotary screw compressors with one liquid cooled VFD rotary Compressor and add air storage tank and flow meter	DNVCA18	5	593,700	68.2
Redesign air system to reduce demand and optimize CFM and pressure. Retire some existing air compressors.	**DNVCA19**	**5**	**471,584**	**56.5**
Replace 2 air cooled fixed speed rotary screw with VFD air cooled oil free rotary compressor. Added flow controller and additional air storage tanks.	DNVCA20	5	432,889	49.4
Replace 2 start/stop compressors with VFD two stage compressor. Added additional air storage.	DNVCA21	5	487,200	46.0
Air plant optimization and fix air leaks. Replace modulation with VFD compressor. Added mist eliminator and flow controller.	DNVCA22	6	646,760	74.0
Install 150 hp VFD Compressor	DNVCA23	6	799,896	0.0
Add VFD compressor to act as lead and keep existing compressors	DNVCA24	6	758,234	96.0
Redesign of lead/trim compressors. Replace water cooled oil rotary screw compressors with water cooled VFD compressors. Additional air storage. New dryer. Flow pressure controller added.	DNVCA25	6	1,972,489	199.3

2.3.2 Description of Methodology

This section describes the methodology generally for the development of site evaluation plans, the execution of the plans, and the final process for producing program results. The site evaluation activities were conducted in accordance with established M&V protocols, including the Uniform Methods Project[2] for compressed air measures. The focus of the work was to develop adjusted gross energy (kWh) and summer peak demand (kW) savings. The on-site M&V activities included:

- Comprehensive documentation review.
- Site-specific measurement, verification, and analysis (MVA) plans.
- Physical verification of installed quantity, technologies, and operating conditions.
- Review and validation of measure eligibility and, where applicable, baseline.
- Time-Of-Use (TOU) and power monitoring for a minimum of four weeks to characterize operating, load, and demand profiles.
- Computation of energy and demand savings.
- Individual site reporting

2.3.2.1 Documentation Review

The first step in the preparation for an on-site engineering assessment was to conduct a thorough review of existing program documents available from National Grid's files. The purpose of the file review was two-fold. First, a comprehensive file review provided a double check of the program tracking system values for each measure by comparing the tracking system values to the estimates contained in the file. Evaluators also assessed the appropriateness of the applied engineering algorithms in determining energy savings and reviewed the inputs, parameters, and assumptions utilized in the estimate. Second, the file reviews provided a means for evaluators to gather relevant information on the project in preparation for the on-site engineering assessments. Initially, DNV GL requested, and received, the project documentation that was available in National Grid's tracking system. It was later observed that there was additional documentation on vendor calculations and other savings information that was provided by National Grid on a site by site basis. The additional information was used where possible based on usefulness and timing of receiving the information.

2.3.2.2 Measurement and Evaluation Plans

Following the final sample selection of custom compressed air applications and prior to beginning any site visits, the DNV GL team developed detailed measurement and evaluation plans for each of the sampled projects. The plans outlined: on-site methods and strategies; monitoring equipment selection, placement, calibration; and analysis issues.

Evaluators utilized the savings analysis methodologies from the Technical Assistance Study (TA) whenever possible. However, in a small number of cases, the TA methodology was unavailable or found to be incorrect or inappropriate. In those cases, the evaluators performed an analysis more appropriate to the measure being evaluated. In most cases, adjustments to savings methodologies were presented and agreed to in the measurement and evaluation plans.

[2] National Renewable Energy Laboratory (NREL) and Nexant, Inc. (2014). Chapter 22: Compressed Air Evaluation Protocol. http://energy.gov/sites/prod/files/2015/01/f19/UMPChapter22-compressed-air-evaluation.pdf

The site evaluation plan played an important role in establishing approved field methods and ensuring that the ultimate objectives of the study were met. Each site visit culminated in an independent engineering assessment of the actual (e.g. as observed and monitored) annual energy, and summer peak demand savings associated with each project.

2.3.2.3 On-Site Data Gathering, Analysis and Reporting

In the context of an energy analysis, the energy consumption of weather dependent measures such as heating, ventilation and air conditioning ("HVAC") equipment, and load-dependent equipment such as air compressors correlates with explanatory variables such as outdoor temperature or production level and operating schedules. Thus, using this definition, all weather-sensitive measures such as HVAC are fundamentally temperature dependent. The load-dependent category includes industrial process measures that run based upon demand for product or according to a defined operating schedule, as well as compressed air measures that operate according to system pressure and air flow.

As weather-dependent and load-dependent measures require distinct M&V approaches, the following section outlines the generic methodology for custom compressed air measures.

Monitoring. The electrical demand of load dependent measures varies as a function of machine loading. The typical approach used for evaluating compressed air measures is using the International Performance Measurement & Verification Protocol ("IPMVP")[3] Option A, Retrofit Isolation. The IPMVP describes Option A as taking measurements on some key parameters and using stipulated values for other key parameters.

Evaluators monitored compressed air system electrical usage by direct power monitoring. The data was incorporated into all analyses and combined with stipulated data for parameters including flow (cfm), pressure, and part-load performance from the Compressed Air & Gas Institute CAGI standard data sheets and discussions with facility personnel.

Verification. All measure equipment was verified during the site visit. Data collection included quantity and size, operating schedules, seasonal usage, system control settings, and other operating characteristics. Equipment and facility operations were discussed with facility personnel to identify any problems in operation.

Analysis. Air compressor loads were calculated using a combination of custom engineering spreadsheets and AIRMaster+, a free online software offered by the U.S. Department of Energy[4]. Performance curves were obtained from manufacturers' CAGI data for baseline operation. Data obtained from site measurements was converted through regression analysis into performance curves across all operating ranges. These performances were then compared in the calculation spreadsheets to verify savings. Regression results are included in site reports in Appendix B.

2.3.2.4 Analysis Procedures

In order to aggregate the individual site results from the custom compressed air samples, DNV GL applied the model-assisted stratified ratio estimation methodology described in References [1] and [2] in Appendix A. The key parameter of interest is the population realization rate, i.e., the ratio of the evaluated savings for all population projects divided by the tracking estimates of savings for all

[3] US Department of Energy (2002). International Performance Measurement & Verification Protocol http://www.nrel.gov/docs/fy02osti/31505.pdf

[4] http://energy.gov/eere/amo/articles/airmaster

population projects. This rate is estimated at the end use level. Of course, the population realization rate is unknown, but it can be estimated by evaluating the savings in a sample of projects. The sample realization rate is the ratio between the weighted sum of the evaluated savings for the sample projects divided by the weighted sum of the tracking estimates of savings for the same projects. The total tracking savings in the population is multiplied by the sample realization rate to estimate the total evaluated savings in the population. The statistical precisions and error ratios are calculated for each level of aggregation.

The results presented in the following section include realization rates (and associated precision levels) for annual kWh savings and summer peak demand (kW) savings as defined by the NY Technical Manual.

3 RESULTS

The custom compressed air analysis consisted of population and sample sites from 2011 and 2012. The sample was post-stratified based on the final disposition of sample points. Case weights were recalculated based on this final sample and are shown in Table 7. The weights reflect the number of projects that each of the sample points represents in their respective populations and allow for the aggregation of results across the strata within each end use.

Table 7: Final Custom Compressed Air Case Weights

Stratum	Maximum Total Gross Savings (kWh)	Projects	Total Gross Savings (kWh)	Projects in Sample	Case Weights
1	98,438	26	1,148,949	5	5.2
2	148,603	12	1,558,103	4	3.0
3	215,006	8	1,627,715	4	2.0
4	331,735	7	1,823,488	4	1.8
5	534,330	5	2,201,177	4	1.3
6	1,775,240	4	3,759,641	4	1.0

3.1 Custom Compressed Air

3.1.1 Custom Compressed Air Site Level Results

Figure 1 presents a scatter plot of weighted evaluated annual MWh savings plotted against the weighted tracking savings for compressed air measures. The dashed line represents a realization rate of 100%. The slope of the solid line in this graph is an indication of the energy savings realization rate and how it relates to a realization rate of 100%. This sample data is scattered below the trend line, which is indicative of a low savings realization rate (i.e., that many of the site level measured savings values are lower than estimated in the tracking system).

Figure 1: Compressed Air Evaluated Savings vs. Tracking Savings (Weighted)

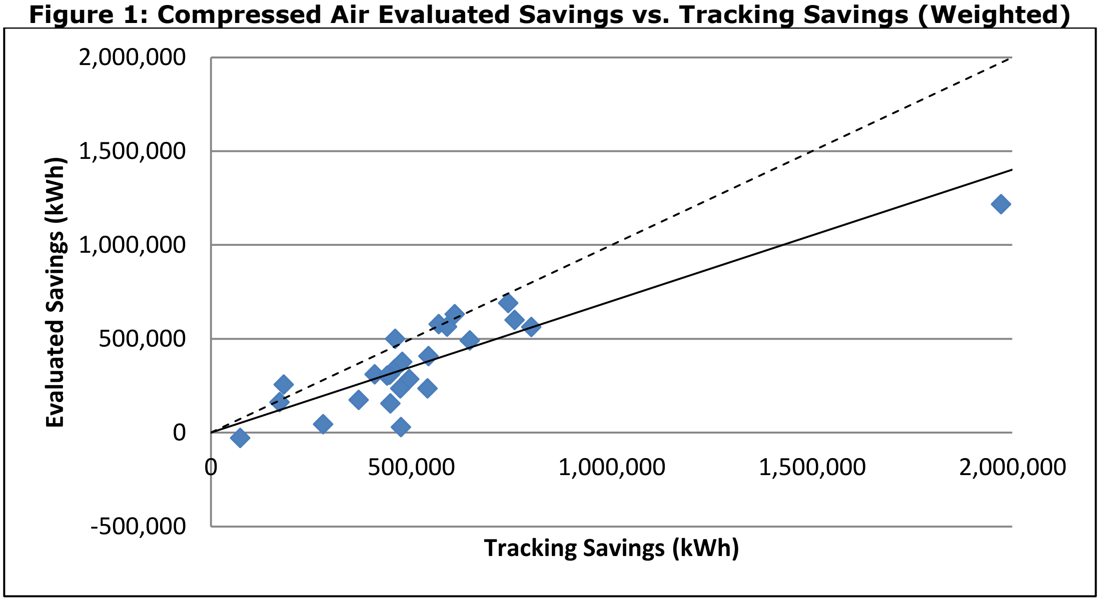


Table 8 presents a summary of the project level results for this impact evaluation. Note that the three projects in bold were all part of the same facility and share a single site as they were all evaluated together as a whole system.

Table 8: Detailed Site Result (Compressed Air)

	Tracking Estimated Savings		Evaluation Savings	
DNV GL Site ID	kWh/yr	Summer Peak kW	kWh/yr	Summer Peak kW
DNVCA01	53,910	16.5	8,271	2.0
DNVCA02	109,376	15.2	110,926	12.5
DNVCA03	32,986	7.0	30,925	7.6
DNVCA04	35,095	11.1	49,053	4.9
DNVCA05	14,135	4.4	-5,658	-1.7
DNVCA06	122,975	15.3	57,907	17.8
DNVCA07	165,114	19.4	94,426	10.0
DNVCA08	153,159	17.7	113,045	27.2
DNVCA09	181,038	64.2	135,583	14.1
DNVCA10	238,896	29.3	188,410	21.6
DNVCA11	204,651	23.4	154,530	12.9
DNVCA12	223,463	27.7	154,045	26.1
DNVCA13	237,276	38.0	13,854	-0.1
DNVCA14	256,061	24.3	149,763	35.0
DNVCA15	262,800	30.0	284,620	32.2
DNVCA16	251,410	0.0	172,575	18.2
DNVCA17	270,315	31.0	134,281	8.2
DNVCA18	593,700	68.2	551,590	63.7
DNVCA19	471,584	56.5	450,230	54.2
DNVCA20	432,889	49.4	187,783	-5.2
DNVCA21	487,200	46.0	504,372	60.7
DNVCA22	646,760	74.0	490,970	55.5
DNVCA23	799,896	0.0	560,896	68.2
DNVCA24	758,234	96.0	599,562	60.4
DNVCA25	1,972,489	199.3	1,216,445	132.0

Table 9 summarizes the energy and demand savings realization rates and primary reasons for discrepancies between the tracking and evaluation estimates of energy savings. The site energy savings realization rates ranged from a low of -40% to a high of 140%. Discrepancies for compressed air measures mainly fell into a few broad categories such as compressor performance differences (e.g. compressor efficiency discrepancies between tracked and evaluated), operating profile differences (e.g. operational loads and hours differences between tracked and evaluated), and savings calculation differences (e.g. one line simple kwh savings calculations used frequently in the tracking savings vs. the 8,760 data points hourly kWh savings analyses used in the evaluation method).

Table 9: Primary Site Discrepancies (Compressed Air)

DNV GL Site ID	Realization Rates		Primary Reasons for Discrepancy
	kWh/yr	Summer Peak kW	
DNVCA01	15%	12%	Compressor performance differences
DNVCA02	101%	82%	Calculation method and compressor performance
DNVCA03	94%	109%	Compressor performance differences
DNVCA04	140%	44%	Possible calculation differences
DNVCA05	-40%	-38%	Tracking calculation error
DNVCA06	47%	116%	Savings calculation differences (one line vs. operating profile)
DNVCA07	57%	52%	Operating profiles
DNVCA08	74%	154%	Compressor performance differences
DNVCA09	75%	22%	Calculation method and compressor performance
DNVCA10	79%	74%	Operating profiles
DNVCA11	76%	55%	Savings calculation differences (one line vs. operating profile)
DNVCA12	69%	94%	Compressor performance differences
DNVCA13	6%	0%	Compressor performance differences
DNVCA14	58%	144%	Operating hours difference
DNVCA15	108%	107%	Savings calculation differences (one line vs. operating profile)
DNVCA16	69%	N/A	Operating profiles
DNVCA17	50%	26%	Compressor performance differences
DNVCA18	93%	93%	Operating profiles
DNVCA19	95%	96%	Savings calculation differences (one line vs. operating profile)
DNVCA20	43%	-11%	Air demand higher than proposed and performance differences
DNVCA21	104%	132%	Operating profiles
DNVCA22	76%	75%	Savings calculation differences (one line vs. operating profile)
DNVCA23	70%	N/A	Operating profiles and compressor performance
DNVCA24	79%	63%	Savings calculation differences (one line vs. operating profile)
DNVCA25	62%	66%	Possible calculation differences

3.1.2 Custom Compressed Air Realization Rates

The site level evaluation results were aggregated using the final adjusted case weights. The site realization rates were estimated and then applied to the total tracking savings to determine their total measured savings. The compressed air realization rate is the ratio of the total measured savings to the total tracking savings. Table 10 summarizes the compressed air results of this analysis. The table shows the results for energy and summer peak demand savings.

The realization rate for custom compressed air measures was found to be 71%. The relative precision for this estimate was found to be ±6.9% at the 90% level of confidence. The error ratio from this study was found to be 0.33, which is much better than the estimate of 0.5 used in the sample design for this study. For the summer peak demand savings, the overall realization rate was 70%, with a relative precision of ±13.1% at an 80% confidence level.

Table 10: Compressed Air Results

End Use	Statistic	Gross kWh Savings (90% Confidence)	Summer Peak kW (80% Confidence)
Custom Compressed Air n=25	Tracking Savings	12,119,073	1,567
	Evaluated Savings	8,583,362	1,090
	Realization Ratio (Evaluated to Tracking)	70.8%	69.6%
	Relative Precision	±6.9%	±13.1%
	Error Ratio	0.33	0.61

3.1.3 Compressed Air Sites with Largest Influence

DNV GL reviewed all sites to determine those that had the largest influence on the compressed air results based on a combination of site savings and sample weight. This section summarizes the top five sites that had the largest influence on the overall realization rate. These sites are discussed in more detail below.

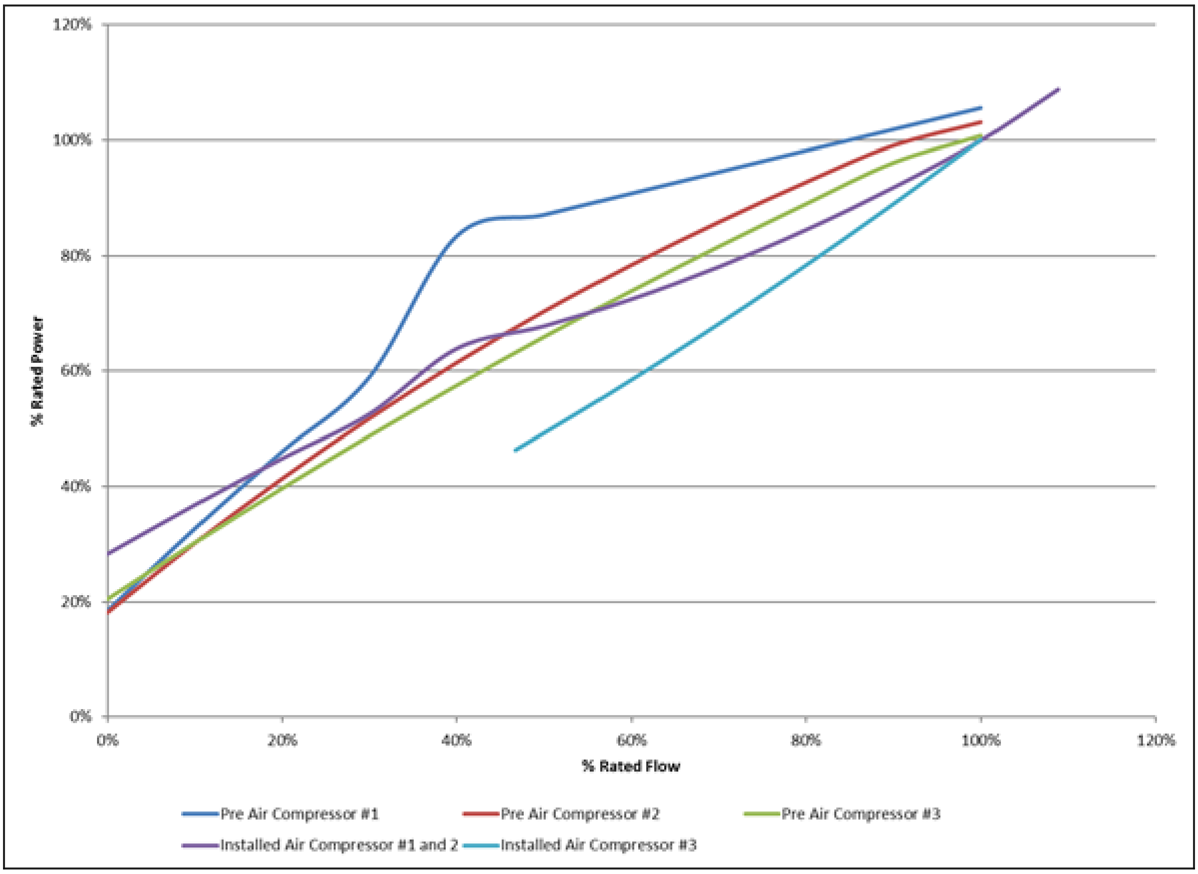
DNVCA25

The project involved the retirement of two (2) pre-retrofit 400-HP water-cooled, oil-injected, single-stage rotary screw compressors and one (1) pre-retrofit 200-HP water-cooled, oil-injected, single-stage rotary screw compressor. The retired compressors were replaced with two (2) 300-HP water-cooled, oil-injected, tandem two-stage rotary screw compressors and one (1) 350-HP water-cooled, oil-injected, tandem two-stage compressor. The project scope also involved the retrofit of the pre-retrofit air dryer with a 5,000 cfm cycling refrigerant air dryer.

Annual energy savings for this project were 62% of the tracking savings estimates. The primary reasons for the decrease in savings were the overall air demand of the facility and the pre-retrofit compressor performance. The tracking savings were estimated based on short term measurement of the pre-retrofit system and the installed system. The pre-retrofit system was measured for a period of eight days. Data collected included pressure, power and flow of each pre-retrofit air compressor at one second intervals. The tracking analysis used only small parts of the data to create an air demand profile for the system as shown in the table below. For example, the tracking analysis used an average over a specific 142 minute period to represent the High Demand period. The evaluation utilized the entire 27 day metering period to estimate the air demand profile of the facility.

	Tracking			Evaluation		
Demand Schedule	CFM	Pre-retrofit Annual Hours estimate	# of Monitored Days	CFM	Pre-retrofit Annual Hours estimate	# of Monitored Days
High Demand	3,206	3,380	0.10	4,134	5,907	27.72
Medium Demand	2,459	2,964	0.07	3,606	2,727	
Low Demand	1,797	2,416	0.06	2,522	126	
Total (CFM-Hours)	22,466,308			34,569,900		

In the table, the total CFM-Hours is used to represent the overall difference in annual compressor system load between the two estimates. The evaluation period shows much higher air demands than the tracking assumption. This results in lower overall savings due to the difference in compressor performance at these higher air flows. The figure below is a graphical representation of the performance of each air compressor at varying airflows. Note that the greatest savings appears to occur between 40% and 60% of full flow. At higher flows, the power values of the pre-retrofit air compressors begin to converge with those of the installed air compressors. The installed compressors #1 and #2 were found to be operating above their rated power at times during the monitoring period. This is depicted by the line representing these compressors, which is extended beyond 100% rated power.



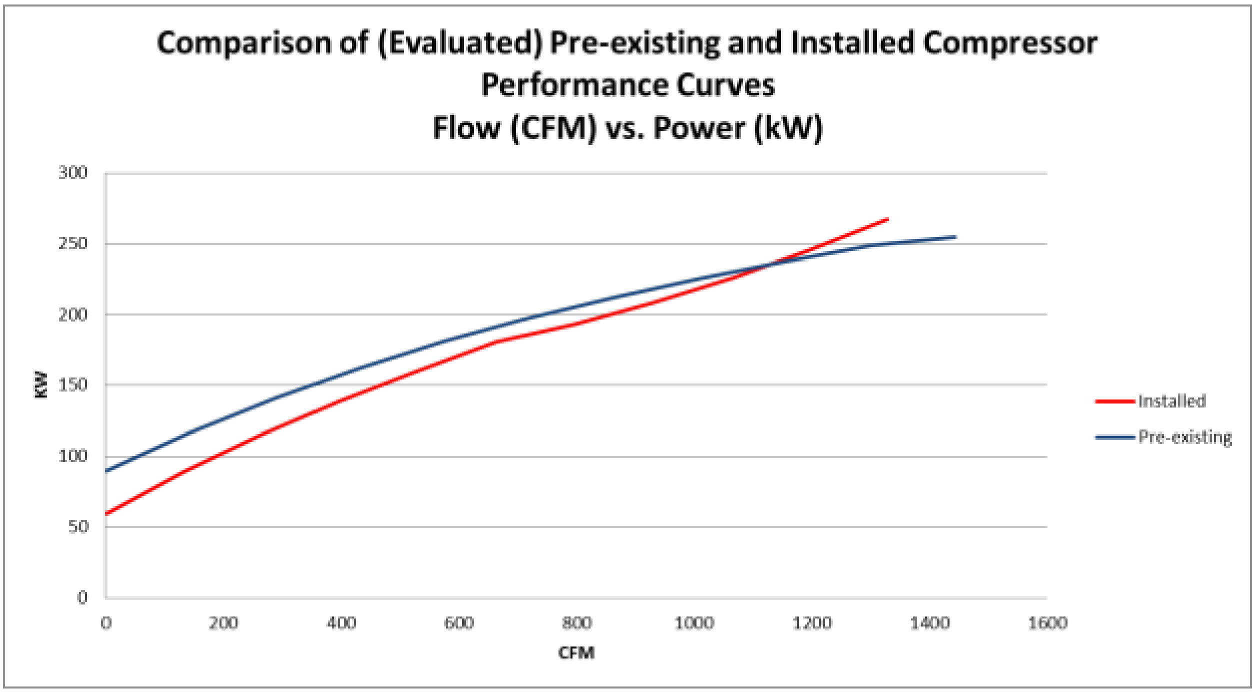
DNVCA13

This project involved the retirement of one (1) pre-retrofit 300-hp air-cooled, oil-injected rotary screw compressor with load/unload controls and the installation of a new 300-hp air-cooled, oil-injected rotary screw compressor with variable displacement flow controls. Additionally, a new 2,000 gallon vertical air receiver tank was installed. The primary reason for the discrepancies found for both the energy and peak demand savings was due to the difference in compressor performance curves. The primary reason for discrepancy between the tracking and evaluated energy savings estimates was the difference between the assumed compressor performance profiles. The tracking savings estimate (documented as a proprietary, hard-coded, vendor savings calculation tool print out) assumes three different average demand schedules and estimates annual hours and compressor load corresponding to the respective schedule’s average demand (cfm). The following table presents the tracking and evaluated compressor load assumed for each demand schedule scenario. The average evaluated pre-retrofit and installed compressor loads were calculated for each average demand schedule by using the corresponding average air demand and the flow (cfm) vs. power (kW) curves developed for the respective compressors.

This approach allows a direct comparison between tracking and evaluated compressor performance estimates.

Demand Schedule Annual Hours	Average Capacity (cfm)	Tracking Pre-retrofit Compressor kW	Tracking Installed Compressor kW	Tracking Demand Reduction (kW)	Evaluated Pre-retrofit Compressor kW	Evaluated Installed Compressor kW	Evaluated Demand Reduction (kW)
3,120	1,085	217.3	197.1	**20.2**	232.9	229.7	**3.2**
1,560	850	214.3	167.6	**46.7**	211.9	200.1	**11.7**
1,560	675	210.7	145.7	**65.1**	192.7	178.5	**14.2**

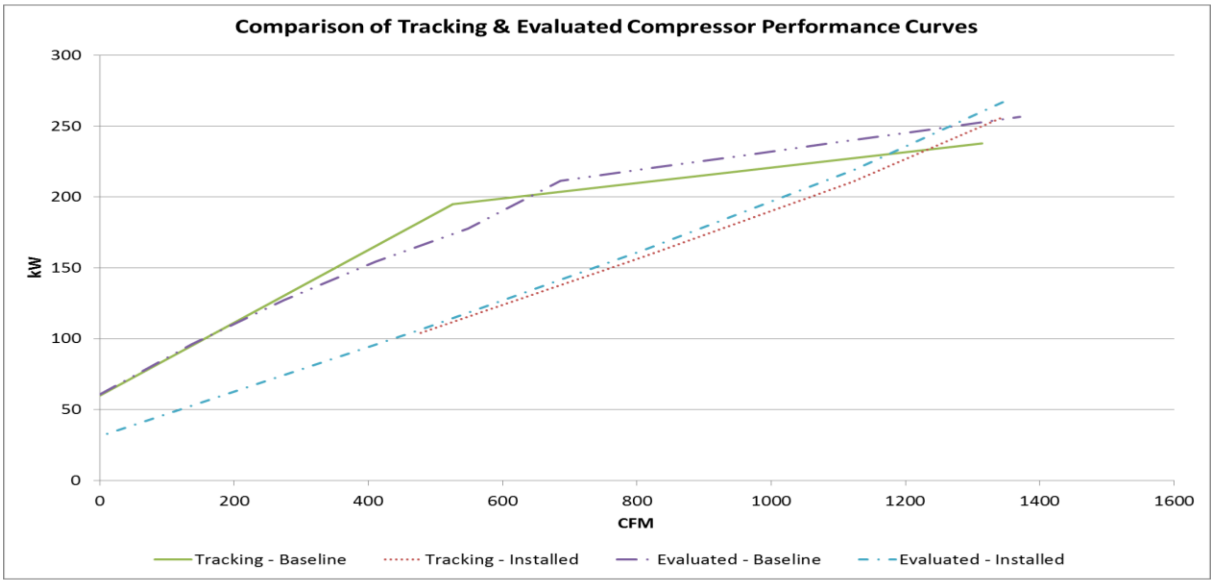
The table above shows that when using the evaluated compressor performance curves the installed compressor operates slightly less efficiently than the pre-retrofit compressor when air demand is high and only slightly more efficiently when air demand is lower. The visual superposition shown below of the evaluated pre-retrofit and installed compressor performance curves (cfm vs. kW) illustrates that the pre-retrofit compressor operates more efficiently when assuming that the supplied air flow from the load/unload compressor follows the optimal performance curve (i.e., the loading/unloading time is ignored). This assumption becomes less reasonable as the frequency of unloading/loading increases. The sampling period of the measured power also has a significant impact on how much error is introduced in to the calculated air flow; having a finer resolution in power measurements increases the accuracy of the calculated installed flow for the corresponding sampling period. The evaluator chose to have a relatively small measurement interval (30 seconds) to increase the accuracy of the calculated flow (and corresponding pre-retrofit compressor load) values. The differences between compressor performance profiles led to a discrepancy of -186,891 kWh (-79%) and -30 kW (-79%).



DNVCA20

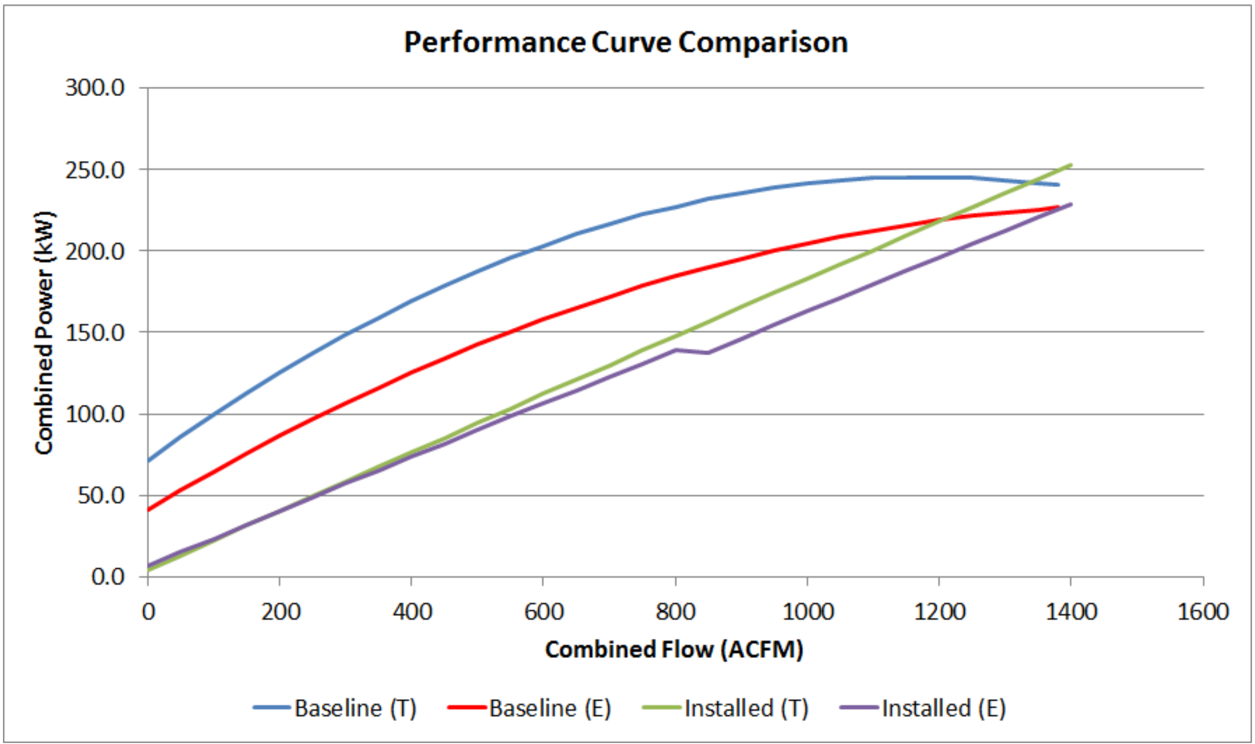
This project involved the retirement of one (1) pre-retrofit air-cooled 200-hp oil-injected rotary screw compressor with inlet modulation controls and one (1) pre-retrofit air-cooled 150-hp oil-injected rotary screw compressor with load/unload controls and a total retrofit storage capacity of 1,000 gallons. These retired compressors were replaced with one (1) air-cooled 335-hp oil-free rotary screw compressor with variable speed (VFD) flow controls. The project scope also installed a new flow controller, one (1) 1,550 gallon vertical air receiver tank, and one (1) 620 gallon vertical air receiver tank. The program claimed savings with a normal replacement baseline reference meaning that the pre-retrofit compressors were not used in the savings analysis. Rather, a comparable baseline compressor (a 300-hp oil-injected single-stage rotary screw compressor with inlet modulation controls) was chosen to estimate savings compared to the proposed compressor.

The primary reason for the discrepancies found for both the energy and peak demand savings was that the air demand profile calculated for the evaluated savings was found to be significantly higher than what was measured during the tracking metering period. The tracking air demand profile had an average flow rate of 825 cfm compared to the evaluated average flow rate of 1,067 cfm (not including the holiday air demand profile). Calculating the average baseline and installed compressor load (kW) at the evaluated average flow rate provides less demand savings (than the tracking case) between the baseline and installed compressor. Since these average loads are also used to calculate annual energy consumption, the evaluated energy savings decreased proportionally to the decrease in average demand difference between the installed and baseline compressor. The chart below presents a visual representation of the compressor performance curves used for both the tracking and evaluation savings, and provides an indication of compressor load (kW) at various air flows. As shown, the delta kW is less at 1,000 cfm versus 800 cfm.



DNVCA23

This customer implemented three compressed air projects at the same facility under three separate project IDs. Project ID DNVCA23 involved the installation of a two-stage rotary screw air compressor with variable speed control in place of two pre-retrofit single stage, inlet modulating compressors. The primary discrepancy between tracking and evaluated savings can be largely attributed to the operating conditions observed during the evaluation. The tracking analysis showed the majority of system operation occurring between 400-700 cfm. Between these loads, the kW reduction was maximized. At loads above 720 cfm, the kW savings decreased. The chart below shows how savings begin to decrease as compressed air flow increases above 720 cfm.



This inverse relationship between savings and compressed air load is the primary source of discrepancy between the tracking and evaluated savings. This facility runs 24/7 and monitoring data showed an average load of approximately 800 cfm and at no point during the evaluation did the compressed air demand drop below 600 cfm.

The tracking analysis also did not estimate any peak demand savings for this project. The compressed air system operates year round and during peak hours, thus peak demand savings should have been calculated. The evaluation thus calculated peak demand savings resulting in a kW savings of 68.2 kW.

DNVCA17

This project involved the installation of two 94 hp variable speed air compressors to replace two pre-retrofit inlet modulating air compressors, one 125 hp and the other 75 hp. The primary source of discrepancy between the tracking and evaluated project savings is a result of the difference between the tracking and evaluated average compressed air load. The tracking analysis stated that both compressors would only operate in rare instances when the system load surpassed 80% of the installed lead compressor's rated capacity, roughly 338 cfm. However, during the trending period, the lowest observed load was approximately 370 cfm. At loads between 370 cfm and 420 cfm both of the installed compressors would have to operate to meet the facility's load, but only baseline compressor #1 would need to operate during the baseline period. The facility operated in this range approximately one quarter of the year, or 2,100 hours which led to a significant decrease in savings.

4 CONCLUSIONS AND RECOMMENDATIONS

4.1 Realization Rates

The custom compressed air end use resulted in an energy realization rate of 71% with a precision of ±6.9%. This resulted in less than expected energy savings of 8,600 MWh between 2011 and 2012.

The following sections present some recommendations for continued improvement in the performance of these custom end uses.

4.2 Program Improvement Recommendations

Provide Raw Pre-Installation Data if Available

This recommendation applies mostly to compressed air, but should be considered for all custom measures. The TA or vendor savings estimate reports seemed to have used pre-implementation meter data for many projects. Having the data available would provide valuable information for use in the post analysis and would also be helpful for assessing and understanding any discrepancies. Some of the TA reports were very well documented while others were just one-line calculations. Asking the equipment vendors and TA firms to provide the raw data with the reports would not be that difficult, but would require some way to transfer large files (e.g., big Excel files). For compressed air projects, "Raw" data includes the compressor "performance curves" used, whether that is CAGI sheets, AirMaster+, manufacturer performance specifications, or actual power/flow data. Having the data available will help evaluators specifically target reasons for discrepancy. In some cases, additional information was available and provided to the evaluation team throughout the study by the Evaluation Study Manager.

Encourage the use of Higher Resolution Air Demand Profiles when Estimating Savings for non-Static Air Compressor Usage

A general theme observed in the discrepancy between tracking and evaluated air demand (average CFM or average kW, average operating hours) was that the evaluated method tended to have greater (observable) resolution in the air demand profile. The TA/vendor reports mostly reported using a high level average method, using a single average CFM and single value for operating hours, or sometimes a few average CFM bins with accompanying operating hours for each bin. A lack of resolution can sometimes over/underestimate air demand by large amounts when the facility's air demand is not static or consistent. There were several sites where this was the case. We also note that other sites had very consistent air demand and, as such, the discrepancy between tracking and evaluated savings due to air demand profile differences was small.

Consider developing a program savings input tool for the TA/vendors to use as opposed to having them submit their own savings calculations. A uniform site data input tool would minimize the variety in data "quality" and would allow for calculations and submissions to be more consistent.

Provide more Documentation on all Measures being Incentivized

Some measures, such as compressed air storage, are difficult to evaluate separately and must be handled as a "whole system" evaluation. This occurs when pre-implementation data is not available at the measure level or tracking savings methodologies do not assess the measures separately (e.g., project is a compressor replacement and a tank expansion but the tracking savings appear to only estimate savings (and incentivize savings) for the compressor retrofit).

We recommend that the program clearly document what measures are being incentivized, and how those measures are being assessed in the savings calculations. Clearly stating the project boundaries will help ensure consistency between the tracking and evaluated savings estimates. The challenges with these measures are that savings are difficult to assess individually and should be incorporated into the compressed air system design savings estimates.

Consider the Impact of Compressed Air Demand Profiles on Energy Savings

Energy savings typically decreases as compressed air flow increases. This is because at higher flow, the baseline and installed air compressor performance (efficiency) begins to converge. In some cases, at very high loads, the baseline compressor could be more efficient than the installed compressor. In these situations, energy and demand savings are reduced. It is recommended that compressed air demand profiles and corresponding compressor performance be reviewed closely during the implementation period. Ideally, pre and post-installation measurement should be done over a period of two to three weeks to develop a more accurate load profile.

Require that TA/Vendors Document the Methodology for Calculating Peak Demand Savings

Peak demand reduction assumptions need to be clearly stated by the TA/vendor as part of the engineering analysis. In many cases, the evaluation team was not able to determine how tracking peak demand reductions were calculated. Other times the peak demand reduction was accepted as annual energy savings divided by operating hours. The evaluation consistently used the New York Technical Manual definition of hottest, non-holiday weekday between 4-5 pm. The use of different peak savings calculations between the tracking and evaluation estimates could result in larger discrepancies in this savings estimate.

4.3 Future Evaluation Recommendations

Flow Metering to be Installed with any New Air Compressor

Compressed air flow is a key variable used to determine compressor power. Unfortunately, flow metering is difficult to do during an evaluation due to the intrusive nature of connecting a flow meter in line with the compressor distribution system. The best time to install a flow meter is at the time of the compressor installation. It is recommended that the program investigate the installation of a flow meter, or include it as part of the incentive, when new systems are being installed. This does add cost to the program, but the benefits would be more accurate data on the air demand of the system, which can be used for evaluation as well as customer real time feedback on operational performance.

Use Error Ratio from this Study for Future Sample Design Planning

The use of the 0.50 for compressed air in the sample design was found to be higher than the actual resulting error ratio of 0.35 for each end use. Future custom compressed air sample designs could use a lower error ratio estimate of 0.4 or 0.5, which would have the effect of reduced sample sizes. If peak demand savings are important, evaluation should consider designing a sample using an error ratio of 0.6.

Collect Available Data from Vendors

Throughout the evaluation, it was found that the original documentation provided from the tracking system was not always sufficient to understand exactly how the tracking energy savings were estimated. The program Study Manager was very helpful with obtaining additional documentation from technical representatives and vendors, which provided much more detail on the savings calculations in some cases. Future evaluation teams should be sure to reach out to all parties, including vendors, to be able to collect as much information on these projects early in the process. This may not always be possible, but the additional information will help evaluators better determine why savings estimates may be different between the tracking and evaluated estimates.

Consider how Future Impact Evaluations are Planned

The evaluation estimated annual energy savings based on observed operating conditions at the time of the evaluation site visits. This period was typically between 1 and 2 years after the implementation of the projects. Future evaluations in New York should consider the impact that this has on savings realization rates since New York is most interested in first year savings resulting from energy efficiency projects. Although it is standard evaluation practice[5] to use observed operating conditions at the time of the evaluation to adjust the baseline, it's possible that some facilities may experience radical changes in production and/or operating schedules between the time of the measure being installed and the time of evaluation. It is recommended that future program and evaluation planners consider this as a key indicator in how and when evaluation studies are planned.

[5] State & Local Energy Efficiency Action Network. Energy Efficiency Program Evaluation Guide. Section 4: Calculating Energy Savings.https://www4.eere.energy.gov/seeaction/sites/default/files/pdfs/emv_ee_program_impact_guide_1.pdf

5 APPENDIX A: REFERENCES

[1] *The California Evaluation Framework,* prepared for Southern California Edison Company and the California Public Utility Commission, by the TecMarket Works Framework Team, June 2005, Chapters 12-13.

[2] *Model Assisted Survey Sampling,* C. E. Sarndal, B. Swensson, and J. Wretman, Springer, 1992

[3] *New York Standard Approach for Estimating Energy Savings from Energy Efficiency Programs – Residential, Multi Family, and Commercial/Industrial Measures (NY Technical Manual)*

[4] New York Evaluation Plan Guidance For EEPS Program Administrators; August 2008 & August 2013

6 APPENDIX B: SITE REPORTS

The DNV GL team completed evaluations of 25 custom compressed air projects as part of this study. Each site culminated in a final site report, which detailed the project, the evaluated savings estimates and findings. The report details the work completed by the DNV GL team to verify the project and re-estimate savings resulting from the rebated energy efficiency measures. Site work included on-site visits, data collection in the form of logger/meter installs and building management system data extracts. Evaluators also conducted interviews with building staff knowledgeable about the operations of the affected equipment.

The site reports also detailed the savings analyses used to estimate hourly energy use, including algorithms, assumptions and calibration methods where applicable.

Each site report was submitted to National Grid for review and comment. Final site reports were issued following evaluator response to questions and comments from National Grid.

DNV·GL

Impact Evaluation of Custom Compressed Air

Appendix B: Site Reports

Niagara Mohawk Power Corporation
d/b/a National Grid ("National Grid")

SITE ID: DNVCA01

Project Type	Early Replacement & Retrofit Add-On
Measure Category	Custom Compressed Air

PROJECT DESCRIPTION

This custom compressed air project involved the replacement of two pre-existing rotary screw air compressors (20-hp and 25-hp) with a new VFD-controlled 50-hp rotary screw compressor. The facility's compressed air end-uses include air-powered hand tools, presses, and conveyors. Table 1 provides the evaluation results while Table 2 provides a summary of the discrepancy analyses.

Table 1: Summary of Evaluation Results

Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
Annual Energy Savings (kWh)	53,910	8,271	15%
Peak Demand Reduction (kW)	16.5	2.0	12%

Table 2: Discrepancy Analysis Summary

Discrepancy Factor	kWh	kW
Operating Conditions	Discrepancy #1 (Compressor Performance): -42,810 or -79%	Discrepancy #1 (Compressor Performance): -13.1 or -79%
Equipment Specifications	N/A	N/A
Calculation Method	Discrepancy #2 (Different Methodology & Air Profile): -2,829 or -5%	Discrepancy #2 (Different Methodology & Air Profile): -1.3 or -8%
Inappropriate Baseline	N/A	N/A

TRACKING SAVINGS

This section summarizes the methodology and assumptions used to estimate the Tracking savings claimed for the project.

Project Description

The customer operates a facility that had a compressed air system whose demand was met by one (1) pre-existing air-cooled rotary screw 20-hp compressor and one (1) pre-existing air-cooled 25-hp rotary screw compressor. The compressed air end-uses were not described in the project documents. The pre-installation form notes a total of 240 gallons pre-existing air storage. These compressors had load/unload controls and were staged such that the 20-hp compressor handled the base load while the 25-hp compressor handled the trim load. The air demand allowed the 20-hp compressor to stay fully loaded during all air demand schedules. During pre-M&V monitoring, it was determined that there were four distinct compressed air demand day type schedules or shifts. The demand schedules are listed in the Baseline Operating Condition section, below. These compressors were replaced with a new 50-hp VFD-controlled air-cooled rotary screw compressor. The project scope also proposed a new 500 gallon horizontal air receiver tank. The tracking savings only claims the compressor replacement savings and does not estimate the incremental savings associated with the air storage tank. The new VFD compressor will handle the entire demand without being fully loaded during peak demand periods.

The proposed Energy Conservation Measures (ECMs) are shown in Table

Table 3: Tracking ECMs

Description of ECM	Quantity
50-hp single-stage air-cooled rotary screw compressor with variable speed (VFD) flow control	1 (claimed)
500 gallon horizontal air receiver tank	1 (not claimed)

Baseline

Table 4 lists the pre-existing equipment characteristics and operating conditions.

Table 4: Pre-Existing Equipment[1]

Equipment	hp	Control	Rated PSIG	Operating PSIG	Capacity (ACFM)
Trim air-cooled rotary screw compressor	25	Load/unload	125	100 - 115	71
Base air-cooled rotary screw compressor	20	Load/unload	125	100 – 115	91
Air Receiver Storage	N/A	N/A	N/A	N/A	240 gallons (Two 120 gallon tanks)

The system air demand was described using four day type schedules or shifts. These day type schedule appear to have been based off the seven days of flow and pressure data collected by the vendor during the pre-implementation phase. The demand schedule is listed below:

[1] These table values are directly from the tracking documentation.

Table 5: Pre-existing Compressed Air Demand Schedule

Demand Schedule	ACFM	Capacity %	Hours per year
1	120	20-hp = 100% 25-hp = 56%	780
2	100	20-hp = 100% 25-hp = 33%	1,040
3	80	20-hp = 100% 25-hp = 11%	1,040
4	75	20-hp = 100% 25-hp = 6%	416

There is no description of other equipment on the compressed air line; the annual operating hours were estimated at 3,276 hours using an unknown method. It appears that the operating hours may have been estimated using the customer's operating schedule.

Proposed Condition

The proposed case retired and removed the pre-existing compressors from service and replaced them with the VFD compressor. The VFD compressor is proposed to handle all air demand and is estimated to operate at part-load, even during the facility's peak demand periods. Table 6 lists the proposed equipment and its operating conditions.

Table 6: Proposed Equipment

Equipment	Hp	Control	Rated PSIG	Operating PSIG	Capacity (ACFM)
Air-cooled rotary screw compressor	50	VFD	100	100 – 115	249
Air Receiver Storage	N/A	N/A	N/A	N/A	500 gallons

The proposed operating conditions require the same demand schedule as the baseline, using the new VFD compressor.

Table 7: Proposed Compressed Air Demand Schedule

Demand Schedule	ACFM	Capacity %	Hours per year
1	120	50-hp = 48%	780
2	100	50-hp = 40%	1,040
3	80	50-hp = 32%	1,040
4	75	50-hp = 30%	416

The project proposed to also have a 500 gallon air receiver tank added to provide the primary air storage for the compressed air system. This addition was proposed to reduce the inconsistent air supply during periods of large air demand.

Tracking Calculation Methodology

The tracking calculation methodology was limited to a vendor savings tool print out that documented the existing system, proposed system and respective annual energy costs for each scenario. This savings tool is supplemented with a data logging report summarizing the pre-implementation M&V data. Approximately one week of flow and pressure measurements were collected in the pre-implementation period. No post-implementation measurements were performed during the post-implementation site inspection. The utilization of the collected flow and pressure data could not be assessed completely; it appears that the data was used to develop the demand schedules listed in the tables above. The savings tool does not appear to account for air storage capacity (e.g., gallons, gallons/cfm) and savings appear to be derived exclusively from the air compressor replacement measure. The annual energy costs are based on the air demand schedules that were described in Table and Table . The annual energy costs are then converted in to annual energy consumptions by applying a $0.10 / kWh rate. The peak summer demand reduction is calculated by dividing the annual kWh savings by the annual operating hours.

Assessment of Tracking Methodology and Analysis

The vendor savings estimate is a software tool print out with no details on what assumptions were used to estimate the annual cost savings. The savings print out is supplemented with a vendor audit summary showing only daily (visual) graphs of time-series pressure and flow measurements over one week for a total of seven graphs. There is no mention of how the pre-installation meter data was used in developing the air demand schedules. Each daily graph has a table summarizing the average pressure and flow measurements for that day. The daily graphs show fairly consistent demand during the core working hours with the system pressure oscillating (between roughly 100 – 115 PSIG) in a saw-tooth pattern typical of load/unload controls. The flow graphs correspondingly follow a step oscillation between the compressors' rated capacities (around 70 and 90 CFM) and unloaded (zero flow). Based on the flow graphs, the 25-hp trim compressor unloads frequently during normal operation. The document does not describe what measuring equipment was used (and where) to obtain the pressure and flow data. The installed compressor system was not monitored in the post-implementation inspection visit; the visit appears to have verified the installation of the installed compressor and noted a change in proposed scope for the additional 500 gallon air storage tank[2].

The tracking savings method, which uses four average compressor load values (one for each "air demand" bucket) minimizes the rigor in the savings estimate by reducing the energy savings method to single line calculations. While this method is reasonable for relatively steady air demand schedules, it can become less accurate for facilities that have erratic or inconsistent air demand schedules. Power (or current) logging can also be performed inexpensively so that unique calibrated performance curves can be generated for the pre-existing compressors. This would improve the accuracy of the pre-existing annual energy consumption because the estimate is based on actual power data rather than pressure and flow data and an assumed flow vs. power relationship from the vendor or compressor manufacturer.

The assumed savings input values could not be sufficiently assessed by the evaluator because of limited information provided in the vendor savings report and tracking documentation. These details would have been useful for assessing the discrepancies between tracking and evaluated savings estimates. The program

[2] The post-implementation site inspection "note" on the installation of the proposed 500 gallon storage tank was not clear. It references a tank vendor's part list sheet and highlights what appears to be what tanks was observed by the site inspector.

implementer should always retain any references, savings input parameter assumptions, or savings calculations in their entirety so that evaluation efforts can provide meaningful and complete assessment of the tracking savings.

EVALUATION METHODOLOGY

The following sub-sections describe project scope and estimated savings based on observed site conditions. The sub-sections go over the pre-existing (baseline) and proposed operating conditions & equipment informed by the site visit and correspondence with the site contact. The sub-sections also discuss the data collection, analysis, and calculation methodology performed to estimate the evaluated savings.

Measure Verification

There were a few discrepancies in the post-installation forms and uncertainties regarding the pre-installation conditions like the compressor specifications and pre-existing air storage capacity. No explicit details were given for the pre-existing compressor performances; tracking savings calculations had to be reverse-calculated from a vendor savings sheets in order to assess the compressor load estimates. The pre-installation form notes that there were two 120-gallon tanks; the proposed case appeared to have a total storage of 500 gallons[3]. The post-installation site inspection form does not mention a 500 gallon tank. Instead, it mentions a total of three pre-existing tanks – a 200 gallon, 240 gallon, and 260 gallon tank - all horizontal. The MRD, however, notes that a 500 gallon tank (along with the proposed VFD compressor) was installed.

The evaluator did not observe the proposed 500 gallon air receiver tank during the site inspection. Upon querying the site contact about the 500 gallon tank, they were unaware of the tank and showed the evaluator two of the three tanks described in the pre-installation site inspection form. The evaluator believes these two tanks were the 200-gallon and 240-gallon tanks. The third tank (presumably the 260 gallon tank mentioned on the post-implementation site inspection form) was not observed by the evaluator.

The 50-hp VFD compressor was observed to be installed and operational. It was operating at a steady discharge pressure of 118 PSIG. The rated operating (discharge) pressure of this compressor is 100 PSIG with a maximum rated operating pressure of 110 PSIG, so it appears that the compressor is working beyond its intended operating limits. A new refrigerant dryer (250 CFM capacity), installed at the same time as the VFD compressor, was also observed to be functional and operating upstream of the two observed receiver tanks. This dryer was not claimed under the compressed air program but appears to have been coincidentally installed in the scope of the project.

When the site contact was queried on the pre-existing compressors, they were uncertain which one had been completely retired and removed, and which one had been retained for backup. The site contact was reluctant in showing the evaluator to the pre-existing compressor (did not have much time); based on the description that the site contact provided, it was interpreted that the pre-existing compressor was disconnected from the compressed air system and was retained as an emergency backup. The site contact believed it was the 25-hp compressor that was retained. The site contact could not give any useful details

[3] So an extra 260 gallon tank or the two 120 gallon tanks were planned to be retired and a new 500 gallon tank is installed. Based on the MRD and vendor quote options, the 500 gallon tank was the plan.

regarding the operating conditions or sequencing of the pre-existing compressors and could only confirm that the pre-implementation site inspection form appeared to be accurate.

The evaluator asked the site contact if there were "production" data available in the form of "number of widgets" or "number of man hours". The site contact did not think that data could be generated easily and suggested that the demand monitored by the power loggers over the planned 3 week period would be representative of "normal" operation throughout the year. Even though normalizing the savings to annual production data is the most desirable scenario for evaluation, the 3 weeks of meter data and the site contact's comment regarding typical operation were considered to be reasonably sufficient supporting sources to annualize the savings observed over the metering period.

Table 8 shows the ECMs and respective quantities installed.

Table 8: ECM Installations

Implemented ECMs	Proposed (tracking)	Implemented (evaluated)
50-hp air-cooled rotary screw compressor with variable speed (VFD) flow control	Installed	Installed
500 gallon vertical air receiver tank	Installed	Not installed
20-hp rotary screw compressor LNL	Retired & Removed	Retired & Removed
25-hp rotary screw compressor LNL	Retired & Removed	Retired & retained for backup

Data Collection

The installed compressor was metered for the evaluation. The total package 3-phase true power of the compressor was monitored using a DENT Elite Pro SP logger with split core CTs rated 50A. The metering period was approximately 4 weeks (November 18 to December 17, 2013) with a logging interval of 30 seconds. Spot power measurements were taken on each phase to verify that the Elite Pro loggers were recorded power values with reasonable accuracy.

Other data collected during the on site visit included nameplates for the compressor, line (discharge) pressures for the metered compressor, and photographs of the installed ECM. Seasonal operating schedules and observed holiday closures were obtained from the site contact, if any.

The site contact had very limited information regarding the evaluated compressed air project and the pre-existing operating conditions of the compressors.

Table 9: Evaluation Measurement Summary

Time-Series Data Information	
Measured Parameter	Total packaged True Power (kW) on 50-hp VFD compressor
Logger Make/Model	DENT Elite Pro SP on 50-hp VFD compressor
Transducer/Equipment Type	(3x) 50A split-core CTs on 50-hp VFD compressor
Installation Location	50-hp VFD compressor: Power compartment in packaged unit
Observation Frequency	30 second interval
Metering Period	November 18 to December 17, 2013
Metered By	DNV GL and RISE electrician

Evaluation Savings Analysis

Approximately one month of time-series true power (kW) data was collected for the 50-hp VFD compressor. These data were used to directly characterize the air demand and performance of the pre-existing and installed compressed air system.

To begin the savings analysis, the metered data had the time stamps formatted for ease of processing. Performance profiles were next generated for the installed and pre-existing compressors:

- *INSTALLED 50-hp air-cooled rotary screw compressor with VFD flow control kW vs. CFM* – This performance curve was generated exclusively from the manufacturer's CAGI sheet for the respective model. Since the compressor is variable-speed, the CAGI sheet lists multiple capacities and their respective packaged input power values at the rated outlet pressure (100 psi in this case). Two CAGI sheets of the same model were obtained – one sheet with a date of August 2011, and the other CAGI sheet from 2012. The sheet dated 2011 was used because the project occurred in early 2012 and the compressor serial number shows that the compressor was manufactured in 2011. A manufacturer cut sheet was also obtained that had the compressor model's rated capacity at various rated operating pressures (e.g., 125 psi, 150 psi, etc.); this sheet was used to estimate the installed compressor's capacity (CFM) at the observed discharge pressure of 118 psi. Based on the site contact interview, this operating pressure (of 118 psi) remains steady throughout facility operation. A linear power (kW) vs. capacity (CFM) trend was then formulated using these CAGI and cut sheet performance data.
- *PRE-EXISTING 20-hp air-cooled rotary screw compressor with load/unload controls: kW vs. CFM* – This performance curve was generated from a generic AirMaster+ compressor profile because no detailed model specifications or cut sheets could be obtained for this specific model. Because of its size, age, hp and flow control, a typical air-cooled single stage rotary compressor profile that was similarly sized (71 ACFM at 125 PSIG) to the actual model was considered to be a reasonable proxy for estimating annual energy savings[4]. In order to develop a performance curve for the compressor, the default "Manufacturer Compressor Details" were modified with the specifications found from the

[4] The AirMaster+ compressor has 21 Bhp, 125 PSIG full load operating pressure; 17.5 kW power at rated conditions

pre-installation inspection form. The rated capacity at full load operating pressure was adjusted from 70 ACFM to the pre-existing compressor capacity of 71 ACFM. The operating cut-in and cut-out/unload pressures remained unchanged at 125 PSIG and 135 PSIG respectively. The AirMaster+ performance profile graph (% full load kW vs. % flow) was then tabulated in 10% flow increments and their corresponding % full load kW values. From this kW vs. flow table, a linear power vs. capacity trend was formulated.

- *PRE-EXISTING 25-hp air cooled rotary screw compressor with load/unload controls: kW vs. CFM –* The performance curve for this pre-existing compressor was generated using the same method as the base load 20-hp compressor[5]. The AirMaster+ performance profile graph (% full load kW vs. % flow) was then tabulated in 10% flow increments and their corresponding % full load kW values. From this kW vs. flow table, a linear power vs. capacity trend was formulated.

Installed Scenario

The performance profile (for the installed compressor) described above was then used to estimate the flow (CFM) corresponding to each time stamp in the metered (kW) data. The compressor power data shows a consistent minimum compressor power around 4.5 kW. Based on the frequency and pattern of this measured power the evaluator reasoned that this is the unloaded compressor demand. It also appears that the compressor was programmed such that it would remain unloaded rather than shutting down (i.e., auto-shutdown timer disabled); or alternatively, that the shutdown timer was set long enough and air demand was consistent enough where the compressor never shut down during occupied hours. The air demand was large enough that the unloaded periods would not last longer than around 5 minutes. The installed compressor would remain energized during the entire occupied period and would only shut off during closed hours.

Pre-existing Scenario

To estimate the corresponding performance of the pre-existing compressors, the calculated flow in the installed case was used along with an assumed flow sequence derived from the pre-installation site inspection form and vendor savings estimate. The pre-installation site inspection form and MRD note that the 20-hp compressor acted as the base load compressor while the 25-hp acted as the trim compressor, turning on only when the 20-hp compressor could not handle the demand. This loading order was used in the evaluated savings analysis. First, pre-existing compressor air flow (ACFM) for each corresponding time stamp were determined based on the calculated installed air flow and the rated capacities of the pre-existing compressors (71 and 91 ACFM for the 20-hp and 25-hp compressors at the observed operating pressure, respectively). The 20-hp is loaded first and the remaining air flow is allocated to the 25-hp compressor. The pre-existing compressor kW vs. CFM trends are then used to calculate the power corresponding to the assigned time-stamp interval flow rates. Because the installed compressor has a greater capacity (232 ACFM at 118 PSIG) than the sum of the pre-existing compressors (71 + 91 ACFM = 162 ACFM), there are time stamp intervals where the calculated air flow of the installed compressor exceeds the pre-existing system capacity. Those extreme air demand periods occurred intermittingly during peak work hours. The unmet air demand wasn't large and consistent enough (the unmet air demand ranged from 0.1 to 13.8 CFM) to be considered unmanageable for the pre-existing scenario. If unmet air demand was continuous and sustained

[5] The AirMaster+ compressor has 26.3 Bhp, 125 PSIG full load operating pressure; 21.7 kW power at rated conditions

for large periods of time (e.g., more than 30 minutes), the evaluator would have assumed a capacity expansion baseline and in situ compressors would not have been used to estimate energy savings. The unmet air demand (if any) for each time stamp interval and the corresponding additional energy (kWh) required for the pre-existing compressors to produce that air demand is calculated and added to each corresponding hour in the final 8,760 profile.

The difference between the pre-existing compressor load and the installed case compressor load for each time stamp interval is the calculated average compressor demand reduction for that time interval. An hourly demand reduction profile for each weekday type (Monday through Sunday and holidays) was then developed by averaging the demand reduction corresponding to their respective hour and weekday bins (for a total of 192 hourly bins). An hourly "unmet air demand penalty" profile was also generated for each weekday type. The additional energy (kWh) calculated (if any) for each 30-second interval time stamp was summed up and allocated to each unique hour in the metering period. These hourly totals were then averaged by week day and hour to develop the profile. Only one demand profile needed to be developed because based on the site contact's comments, the facility does not experience any forecasted or measureable seasonal fluctuations in its production output or compressed air demand. Therefore, the Evaluation team considered it reasonable to assume the one month of meter data as representative of the load profile that the facility experiences throughout a typical year. The hourly demand reduction and "unmet air demand penalty" day type profiles were then applied to the New York TM Reference Year (1995) 8,760 profile to calculate the annual electricity savings (kWh)[6]. The peak demand reduction was calculated by averaging the demand reduction calculated during the 4 P.M. – 5 P.M. hour on all non-holiday weekdays.

EVALUATION RESULTS

The total evaluated electric savings was determined to be 8,271 kWh and 2.0 kW peak summer demand reduction. The tracking savings are 53,910 kWh and 16.5 kW peak summer demand reduction. The gross realization rates (GRR %) comparing the evaluated savings to the tracking savings are 15% for kWh and 12% for kW.

Primary Reasons for Savings Discrepancy

1. *Discrepancy #1 (Compressor Performance)* - The evaluated compressor performance profiles were based on CAGI sheets, manufacturer cut sheets, and AirMaster+. The sources for the tracking compressor performance assumptions could not be completely assessed but single average values were derived for both pre-existing and proposed compressor loads. To isolate the compressor performance discrepancy, the evaluator used the evaluated compressor performance curves to estimate the pre-existing and proposed compressor loads at the assumed tracking air demand conditions. These average compressor loads were multiplied by the tracking annual operating hours to calculate annual energy and demand reduction savings. This led to a kWh discrepancy of -42,810 kWh and a demand discrepancy of -13.1 kW (or -79% kWh and -79% kW). The evaluated estimates made for the average pre-existing compressor loads (17.9 kW for the 20-hp and 10.6 kW for the 25-hp) are *lower* than the tracking estimates (20.3 kW for 20-hp and 16.9 kW for 25-hp). Additionally, the evaluated estimate made for the average installed compressor load (25.1 kW) was *higher* than

[6] The 8,760 hourly demand reduction profile was based on the reference year of 1995 (uses weekday and holiday dates during that year) to standardize results

the tracking estimate (20.7 kW). The evaluated savings calculation for discrepancy #1 effectively uses a smaller difference in average demand reduction than the tracking savings calculation. The reason for this demand difference discrepancy could not be fully addressed due to lack of tracking savings documentation and because the savings calculation uses a proprietary savings tool. It is therefore recommended that any claimed tracking savings should be fully documented and have complete, "working" savings calculations[7].

2. *Discrepancy #2 (Air Demand and Calculation Method)* – The tracking calculation uses average compressor loads for four different air demand bins and multiplies these values by the annual operating hours of each bin to estimate annual energy consumption. The evaluated method developed hourly load profiles categorized by weekday to generate 192 hourly bins. This method increases the resolution of the load profile and can increase the accuracy of annual extrapolations when estimating savings. The evaluated metering period also observed air demand that was substantially higher than the demand profiles estimated in the tracking savings calculation. For example, the tracking savings estimate assumes a "peak" air demand bucket of 120 CFM. The evaluated metering period observed "peak" hourly air demands as high as 155 CFM. The evaluated peak demand reduction was also calculated using a different method from the tracking savings. While the tracking savings divides the annual energy savings by the annual operating hours to estimate peak demand reduction, the evaluated method calculates peak demand reduction by averaging the hourly compressor demand reduction for the 4 P.M. – 5 P.M. hour on all non-holiday weekdays. The discrepancy was calculated to be -2,829 kWh and -1.3 kW (or -5% kWh and -8% kW), relative to discrepancy #1.

[7] By "working", the evaluator basically means a workable unlocked spreadsheet format where all calculation input values can be identified or reverse-calculated. In this case, the savings calculation was effectively a print out, meaning the evaluator could not determine what input variables were used to calculate the energy savings.

SITE ID: DNVCA02

Project Type	Early Replacement and Add-On
Measure Category	Custom Compressed Air

PROJECT DESCRIPTION

The project involved the retirement of one (1) pre-existing air-cooled 100-hp rotary screw compressor and one (1) pre-existing 100-hp water-cooled rotary screw compressor. Both pre-existing compressors had inlet modulation flow controls. The retired compressors were replaced with a new air-cooled 94-hp rotary screw compressor with variable speed (VFD) flow controls. Compressed air end-uses include air-powered hand tools, presses, cutters, and surface coating machines. Table 1 provides the gross impact results while Table 2 provides a summary of the discrepancy analyses.

Table 1: Summary of Evaluation Results

Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
Annual Energy Savings (kWh)	109,376	110,926	101%
Peak Demand Reduction (kW)	15.16	12.5	83%

Table 2: Discrepancy Analysis Summary

Discrepancy Factor	kWh	kW
Operating Conditions	Discrepancy #1 (Compressor Performance at Observed Operating Conditions): -18,742 (-17%)	Discrepancy #1 (Compressor Performance at Observed Operating Conditions): 0.09 (1%)
Equipment Specifications	N/A	N/A
Calculation Method	Discrepancy #2 (Different Calculation Method): 20,292 (19%)	Discrepancy #2 (Different Calculation Method): -2.71 (-18%)
Inappropriate Baseline	N/A	N/A

TRACKING SAVINGS

This section summarizes the methodology and assumptions used to estimate the Tracking savings claimed for the project.

Project Description

The customer had a compressed air system whose demand was primarily met by the air-cooled 100-hp rotary screw compressor. The pre-existing water-cooled 100-hp rotary screw compressor experienced negligible use because it was used only during backup (e.g. maintenance) and emergency circumstances.

The primary 100-hp compressor had inlet modulation with blow down flow controls and was operating with no additional primary storage. A pre-existing heatless regenerative desiccant-based dryer with standard controls and a rated capacity of 500 scfm and purge flow of 77 scfm was attached to the compressed air line after the compressor packaged unit. No other information was given regarding the dryer type or controls. The proposed 94-hp VFD compressor would handle the entire demand without being fully loaded during peak demand, due to the added storage. The project scope also installed a new 450 scfm cycling refrigerated air dryer and a 1,060 gallon air receiver tank; however, since the receiver tank was not incentivized or considered in the tracking savings, the evaluation did not assess its incremental savings. Table 3 shows the ECMs and respective quantities installed.

Table 3: Tracking ECMs

Description of ECM	Quantity
94-hp air-cooled, oil-injected rotary screw compressor with variable speed (VFD) flow control	1
1,060 gallon vertical air receiver tank	1
450 scfm cycling refrigerant air dryer	1

Baseline

The pre-installation inspection form notes that the operating (discharge) pressure was set at 107 psig; and that inadequate pressure, air quality, and pressure fluctuations were notable problems. The compressors' manufactured dates were noted as 1993.

The following bullet items describe the pre-existing system and schedule per tracking documentation. Table 4 summarizes the pre-existing compressor condition as described by the tracking documentation.

- 100-hp air-cooled rotary screw compressor with inlet modulation is sole primary compressor;
- Heatless regenerative desiccant air dryer with 500 cfm rated capacity and average purge rate of 72.78 cfm;
- No additional air storage beyond transmission piping;
- Average Flow is 297 cfm (from tracking savings estimate for dryer savings);
- Average delivered pressure was 82 psig (from vendor report). Discharge pressure was 107 psi (at time of observation by program inspector); and
- 7,213 annual operating hours reported in the tracking savings form, based off the estimated business and production hours from the pre-inspection form.

Table 4: Pre-Existing Equipment

Equipment	hp	Control	Rated PSIG	Operating PSIG	Capacity (ACFM)
Air-cooled, oil-injected rotary screw compressor	100	Inlet modulation with blowdown	125	107	450

The Utility documents include a vendor evaluation report that performed an air demand survey over a period of one week. The survey was able to determine estimates for the pre-existing demand profile of the pre-existing compressed air system. The following table summarizes the demand profile observed over the one week of monitoring:

Table 5: Baseline Capacity Demand Profile[8]

Flow Range (cfm)	0 - 100	101 – 300	301 – 500	500+
Percent Time (%)	17.66%	35.93%	46.19%	0.22%

Proposed Condition

The project proposed to replace the pre-existing primary 100-hp compressor with a 94-hp air-cooled rotary screw air compressor. The proposed compressor's flow control uses a variable speed drive to modulate flow based on observed demand and is rated to consume 83.8 kW delivering 436 acfm at 100 psig (per the "Minimum Requirements Document"). The replaced compressor would be retained for backup purposes while the other pre-existing compressor (the water-cooled 100-hp compressor) was decommissioned and removed from service. The pre-existing desiccant air dryer was proposed to be replaced by a 450 scfm cycling refrigerated dryer.

The project proposed to also have a 1,060 gallon air receiver tank added to provide the primary air storage for the compressed air system. This addition was proposed to reduce the inconsistent air supply during periods of large air demand.

[8] From Vendor Report. The tracking savings uses an average of 297 CFM

Table 6: Proposed Equipment

Equipment	hp	Control	Rated PSIG	Operating PSIG	Capacity (ACFM)
Air-cooled, oil-injected, rotary screw compressor	94	VFD	100	100	436
Refrigerated cycling dryer	N/A	Cycling	100	N/A	450

Tracking Calculation Methodology

The tracking calculation methodology was limited to a two-page hand-written copy of the savings calculations that references the vendor savings report that was included with the project documentation. The tracking savings calculation assumes (based on a report section that was not included in the tracking documentation) that the pre-existing compressor operated with an average demand of 62.77 kW and operated 7,213 hours per year. The proposed compressor was estimated to operate with an average demand of 51.48 kW (referenced from "Table 6.2") with the same operating hours of the pre-existing compressor. The difference in annual energy consumption between the two scenarios was taken to be the annual energy savings from the compressor replacement. The air dryer savings were calculated by assuming a pre-existing air dryer "demand" of 14.556 kW (based on a purge flow of 72.78 cfm @ 100 psi and the assumed pre-existing specific compressor power of 20 kW/100 cfm) and a 30% utilization factor (i.e., the dryer runs 30% of the time) over the annualized operating period of 7,213 hours. The proposed air dryer has an identical annual run time (7,213 x 30% = 2,164 hours) but an estimated demand of only 1.64 kW. The proposed air dryer demand was calculated by assuming an average flow of 297 cfm, a full rated power of 2.49 kW and 450 cfm, and a linear kW vs. cfm performance correlation. The difference in annual energy consumptions between the pre-existing and proposed air dryers is the estimated annual dryer savings.

It does not appear that post-installation power monitoring was performed for the compressor or the dryer in order to verify the pre-installation assumptions and savings calculations. However, it does appear that a program site inspection occurred to confirm that the proposed compressor, receiver tank, and dryer were installed.

Assessment of Tracking Methodology and Analysis

The tracking savings method, which uses selected average measurements from the vendor investigation report, minimizes the rigor in the savings estimate by reducing the energy savings method to one line calculations. This method appears to have been chosen because the energy savings were more conservative than the vendor's savings estimate.

The assumed savings input values could not be sufficiently assessed by the evaluator because the vendor savings report did not contain details on how average compressor power (and dryer power) was calculated for the pre-existing and proposed scenarios. They appear to be based on amperage (current) data and assumed power factor, compressor motor efficiency, and motor load factor. This assessment is important because it would have helped in determining how the pre-existing dryer power and utilization factor was estimated. Based on the information available to the evaluator, it appears that the purge flow relating to the desiccant dryer was carried over in to the proposed compressor's average flow, essentially "under counting" a portion of the incremental compressor/dryer savings. The pre-existing compressor flow corresponding to the dryer's purge air should have been removed from the proposed compressor flow assumption because in the proposed case the desiccant dryer has been replaced with a refrigerant dryer that does not require purge air. Thus, the proposed air demand should have been the average flow (297 cfm) minus the average dryer purge flow (72.78 cfm), or around 224 cfm.

It is recommended that tracking documentation retains all referenced sources and have savings calculations presented completely so that the claimed tracking savings can be sufficiently assessed by the evaluator; otherwise, time and speculation must be spent to attempt to "reverse calculate" the claimed tracking savings to try and figure out what assumptions were made, where they came from, and why those assumptions were made. In this project's case, the claimed tracking savings took specific findings from the vendor report and used those assumptions to estimate savings using one line equations, The raw data that was used to generate the assumptions and average values reported in the vendor report should be retained by the program administrator and included in the tracking documents.

EVALUATION METHODOLOGY

The following sub-sections describe project scope and estimated savings based on observed site conditions. The sub-sections go over the pre-existing (baseline) and proposed operating conditions & equipment informed by the site visit and correspondence with the site contact. The sub-sections also discuss the data collection, analysis, and calculation methodology performed to estimate the evaluated savings.

Measure Verification

The baseline condition was largely determined from the tracking documentation. The facility site contact was only able to verify the pre-existing compressor specifications, compressor sequence logic, compressor flow control strategies, and the operating pressure given on the pre-installation inspection form. The site contact commented that the pre-existing production process had not changed significantly so was therefore confident that the pre-existing baseline conditions recorded in the project documentation are likely accurate.

All of the proposed energy conservation measures listed in Table 3 were verified as having been installed and operating as generally proposed. The discharge (line) pressure for the installed compressor was observed to be steady at 115 psig. Unload pressure is programmed at 125 psig. During the site visit, the observed compressor load (per the compressor display reading) ranged between 49% and 62%. Corresponding spot power measurements could not be confidently correlated because the motor speed was modulating during measurement and the load range was too small to develop a reasonable performance curve from actual spot capacity and power measurements. The refrigerant air dryer glycol temperature was observed to be 37 °F; it appeared that the air dryer was performing adequately and maintaining the temperature set point. The pre-existing primary compressor and desiccant dryer had been retired and removed from the facility; the other pre-existing compressor was retained for backup purposes as proposed.

Table shows the ECMs and respective quantities installed.

Table 7: Proposed versus Implemented ECMs

Implemented ECMs	Proposed (tracking)	Implemented (evaluated)
New 94 hp air cooled rotary screw compressor	Installed	Installed
New 1,060 gallon vertical air receiver tank	Installed	Installed
New 450 scfm cycling refrigerant air dryer	Installed	Installed
Pre-existing Heatless Regenerative Desiccant 500 scfm Air Dryer	Retired & Removed	Retired & Removed
Pre-existing 100-hp rotary screw compressor	Retired & Removed	Retired & Removed
Pre-existing 100-hp rotary screw compressor	Retired & Retained for backup	Retired & Retained for backup

Data Collection

The installed compressor and dryer were metered for the evaluation. The total package 3-phase true power of the compressor and dryer were metered using DENT Elite Pro SP loggers with split core CTs rated at 200A and 50A, respectively. The metering period was approximately 4 weeks (November 19 to December 17, 2013) with a logging interval of 30 seconds. Spot power measurements were taken on each phase of the installed Compressor and dryer to verify that the Elite Pro loggers were recording power values with reasonable accuracy.

Other data collected during the on site visit included nameplates for the metered equipment, line (discharge) pressures for the metered compressor, and photographs of the installed ECMs (compressor, tank, and dryer). Seasonal operating schedules and observed holiday closures were obtained from the site contact.

The site contact was not aware of production data that would be in a format useful for normalizing annual energy consumption to. When the evaluator asked if the facility had any notable seasonality, the site contact gave fairly specific schedules revolving around “season 1” (May through October) and “season 2” (November through April). The site contact noted that the facility operates on a 3-shift schedule (24 hours) and each shift has fairly consistent tasks that do not change over the two identified “seasons”.

The site contact had very limited information regarding the compressed air project under evaluation and the pre-existing operating conditions of both the dryer and compressor. The table below documents the instrumentation used.

Table 8: Evaluation Measurement Summary

Time-Series Data Information	
Measured Parameter	Total packaged True Power (kW) on installed compressor Total packaged True Power (kW) on installed dryer
Logger Make/Model	DENT Elite Pro SP on installed compressor DENT Elite Pro SP on installed dryer
Transducer/Equipment Type	(3x) 200A split-core CTs on installed compressor (3x) 50A split-core CTs on installed dryer
Installation Location	Compressor: Power compartment in packaged unit Dryer: Local disconnect
Observation Frequency	30 second interval
Metering Period	4 weeks (November 19 to December 17, 2013)
Metered By	DNV GL and RISE electrician

Evaluation Savings Analysis

Approximately one month of time-series true power (kW) data was collected for the installed compressor and for the installed dryer. These data were used to directly characterize the air demand and performance of the pre-existing and installed compressed air system.

To begin the savings analysis, the metered data had the time stamps formatted for ease of processing. Performance profiles were next generated for the installed and pre-existing compressors and dryers, as bulleted below:

- *INSTALLED 94-hp air-cooled rotary screw compressor with VFD flow controls: kW vs. CFM* – This performance curve was generated exclusively from the manufacturer's CAGI sheet for the respective model. Since the compressor is variable-speed, the CAGI sheet lists multiple capacities and their respective packaged input power values at the rated outlet pressure (125 psig in this case). A manufacturer cut sheet was also obtained to determine the installed compressor's capacity (CFM) at the observed discharge pressure of 115 psig. Based on the site contact interview, this operating pressure (of 115 psi) remains steady throughout facility operation. A linear power (kW) vs. capacity (CFM) trend was then formulated using these CAGI and cut sheet performance data.
- *INSTALLED 450 scfm air cooled cycling refrigerant air dryer* – The performance of the dryer was not correlated to the air flow corresponding to the compressor power that occurred during the same 30-second time stamp. The dryer power data was only used to develop the installed dryer load profile; the power data were not used to develop the pre-existing dryer performance and load profile because the pre-existing desiccant dryer cycled based on a timer and not by demand so there was no way to use the installed dryer power to estimate the corresponding pre-existing dryer performance. The installed dryer specifications were still used to perform sanity checks on the power data.

- *PRE-EXISTING 100-hp air-cooled rotary screw compressor with inlet modulation with blowdown flow controls: kW vs. CFM* – This performance curve was generated from two sources: (1) AirMaster+; and (2) manufacturer's CAGI sheet for the respective model. The manufacture's cut sheet was also obtained to cross-verify with the CAGI sheet to ensure the correct model specifications were retrieved. In order to develop a performance curve for the compressor, a similarly sized (in rated hp, ACFM, and full load pressure) single stage rotary screw compressor with inlet modulation with blowdown flow controls was selected from the AirMaster+ compressor database. The default "Manufacturer Compressor Details" were then modified with the specifications found from the CAGI sheet. The full load ("cut-in") pressure was adjusted from the rated pressure of 125 psi to the pre-existing discharge pressure of 107 psi (unloading begins at 120 psi). The AirMaster+ performance profile graph (% full load kW vs. % flow) was then tabulated in 10% flow increments and their corresponding % full load kW values. From this kW vs. flow table, a cubic power vs. capacity trend was formulated.
- *PRE-EXISTING 100-hp water-cooled rotary screw compressor with inlet modulation with blowdown flow controls* – This pre-existing compressor (referred to as "compressor #2" in the pre-installation documentation) was a backup compressor that only operated when the primary compressor was unloaded and shut down for servicing. Pre-installation documents comment that the compressor ran for only 2 hours during the pre-installation auditing period (that lasted 192 hours). Because this pre-existing compressor was used only for maintenance relief and because its performance characteristics are relatively similar to the primary compressor, the evaluator chose to base pre-existing compressor usage solely on the primary compressor. The inclusion of the "backup" compressor in the calculated annual compressor usage would have made a negligible impact compared to only using the primary compressor.
- *PRE-EXISTING 500 scfm Heatless Regenerative Desiccant Dryer w/ Standard Control* – Very little information was available regarding the controls and performance specifications of the pre-existing dryer. The site contact did not have any useful information about the pre-existing dryer. The vendor savings calculation and referenced dryer model specifications ultimately had to be used as a starting point. A manufacturer cut sheet was then obtained for a similar heatless desiccant (two-tower) dryer (from the same manufacturer) that matched the description and specifications in the vendor's dryer savings calculation. The pre-existing dryer was assumed to have a "variable cycle control" that the operator could adjust depending on air drying demand. The assumed cycle time was held constant at 10 minutes (5 minutes on, 5 minutes off) with a purge rate of 72.78 scfm. This purge rate was assumed by the vendor and was also chosen by the evaluator to be a conservative estimate compared to the rated approximate purge rate of 77 scfm. The power demand contributed toward the pre-existing compressor was calculated by estimating the pre-existing compressor load at the corresponding air demand with and without the desiccant dryer using compressed air to purge and regenerate one of the desiccant towers during purge cycling. The desiccant dryer was assumed to draw 0.08 kW when "idle" and not purging. The difference in the pre-existing compressor loads (one without the dryer purging, and one with the dryer purging and consuming a rate of 72.78 cfm) was taken to be the demand associated with the pre-existing dryer so that direct savings comparisons (i.e., dryer vs. dryer savings, compressor vs. compressor savings) could be made.

Installed Scenario

The performance profile (for the installed compressor) described above was then used to estimate the flow (CFM) corresponding to each time stamp in the metered (kW) data. Unloading times were not considered because the expected frequency is negligibly low compared to the air demand and corresponding loaded runtimes at this facility. The installed dryer meter data was not manipulated in any way and was only cross-referenced in the pre-existing scenario in order to estimate periods where the dryer was not in operation (e.g., certain weekend days or closed periods).

Pre-existing Scenario

To estimate the corresponding performance of the pre-existing 100-hp compressor, the calculated flow in the installed case had to be used in combination with the additional compressed air used by the pre-existing dryer during regenerative purging. Without details on the controls and sequencing of the pre-existing dryer, the evaluator chose to use a 10 minute cycle (5 minutes purging, 5 minutes not purging) which corresponds to the manufacturer's "100% load" condition for the respective models' desiccant dryers. An arbitrary time stamp was chosen to build the pre-existing dryer's cycling profile. When the pre-existing dryer cycled on to purge a desiccant tower, the pre-existing air demand was calculated to be the estimated installed air demand plus the additional dryer purge rate of 72.78 cfm. When the desiccant dryer cycles off and is no longer purging a desiccant tower, the pre-existing air demand was taken to be equivalent to the calculated installed air demand. Using this method of separating facility air demand from the pre-existing dryer air demand, the evaluator was able to isolate compressor and dryer savings. Using the kW vs. CFM performance profile developed for the pre-existing compressor, pre-existing compressor loads corresponding to the calculated pre-existing air demand were calculated for each time stamp interval. One compressor load column included the dryer load while the other column omitted the dryer load. The pre-existing dryer load (kW) was then calculated by taking the difference between these two columns.

The difference between the pre-existing compressor load and the installed case compressor load for each time stamp interval is the calculated compressor demand reduction for that time interval. The difference between the pre-existing dryer load and the installed case dryer load for each time stamp interval is the calculated dryer demand reduction for that time interval. The total demand reduction for each respective time interval is the sum of those two columns. Two hourly demand reduction profiles for each weekday type (Monday through Sunday and holidays for a total of 192 hourly bins per profile) were then developed by averaging the demand reduction corresponding to their respective hour and weekday bins. Two profiles needed to be developed because the facility has seasonal shift adjustments in operation and production. The hourly demand reduction profiles were then applied to the New York TM Reference Year (1995) 8,760 profile to calculate the annual electricity savings (kWh).[9] The peak demand reduction was calculated by averaging the 4-5 P.M. hour for all non-holiday weekdays based on the NY ISO peak definition and observed holiday schedule.

EVALUATION RESULTS

The total evaluated electric savings was determined to be 110,926 kWh and 12.5 kW peak demand reduction. The tracking savings are 109,376 kWh and 15.16 kW peak demand reduction. The gross

[9] The 1995 reference year was chosen to standardize the 8,760 demand reduction profile to the 1995 weekday and holiday dates.

realization rates (GRR %) comparing the evaluated savings to the tracking savings are 101% for kWh and 83% for kW.

Primary Reasons for Savings Discrepancy

1. *Discrepancy #1 (Compressor Performance Profiles)* - The evaluated compressor performance profiles were based on CAGI and cut sheets. The evaluated pre-existing dryer performance was based on the pre-existing compressor performance and the assumed purge rate of the dryer. The sources for the tracking compressor and dryer performance assumptions could not be completely assessed but single average values were used for both pre-existing and proposed compressor and dryer loads. To isolate this discrepancy, the evaluator used the evaluated compressor performance curves and dryer purge rate assumptions to estimate the pre-existing and proposed compressor and dryer loads at the tracking average air demand of 297 cfm. These average single value loads were multiplied by the tracking annual operating hours (and the usage factor of 0.3 for the dryer annual usage) to calculate annual energy and demand reduction savings. This led to a kWh discrepancy of -18,742 kWh and 0.09 kW (or -17% kWh and 1% kW).
2. *Discrepancy #2 (Hourly Flow and Load Profiles; Calculation Method)* – The tracking calculation uses a single point average compressor and dryer load and multiplies these values by the annual operating hours to estimate annual energy consumption. The evaluated method developed hourly load profiles categorized by weekday and season. This method increases the resolution of the load profile and can increase the accuracy of annual extrapolations when estimating savings. The discrepancy was calculated to be 20,292 kWh and -2.71 kW (or 19% kWh and -18% kW).

More Comments on Discrepancy #1

The tracking average pre-existing compressor load was estimated to be 62.77 kW while the evaluated average pre-existing compressor load was calculated to be 70.49 kW (using the tracking average air demand of 297 cfm and without dryer purge load). The tracking average installed compressor load was estimated to be 51.48 kW while the evaluated average installed compressor load was calculated to be 59.08 kW. The difference between the tracking average pre-existing and installed compressor load is 11.29 kW while the difference between the evaluated average pre-existing and installed compressor load is 11.41 kW. The difference in compressor demand reduction between tracking and evaluated was only 0.12 kW or 866 kWh using the tracking assumed 7,213 annual operating hours. The remaining discrepancy of -19,608 kWh comes from the difference between the tracking dryer loads (14.556 kW for the pre-existing; 1.64 kW for the installed) and the evaluated dryer loads (5.44 kW for the pre-existing; 1.60 kW for the installed). The dryer load discrepancy cannot be completely assessed because the assumptions that fed in to the tracking pre-existing dryer load estimates (where the largest discrepancy exists) were not documented.

Peak Demand Discrepancy

The tracking peak demand reduction was calculated by dividing the annual energy savings by the assumed annual operating hours (i.e., average demand reduction). This estimate has no real association with the facility's compressor demand that is coincident with the defined NY ISO peak period. The evaluated peak demand reduction estimate was based on the NY ISO peak period.

SITE ID: DNVCA03

Project Type	Retrofit
Measure Category	Custom Compressed Air

PROJECT DESCRIPTION

The customer custom mounts hardware and electrical components on heavy duty vehicles and utilizes the compressed air system to operate pneumatic tools in the shop. By replacing two pre-existing air compressors, one load/unload and one start/stop, the customer was able to reduce the run time of the compressed air system and reduce compressor energy consumption at lower loads. Table 1 summarizes the initial savings estimates prior to the retrofit and the revised or evaluated savings values following project implementation. Table 2 summarizes the discrepancies between the tracking and evaluated savings.

Table 1: Summary of Evaluation Results

Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
Annual Energy Savings (kWh)	32,986	30,925	94%
Peak Demand Reduction (kW)	7.0	7.8	111%

Table 2: Discrepancy Analysis Summary

Discrepancy Factor	kWh	kW
Operating Conditions	Performance Curves: -2,061 kWh; -6%	
Equipment Specifications		
Calculation Method		Inappropriate Method: 0.8 kW, 11%
Inappropriate Baseline		

TRACKING SAVINGS

This section summarizes the methodology and assumptions used to estimate the Tracking savings claimed for the project.

Project Description

The customer custom mounts hardware and electrical components on a variety of heavy duty vehicles. A technical assistance study was performed in order to determine energy conservation opportunities within the facility's compressed air system, which provides compressed air to power pneumatic hand tools. The technical assistance study determined that one 30 HP variable speed compressor could adequately meet the compressed air needs of the facility and decrease the customer's annual energy requirements by reducing run time and decreasing compressed air energy consumption at low loads.

Table 3: Tracking ECMs

Description of ECM	Quantity
Installation of a 30 HP Variable Speed Compressor	1

Baseline

Prior to the retrofit, the customer operated two compressors to meet the facility's compressed air load. The specifications of the two pre-existing compressors are outlined in Table 4.

Table 4: Pre-Existing Equipment

Description	Stages	HP	Control Method	Rated PSIG	Operating PSIG	Capacity (ACFM)	Date of Installation
Oil Injected Rotary Screw	1	10	Start/Stop	125	110	38	2007*
Oil Injected Rotary Screw	2	25	Load/Unload	125	110	110	2009*

Prior to the retrofit, both compressors were used to meet the facility's compressed air needs. For loads up to 33 ACFM, Compressor #2 would meet the full load requirements while Compressor #1 ran unloaded. At loads exceeding 33 ACFM, Compressor #1 acted as the lead compressor and Compressor #2 acted as the trim compressor.

*Note: The customer installed compressors 1 and 2 in 2007 and 2009, respectively, but purchased the compressors on the secondary market. The customer suspects that the compressors were approximately 5 years old at the time of purchase.

Proposed Condition

As a result of the retrofit, the customer installed one 30 HP variable speed compressor to meet the facility's compressed air load. The specifications for the installed compressor are outlined in Table 5.

Table 5: Installed Equipment

Description	Stages	HP	Control Method	Rated PSIG	Operating PSIG	Capacity (ACFM)
Oil Injected Rotary Screw	1	30	VSD	125	110	150

Tracking Calculation Methodology

In order to calculate the initial project savings, the pre-existing compressed air system was fitted with pressure and power data loggers for a period of one week. The flow data was split into 15 separate bins based on compressed air demand. The % time at each load bin was multiplied by 4,160 operating hours to calculate the annual hours at each load bin based on one week of trend data. The tracking analysis utilized AirMaster+ to generate performance curves exhibiting the relationship between compressed air demand (ACFM) and power consumption (kW) using equipment nameplate information. The performance curves were used in conjunction with the compressor sequence of operations to determine a system kW demand vs. flow relationship which included the kW demand of both compressors. The kW demand and annual operating hours for each load bin were multiplied in order to calculate the annual kWh for each load bin.

The installed compressor annual energy consumption was calculated in a similar manner. The % load of the compressor was determined using the load profile used in the baseline calculations. The kW demand for each bin was subsequently determined using AirMaster+ performance curves. The kW demand and annual operating hours for each bin were multiplied in order to calculate the annual kWh for each bin. The annual kWh for all 15 bins were summed to calculate the installed case annual kWh. The kW vs. ACFM data for the pre-existing and proposed compressed air systems as calculated by AirMaster+ are shown in Table 6.

Table 6: Compressor Performance Data

ACFM	Baseline kW	Installed kW
0	9.0	2.1
10	11.4	3.8
20	13.7	5.6
30	16.0	7.4
40	18.3	9.2
50	20.5	11.0
60	22.6	12.7
70	24.7	14.5
80	26.7	16.3
90	28.7	18.1
100	30.6	19.9

Equations:

1. Individual Load kWh = (kW at Specific Load) x (Number of Hours at Load)
2. System kWh = Individual Load 1 kWh + Individual Load 2 kWh + …+ Individual Load 15 kWh
3. kWh Savings = System kWh_{Base} –System $kWh_{Proposed}$

Assumptions:

1. Compressed air flow profile for Monday – Friday was averaged into one hour increments. A one day profile was then generated averaging the values from the 5 day period.
2. Tracking analysis didn't report any savings for Saturday and Sunday as this was claimed as the non-production days of the week.

Assessment of Tracking Methodology and Analysis

1. Trend data which served as the basis of the savings calculations were not provided with the tracking documentation

2. Assumed no production occurred on Saturday or Sunday. However, during the onsite evaluation it was determined that the customer occasionally performs work on Saturday during periods of high production volume.
3. The project documentation does not detail how the peak demand reduction was calculated. The peak demand reduction seems to correspond to the demand reduction at low demand (between 2 and 5 CFM) but no justification was given for why these load bins were chosen.

EVALUATION METHODOLOGY

The following sub-sections describe project scope and estimated savings based on observed site conditions. The sub-sections go over the pre-existing (baseline) and proposed operating conditions & equipment informed by the site visit and correspondence with the site contact. The sub-sections also discuss the data collection, analysis, and calculation methodology performed to estimate the evaluated savings.

Measure Verification

The conditions found on site were similar to those outlined in the tracking analysis. The customer's compressed air system powers pneumatic tools in the machine shop. Furthermore, the evaluator was able to visually verify nameplate information of the pre-existing and installed compressors, as all three compressors were onsite at the time of the evaluation.

Since no time series trend data was available onsite, the evaluator was forced to utilize spot verification to substantiate the system operating pressure claimed in the tracking calculations. During the onsite evaluation, the evaluation engineer utilized the pressure gauge located on the facility's compressed air storage tank as that was only gauge both readily identifiable and accessible. For the duration of the site audit, the evaluator observed a system operating pressure of 109 PSIG, which validates the system pressure of 110 PSIG used in the tracking analysis.

Additionally, no control data was available to verify the pre-existing compressor sequence of operations. However, through an interview conducted during the evaluation, the site contact was able to verify that the sequencing used in the tracking analysis was accurate. Table 7 shows the ECMs and respective quantities installed.

Table 7 : ECM Installations

Implemented ECMs	Proposed (tracking)	Implemented (evaluated)
30 HP Variable Speed Compressor	Installed	Installed
10 HP Start/Stop Compressor	Removed and Retired	Retired/Retained as backup
25 HP Load/Unload Compressor	Removed and Retired	Retired/Retained as backup

Data Collection

An ElitePro SP kW logger was installed on the variable speed compressor for a period of 4 weeks. The evaluation engineer used this time series kW data to create an hourly compressed air system operating profile. Table 8 outlines the specifications of the kW data logger installed during the evaluation.

Table 8: Evaluation Measurement Summary

Time-Series Data Information	
Measured Parameter	Total Package True Power (kW)
Logger Make/Model	Dent ElitePro SP kW Logger
Transducer/Equipment Type	(3x) 100A split-core CTs
Installation Location	Outlet of VSD on the installed compressor
Observation Frequency	1 minute interval
Metering Period	4 weeks (November 6, 2013 – December 3, 2013)
Metered By	DNV GL and RISE electrician

The customer was also asked to provide payroll hours for one year encompassing the trending period. The payroll data showed man hours billed during the trending period, November 7 – December 4, 2013 and on an annual basis from December 1, 2012 – December 1, 2013. The payroll data was used to verify the initial annual hour estimates used in the tracking analysis. The payroll data included only hours worked by the shop workers and excluded employees who would not have a direct effect on the compressed air system power consumption including office and sales personnel.

The customer provided normal operating hours – the facility usually operates between 8A-5P Monday through Friday with the occasional Saturday. During the summer they usually have Saturdays off, the rest of the year they sometimes work 8A-12P. However, trend data collected during the evaluation showed production occurring on Saturday and Sunday. The method by which the evaluator dealt with this discrepancy is outlined in the section below.

Evaluation Savings Analysis

The evaluation engineer utilized the trend data collected during the onsite evaluation to develop an 8,760 compressed air load profile. Using the load profile, the evaluator calculated the pre and post retrofit kW demand using AirMaster+ curves for the pre-existing compressors and CAGI performance curves for the installed compressor.

The peak demand reduction was calculated in compliance with the NYISO, which states that system peaks generally occur during the hour ending at 5pm on the hottest non-holiday weekday. The New York Technical Manual (TM) states that this peak occurs on Friday, July 21, 1995 between 4 P.M. – 5 P.M. However, since compressor measures are not weather dependent, the peak demand reduction for this evaluation was calculated by taking the average peak demand reduction for all non-holiday weekdays between the hours of 4-5PM.

Installed Scenario

In order to calculate project savings, the evaluator developed an hourly operating profile for the customer's compressed air system. To accomplish this, the evaluator utilized the installed compressor power consumption data collected between 11/6/13 – 12/3/13 and compressor performance curves which outline the relationship between compressed air demand and power consumption and are generated using CAGI performance data. Using this relationship, the evaluator was able to generate a lookup table which listed the average compressed air demand from the trending period based on hour and day type. This lookup table was used to generate an 8,760 load profile by matching each hour and day type throughout the year to the corresponding average compressed air demand in the lookup table. However, merely annualizing the average compressed air load assumes 8,760 hours of operation.

Customer-provided payroll data was used to verify the annual production hour estimate used in the tracking analysis. The tracking analysis assumed 4,160 annual operating hours for savings estimation. The payroll data provided was man hours worked during the trending period, as well as total man hours worked between December 1, 2012 and December 1, 2013. In order to differentiate between "off" hours and "unloaded" hours, the evaluator verified annual operating hours using hours above 10 ACFM demand. A value of 0.05 hours above 10 ACFM demand per man hour worked was calculated using payroll data and power trend data. This value was multiplied by the annual man hours worked between December 2012 and December 2013, which estimated 2,196 annual hours above 10 ACFM demand. This validated the initial annual operating hours estimate used in the tracking analysis as the initial savings calculations estimated 2,080 annual hours above 10 ACFM demand.

In order to obtain 4,160 annual hours of operation, the evaluator first assumed no production during 10 major Federal Holidays, as indicated by the site contact during an onsite interview. Additionally, the site contact stated that production did not occur on Sundays and most Saturdays throughout the year. Since the trend data collected during the evaluation show production on Saturday and Sunday during the trend period, the evaluation engineer assumed that this production occurred due to cyclicality in load. As such, the evaluation engineer assumed no production on 93 total Saturdays and Sundays throughout the year in order to obtain the correct number of operating hours resulting from the calculation mentioned above. The result of the previous steps is an 8,760 compressed air load profile which correctly reflects 4,160 annual hours of operation.

Once the correct compressed air load profile was generated, the corresponding kW demand for each load was calculated based on a performance curve taken from the CAGI data sheet. The 8,760 hourly kW were summed in order to calculate the annual compressor power consumption for the post-installation period.

Pre-existing Scenario

The pre-existing compressed air system power consumption was determined based on the corrected 8,760 compressed air load profile which reflects 4,160 annual hours of operation and performance curves generated in AirMaster+. The AirMaster+ performance curves were generated using the compressor nameplate information and system operating parameters utilized in the tracking analysis and verified on site. AirMaster+ then generates a % Power vs. % Flow curve for the specified compressor. Dummy flows were input into the 'Profile' tab in AirMaster+ which automatically generates a Capacity (ACFM) vs. Power (kW) relationship. Using this relationship, the evaluator was able to calculate the 8,760 kW demand as a function of the 8,760 compressed air demand from the post-installation period. The 8,760 kW were then summed in order to calculate the annual compressor power consumption for the pre-existing period.

EVALUATION RESULTS

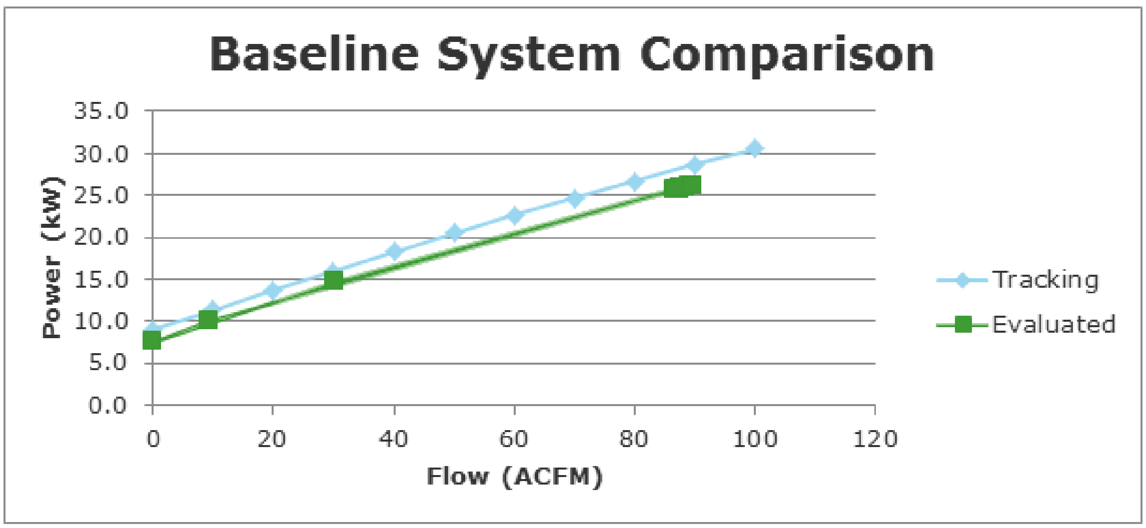
The total evaluated electric savings were determined to be 30,925 kWh and 7.8 kW peak demand reduction. The tracking savings are 32,986 kWh and 7.0 kW peak demand reduction. The gross realization rates (GRR) comparing the evaluated savings to the tracking savings are 94% for kWh savings and 109% for peak demand reduction.

Primary Reasons for Savings Discrepancy

1. Operating Conditions [-2,061 kWh, -6%]

    a. Performance Curve Discrepancy

        i. The performance curves generated during the evaluation using AirMaster+ showed a slight divergence from the kW vs. flow relationship used in the tracking analysis. The installed compressor performance curves remained unchanged as they were taken from the CAGI data sheet. However, the revised baseline system performance curves show that the kW demand in the tracking analysis was overestimated. The figure below exhibits the difference between the tracking and evaluated baseline compressed air systems.



2. Calculation Methodology [0.8 kW, 11%]

    a. Demand Reduction Calculation

        i. The tracking peak demand reduction was calculated by dividing the annual energy savings by the assumed annual operating hours (i.e., average demand reduction). This estimate has no real association with the facility's compressor demand that is coincident with the defined New York TRM peak hour for the Albany area (Friday, July 21, 1995 4 P.M. – 5 P.M.). The evaluated peak demand reduction estimate was based on this specific peak hour. However, since compressed air measures are not weather dependent, the peak demand reduction was calculated by taking the average demand reduction for all non-holiday weekdays between 4-5PM.

SITE ID: DNVCA23, DNVCA04, DNVCA07

Project Type	Retrofit
Measure Category	Custom Compressed Air

PROJECT DESCRIPTION

This customer implemented three compressed air projects at the same facility. Project ID DNVCA23 involved the installation of a two-stage rotary screw air compressor with variable speed control in place of two pre-existing single stage, inlet modulating compressors, Project ID DNVCA04 involved the installation of a 3,000 gallon compressed air storage tank with a pressure and flow controller, and Project ID DNVCA07 involved the identification and repair of approximately 200 air leaks of various sizes within the compressed air system.

Note: Project DNVCA07 was not eligible for a National Grid Incentive as it was a low cost measure and did not meet payback period program requirements. Table 1 outlines the savings as a result of each individual project implemented at the customer's facility.

Table 1: Summary of Evaluation Results

Savings Quantity	DNVCA23	DNVCA04	DNVCA07
Tracking Annual Energy Savings (kWh)	799,896	35,095	165,114
Tracking Peak Summer Demand Reduction (kW)	0	11.0	19.4
Evaluated Annual Energy Savings (kWh)	560,896	49,053	94,426
Evaluated Peak Summer Demand Reduction (kW)	68.2	4.9	10
Energy Gross Realization Rate (%)	0.70	1.40	0.57
Peak Demand Gross Realization Rate (%)	NaN	0.44	0.49

Table 2, Table 3, and Table 4 outline the sources of discrepancy between the tracking and evaluated savings for projects DNVCA23, DNVCA04, and DNVCA07, respectively.

Table 2: Project ID DNVCA23 Discrepancy Analysis Summary

Discrepancy Factor	kWh	kW
Operating Conditions	Discrepancy #1 (Load Discrepancy): -118,918 kWh; -15% Discrepancy #2 (Curve Discrepancy): -120,056 kWh, -15%	
Equipment Specifications		
Calculation Method		Discrepancy #3 (Calculation Method): 68.2 kW; NaN%
Inappropriate Baseline		

Table 3: Project ID DNVCA04 Discrepancy Analysis Summary

Discrepancy Factor	kWh	kW
Operating Conditions		
Equipment Specifications		
Calculation Method	Discrepancy #1 (Calculation Method): 13,958 kWh; 40%	Discrepancy #1 (Calculation Method): -6.3 kW; -56%
Inappropriate Baseline		

Table 4: Project ID DNVCA07 Discrepancy Analysis Summary

Discrepancy Factor	kWh	kW
Operating Conditions	Discrepancy #1 (Curve Discrepancy): 15,731 kWh; 10%	Discrepancy #1 (Curve Discrepancy): 2 kW; 9%
Equipment Specifications		
Calculation Method	Discrepancy #2 (Calculation Method): -86,419 kWh; -52.3%	Discrepancy #2 (Calculation Method): -11.6 kW; -60%
Inappropriate Baseline		

TRACKING SAVINGS

This section summarizes the methodology and assumptions used to estimate the Tracking savings claimed for the project.

Project Description

The customer operates a manufacturing facility year round. The customer's compressed air system was surveyed and evaluated to determine opportunities to reduce energy consumption and process expenditures. As detailed above, although this compressed air system upgrade project is a single turnkey project, the tracking data divided it into three different sub-projects and each of these sub projects applied for incentive in three separate applications. The detail project scopes of these three sub projects are described below:

Application ID# DNVCA23: This project involved the installation of a two-stage rotary screw air compressor with variable speed control in place of the two pre-existing 125 and 75 hp compressors with inlet modulation with blow down. The project savings were a result of the increased efficiency of the VSD compressor at part loads.

Application ID# DNVCA04: This project involved the installation of a 3,000 gallon compressed air storage tank with pressure and flow controls in addition to the 1,060 gallons of compressed air storage already available on site. The tank installation enables an 8 PSIG reduction in system pressure while allowing a maximum pressure fluctuation of +/- 2 PSIG, reducing artificial demand due to overpressure.

Application ID# DNVCA07: This project involved the identification and repair of approximately 200 air leaks within the compressed air system. The air leak repair claimed to have resulted in the elimination of approximately 113 ACFM of artificial compressed air demand. Table 5 outlines the ECM's listed in the tracking data.

Table 5: Tracking ECMs

Description of ECM	Quantity
Install 150 hp Variable Speed Compressor	1
Install 3,000 Gallon Compressed Air Tank	1
Repair Approximately 200 Air Leaks	1

Baseline

During the baseline period, the customer operated 3 air compressors to meet the facility's compressed air demand, one 150 hp, one 125 hp, and one 75 hp. All the three pre-existing compressors were using inlet modulation with blow down control strategy to control the compressor flow to the end users. The pre-existing compressors operated such that compressors #1 and #2 would ramp up at the same % speed to meet the facility load. If the air load surpassed 1380 ACFM, all three compressors would operate in the same sequence to meet the system load. During the vendor evaluation, the facility air demand never surpassed the combined capacity of compressors #1 and #2. Therefore, compressor #3 ran unloaded for the entirety of the ex-ante trending period.

Table 6: Pre-Existing Equipment

Name	hp	Control	Rated PSIG	Operating PSIG	Capacity (ACFM)
Comp #1	150	Inlet modulation w/ blow down	125	100	760
Comp #2	125	Inlet modulation w/ blow down	125	100	620
Comp #3	75	Inlet modulation w/ blow down	125	100	352

Additionally, the compressed air system operated without pressure/flow controls and suffered from excessive demand due to the presence of numerous air leaks within the system.

Proposed Condition

Project ID# DNVCA23: During the proposed period, two of the three pre-existing (one 125 hp and one 75 hp) compressors were removed and replaced with a VSD controlled compressor. The proposed compressor is rated for 150 hp and provides a maximum capacity of 800 CFM. The proposed compressor was installed in close proximity to the existing 150 hp inlet modulating air compressor and operated as the lead and trim compressor. During the periods when the plant demand is below 800 CFM the proposed compressor will meet the demand and provide efficient part load operation. During periods when the air load is over 800 CFM the existing 150 hp, 760 CFM compressor will run at full load with the proposed compressor running at part load as needed to meet the demand.

Table 7: Proposed Equipment

Name	hp	Control	Rated PSIG	Operating PSIG	Capacity (ACFM)
Comp #1	150	Inlet modulation w/ blow down	125	100	760
Comp #2	150	Variable Speed Drive	100	100	800

Project ID# DNVCA04: The proposed conditions for project ID# DNVCA23 served as the pre-existing conditions for project ID# DNVCA04. As a result of this project, the customer installed a 3,000 gallon compressed air tank with flow/pressure controls. The flow/pressure controls maintain the demand side system pressure in the range of 85 to 90 PSI and allow a maximum pressure fluctuation of +/- 2 PSI. Doing so allows an average reduction in supply side pressure of approximately 8 PSI.

Project ID# DNVCA07: Similarly, the proposed conditions for project ID# DNVCA04 serve as the pre-existing conditions for project ID# DNVCA07. By identifying, tagging, and repairing the roughly 200 air leaks within the compressed air system, the customer was able to eliminate approximately 113 CFM of artificial demand.

Tracking Calculation Methodology

Application ID# DNVCA23:

The energy savings were calculated by taking the difference between each system's kWh as shown in Table 9. The compressed air system load profile was split into 5 separate bins or shifts based on the ACFM demand. The kW demand for each compressor was determined using the compressor sequencing and data generated by the Department of Energy's AirMaster+ software, shown in Table 9. The kW demand and annual operating hours for each load profile bin were multiplied in order to calculate annual kWh for each bin. The annual kWh for all 5 bins were summed to calculate the baseline case annual kWh.

The installed compressed air system annual power consumption was calculated in a similar manner. The % load of the compressors was determined using the load profile used in the baseline calculations. The kW demand for each bin was subsequently determined using kW vs. flow data provided by the manufacturer. The kW demand and annual operating hours for each load profile bin were multiplied in order to calculate the annual kWh for each bin. The annual kWh for all 5 bins were summed to calculate the installed case annual kWh. The tracking savings calculations are shown in their entirety in Table 8.

Table 8: Compressor Performance Data

ACFM	Baseline kW	Installed kW
0	71.0	0.0
95	95.0	24.3
190	118.9	42.3
285	142.8	58.2
380	166.8	74.3
475	190.7	86.5
570	210.8	103.0
665	215.9	119.4
760	221.0	135.8
855	226.0	160.6
950	231.1	179.0
1045	236.2	164.4
1140	241.2	210.5
1235	246.3	222.8
1330	251.4	239.2
1425	-	255.6

Table 9: DNVCA23 Tracking Analysis

Compressor Average Load Profile					
Shift	1	2	3	4	5
Annual Hours	1144	1404	3952	2080	156
Existing Avg. Demand ACFM	240	400	560	720	1040
Proposed Avg. Demand ACFM	127	287	447	607	927
Existing					
Compressor ACFM Capacity	% Load				
760	0.17	0.29	0.41	0.52	0.75
620	0.17	0.29	0.41	0.52	0.75
	ACFM				
Compressor 1	132.2	220.4	308.4	396.5	572.7
Compressor 2	107.8	179.8	251.6	323.5	467.2
System (kW)	144	176.6	198	214	237.5
System (kWh)	164,679	247,901	782,481	445,174	37,046
				Total	**1,677,282**
Proposed					
Compressor ACFM Cap.	% Load				
800	0.3	0.5	0.7	0.9	0.35
760	0	0	0	0	1
	ACFM				
Compressor 1	240	400	560	720	280
Compressor 2	0	0	0	0	760
Total	240	400	560	720	1040
Compressor 1 (kW)	50.6	76.8	101.2	128.9	57.3
Compressor 2 (kW)	0	0	0	0	221
System Total (kW)	50.6	76.8	101.2	128.9	278.3
System (kWh)	57,932	107,883	400,061	268,091	43,418
				Total	**877,386**

Equations:

1. Individual Load kWh = (kW at Specific Load) x (Number of Hours at Load)
2. Total System kWh = Load 1 kWh + Load 2 kWh +…+ Load 5 kWh
3. kWh Savings = Total System kWh_{Base} – Total System $kWh_{Proposed}$

Assessment of Tracking Methodology and Analysis

1. The tracking analyses rely on only one week of compressor trend data in order to annualize annual energy consumption. One week of data may not accurately depict normal compressor load.

2. It is unclear how peak demand reduction was calculated for all three projects. No peak DR was reported as a result of the compressor replacement but peak savings were reported for the tank installation and air leak repair.

Application ID# DNVCA04:

The savings associated with the tank installation were calculated using a general rule of thumb set forth by the Compressed air and Gas Institute (CAGI), which states that total power consumption decreases by 1% for every 2 PSIG reduction in system operating pressure. The tracking analysis assumes an 8 PSIG reduction resulting from the tank installation, applied to the installed compressed air system, resulting in a 4% decrease in system energy consumption. The tracking analysis utilized the installed compressors for the baseline and proposed periods and can be seen in its entirety in Table 10.

Table 10: DNVCA04 Tracking Analysis

Compressor Average Load Profile					
Shift	1	2	3	4	5
Annual Hours	1144	1404	3952	2080	156
Average Demand ACFM	240	400	560	720	1040
PSIG Reduction	8	8	8	8	8
Existing					
Compressor Capacity	% Load				
800 ACFM	0.3	0.5	0.7	0.9	0.35
760 ACFM	0	0	0	0	1
	ACFM				
Compressor 1	240	400	560	720	280
Compressor 2	0	0	0	0	760
Total	240	400	560	720	1040
Compressor 1 (kW)	50.6	76.8	101.2	128.9	57.3
Compressor 2 (kW)	0	0	0	0	221
System Total (kW)	50.6	76.8	101.2	128.9	278.3
System (kWh)	57,932	107,883	400,061	268,091	43,418
				Total	**877,386**
Proposed					
Compressor Capacity	% Load				
800 ACFM	0.3	0.5	0.7	0.9	0.35
760 ACFM	0	0	0	0	1
	ACFM				
Compressor 1	240	400	560	720	280
Compressor 2	0	0	0	0	760
Total	240	400	560	720	1040
Compressor 1 (kW)	48.6	73.8	97.2	123.7	55
Compressor 2 (kW)	0	0	0	0	212.1
System Total (kW)	48.6	73.8	97.2	123.7	267.1
System (kWh)	55,615	103,568	384,059	257,368	41,681
				Total	**842,291**

Equations:

1. DNVCA04 Operating Pressure (PSIG) = DNVCA23 Operating Pressure (PSIG) – 8 PSIG
2. Hourly kW Reduction = DNVCA23 Hourly kW * (8%)
3. kWh Savings = Sum(Hourly kW Reduction)

Assessment of Tracking Methodology and Analysis:

1. The tracking analysis relies on only one week of compressor trend data in order to annualize annual energy consumption. One week of data may not accurately depict normal compressor load.
2. The tracking analysis does not document how peak demand reduction was calculated.

The tracking analysis assumes an 8 PSIG reduction in system operating pressure but no trend data or spot measurements are available to substantiate those claims. Additionally, the tracking analysis utilizes a deemed approach to project savings. No actual measurements or calculations were performed to determine the applicability of the CAGI rule of thumb to the customer's system.

Application ID# DNVCA07:

Finally, the savings associated with the compressed air leak repair were calculated by merely assuming a 113 ACFM decrease in compressed air system demand as a result of the identification and repair of the air leaks. Once again, the tracking analysis from project DNVCA07 utilizes the installed compressors for the baseline and proposed periods and can be seen in its entirety in Table 11.

Table 11: DNVCA07 Tracking Analysis

Compressor Average Load Profile					
Shift	1	2	3	4	5
Annual Hours	1144	1404	3952	2080	156
Existing Avg. Demand ACFM	240	400	560	720	1040
Proposed Avg. Demand ACFM	127	287	447	607	927
Existing					
Compressor Capacity	% Load				
800 ACFM	0.3	0.5	0.7	0.9	0.35
760 ACFM	0	0	0	0	1
	ACFM				
Compressor 1	240	400	560	720	280
Compressor 2	0	0	0	0	760
Total	240	400	560	720	1040
Compressor 1 (kW)	50.6	76.8	101.2	128.9	57.3
Compressor 2 (kW)	0	0	0	0	221
System Total (kW)	50.6	76.8	101.2	128.9	278.3
System (kWh)	57,932	107,883	400,061	268,091	43,418
				Total	**877,386**
Proposed					
Compressor Capacity	% Load				
800 ACFM	0.2	0.4	0.6	0.8	0.2
760 ACFM	0	0	0	0	1
	ACFM				
Compressor 1	127	287	447	607	167
Compressor 2	0	0	0	0	760
Total	127	287	447	607	927
Compressor 1 (kW)	30.3	58.5	82.9	109.4	37.9
Compressor 2 (kW)	0	0	0	0	212.1
System Total (kW)	30.3	58.5	82.9	109.4	258.9
System (kWh)	34,663	82,134	327,621	227,469	40,385
				Total	**712,272**

Equations:

1. DNVCA07 Hourly Demand (ACFM) = DNVCA23 Hourly Demand (ACFM) – 113 ACFM
2. Individual Load kWh = (kW at DNVCA07 Hourly Demand) x (Number of Hours at Load)
3. Total System kWh = Load 1 kWh + Load 2 kWh +…+ Load 5 kWh

kWh Savings = Total System kWh $_{\text{Base}}$ – Total System kWh $_{\text{Proposed}}$

Assessment of Tracking Methodology and Analysis:

1. The tracking analyses rely on only one week of compressor trend data in order to annualize annual energy consumption. One week of data may not accurately depict normal compressor load.
2. The tracking analysis does not document how peak demand reduction was calculated.
3. Similarly, for Project DNVCA07, the tracking analysis assumes a 113 ACFM reduction in artificial demand as a result of the air leak repair but there is no evidence that substantiates the compressed air demand reduction estimates. No data was collected regarding what types of leaks were repaired, the number and the size of the leaks, or even the location of the leaks.

EVALUATION METHODOLOGY

The following sub-sections describe project scope and estimated savings based on observed site conditions. The sub-sections go over the pre-existing (baseline) and proposed operating conditions & equipment informed by the site visit and correspondence with the site contact. The sub-sections also discuss the data collection, analysis, and calculation methodology performed to estimate the evaluated savings.

Measure Verification

The conditions found on site were similar to those outlined in the tracking analysis. The customer's compressed air system is used to actuate pneumatic valves in the customer's manufacturing facility. The following site conditions were found during the evaluation as they pertain to the three projects performed at the customer's facility.

Project ID# DNVCA23:

The evaluator was able to visually verify the nameplate information of the installed air compressors. Since the pre-existing air compressors were removed from the facility, visual verification of nameplate information was not possible. However, through the onsite interview, the customer was able to verify the specifications outlined in the tracking data. The proposed vs. implemented ECM summary for project ID# DNVCA23 can be found below in Table 12.

Table 12: Project ID# DNVCA23 Proposed versus Implemented ECMs

Implemented ECMs	Proposed (tracking)	Implemented (evaluated)
150 hp variable speed compressor	Installed as Primary #1	Installed as Primary #1
150 hp Compressor with Inlet Mod & Blow down	Retained as Primary #2	Retained as Primary #2
125 hp Compressor with Inlet Mod & Blow down	Retired & Removed	Retired & Removed
75 hp Compressor with Inlet Mod & Blow down	Retired & Removed	Retired & Removed

Project ID# DNVCA04:

The evaluator was able to visually verify the installation of the proposed 3,000-gallon storage tank with the pressure and flow controller. The evaluator was also able to observe system operating pressure around 90 PSIG. However, no additional data was available which shows the system operating pressure prior to the retrofit. As such, the evaluator was not able to verify the reduction in system operating pressure. The proposed vs. implemented ECM summary for project ID# DNVCA04 can be found below in Table 13.

Table 13: Project ID# DNVCA04 Proposed versus Implemented ECMs

Implemented ECMs	Proposed (tracking)	Implemented (evaluated)
3,000 gallon compressed air tank	Installed	Installed

Project ID# DNVCA07:

The evaluator was not able to verify the measure associated with air leak repair. During the evaluation, it was discovered that no data was collected which showed neither the location nor the size of the pre-existing air leaks. The proposed vs. implemented summary for project ID# DNVCA07 can be found below in Table 14.

Table 14: Project ID# DNVCA07 Proposed versus Implemented ECMs

Implemented ECMs	Proposed (tracking)	Implemented (evaluated)
Air Leaks - 113 ACFM of Artificial Demand	Identified & Repaired	Could not be verified

Data Collection

Data loggers were installed on the compressed air system for 4 weeks in order to generate an hourly operating profile for the facility. Due to accessibility issues, an amp logger was installed on the compressor #1 for the trending period to record the time series current of the compressor #1. Compressor #2 was fitted with a power logger for the same period to monitor kW. Table 15 outlines the specifications of the data logger installed during the onsite evaluation

Table 15: Evaluation Measurement Summary

Time-Series Data Information		
Measured Parameter	Total package True Power (kW)	Total package Current (A)
Logger Make/Model	DENT Elite Pro SP	HOBO Microstation
Transducer/Equipment Type	(3x) 100A split-core CTs	(3x) 100A split-core CTs
Installation Location	Compressor #2 Power Compartment	Compressor #1 Power Compartment
Observation Frequency	1 minute	1 minute
Metering Period	4 weeks (11/6/13 – 12/4/13)	4 weeks (11/6/13 – 12/4/13)

Metered By	DNV GL and RISE Electrician	DNV GL and RISE Electrician

Evaluation Savings Analysis

In order to evaluate the effects of each retrofit project, the evaluator applied each retrofit individually to the pre-existing compressed air system. Table 16 summarizes the baseline and installed conditions for each project evaluation. The evaluator used a tiered approach to avoid double counting any savings. The evaluator worked backwards from the as-built conditions found onsite. Therefore, the as-built conditions served as the proposed conditions for project ID# DNVCA23. The pre-existing conditions for project ID# DNVCA23 also served as the installed conditions for project ID# DNVCA04. Similarly, the pre-existing conditions for project ID# DNVCA04 served as the installed conditions for project ID# DNVCA07. The pre-existing conditions for project ID# DNVCA07 were the site conditions before any work was performed at the facility.

Table 16: Evaluation Pre/Post Summary

Project #	Baseline	Proposed	Savings Evaluated
DNVCA23	Compressors: Pre-Existing Storage: 4,060 Gallons Air Leaks: 0 ACFM	Compressors: Installed Storage: 4,060 Gallons Air Leaks: 0 ACFM	VSD Compressor Savings
DNVCA04	Compressors: Pre-Existing Storage: 1,060 Gallons Air Leaks: 0 ACFM	Compressors: Pre-Existing Storage: 4,060 Gallons Air Leaks; 0 ACFM	Pressure Reduction Savings
DNVCA07	Compressors: Pre-Existing Storage: 1,060 Gallons Air Leaks: 113 ACFM	Compressors: Pre-Existing Storage: 1,060 Gallons Air Leaks: 0 ACFM	Air Leak Repair Savings

The evaluation engineer utilized power and current trend data collected during the onsite evaluation along with CAGI performance curves for the newly installed variable speed compressor and AirMaster+ curves for the retained inlet modulating compressor to develop an 8,760 compressed air load profile. This 8,760 compressed air load profile was applied to conditions outlined in Table 17 to determine the savings for each individual project.

Additionally, the summer peak demand reduction was calculated in compliance with the NYISO, which states that system peaks generally occur during the hour ending at 5pm on the hottest non-holiday weekday. The New York TRM states that this peak occurs on Friday, July 21, 1995 between 4 P.M. – 5 P.M. However, since compressed air system operation at this facility is not weather dependent, the peak demand reduction was calculated as the average demand reduction for all non-holiday weekdays between 4 P.M and 5 P.M.

Project ID#: DNVCA23

This project evaluated the impact of the VFD compressor retrofit. The installed conditions featured a 150 hp VFD compressor and a 150 hp inlet modulation compressor with 4,060 gallons of compressed air storage available. The baseline equipment featured three inlet modulating compressors, one 150 hp, one 125 hp, and one 75 hp with 4,060 gallons of compressed air storage available.

Installed Scenario

In order to calculate project savings, the evaluator first developed an hourly operating profile for the customer's compressed air system. To accomplish this, the evaluator utilized the installed compressor power consumption and current data collected between 11/6/13 – 12/4/13 and compressor performance curves which outline the relationship between compressed air demand and power consumption and are generated using CAGI performance data for the newly installed variable speed compressor and AirMaster+ curves for the retained inlet modulating compressor. Using this relationship, the evaluator was able to generate a lookup table which listed the average compressed air demand from the trending period based on hour and day type. This lookup table was used to generate an 8,760 load profile by matching each hour and day type throughout the year to the corresponding average compressed air demand in the lookup table.

The installed scenario utilized the 8,760 load profile outlined in the section above. The corrected 8,760 load profile was used in conjunction with CAGI performance data for the variable speed compressor and AirMaster+ curves for the inlet modulating compressor to develop an 8,760 kW demand based on the compressor sequence of operations. According to the tracking analysis (and confirmed during the onsite evaluation), the 150 hp variable speed compressor was used as the lead compressor up to loads of 760 ACFM. At loads above 760 ACFM, the 150 hp inlet modulating compressor would operate at full load while the variable speed compressor would act as the trim compressor. The annual energy consumption was calculated by summing the hourly compressor kW.

Pre-existing Scenario

The pre-existing compressed air system power consumption was determined based on the corrected 8,760 compressed air load profile generated earlier, and performance curves generated in AirMaster+ for the pre-existing compressors. The pre-existing system utilizes the three pre-existing inlet modulating compressors (one 150 hp, one 125 hp, and one 75 hp) but maintains the same storage capacity as the proposed period. According to the tracking analysis (and confirmed during the onsite evaluation), at loads up to 1380 ACFM, the 150 and 125 hp compressors would operate at the same speed to meet the facility's compressed air load. At loads above 1380, all three compressors would follow the same sequence. The 8,760 kW based on the 8,760 compressed air load were subsequently summed in order to calculate the pre-existing annual energy consumption. The difference between the installed and pre-existing annual 8,760 served as the basis for project savings.

Project ID#: DNVCA04

This project evaluated the impact of the compressed air storage tank installation. The installed scenario featured the pre-existing conditions of the Project ID# DNVCA23 (3 inlet modulating compressors, one 150 hp, one 125 hp, and one 75 hp) with 4,060 gallons of compressed air storage. The baseline system utilizes the same compressors but reflects the availability of only 1,060 gallons of compressed air storage.

Installed Scenario

The pre-existing scenario for project ID# DNVCA23 serves as the installed scenario for project ID# DNVCA04. The installed scenario for project ID# DNVCA04 utilizes the pre-existing compressors, 4,060 gallons of compressed air storage, and 0 ACFM of compressed air leaks.

Pre-existing Scenario

The pre-existing compressed air system power consumption was determined based on the 8,760 compressed air load profile generated earlier, and performance curves generated in AirMaster+. The pre-existing system utilizes the same equipment as the installed scenario. However, the AirMaster+ performance curves reflect the absence of the 3,000 gallon compressed air storage tank installed as a result of the retrofit where the compressed air profile was modelled by AirMaster+ with 1060 gallon tank. The 8,760 data point (kW) calculations based on the 8,760 compressed air load data points were then summed in order to calculate the pre-existing annual energy consumption. The difference between the installed and pre-existing annual 8,760 served as the basis for project savings.

Project ID#: DNVCA07

This project evaluated the impact of the air leak repair performed at the customer's facility. The installed conditions feature the pre-existing compressed air equipment from Project ID# DNVCA04 (3 inlet modulating compressors with 1,060 gallons of compressed air storage). The baseline period utilizes the same equipment; however, the hourly load in the baseline case is increased by 113 ACFM in order to simulate the presence of the air leaks within the system.

Installed Scenario

The pre-existing scenario for project ID# DNVCA04 serves as the installed scenario for project ID# DNVCA07. The installed scenario for project ID# DNVCA07 utilizes the pre-existing compressors, 1,060 gallons of compressed air storage, and 0 ACFM of compressed air leaks.

Pre-existing Scenario

The pre-existing compressed air system power consumption was determined based on the 8,760 compressed air load profile generated earlier, and performance curves generated in AirMaster+. The pre-existing system utilizes the same equipment as the installed system. As such, the pre-existing and installed compressor performance curves are identical. The 8,760 hourly compressed air demands were each increased by 113 ACFM in order to simulate the presence of approximately 200 compressed air leaks. The 8,760 data point (kW) calculations based on the 8,760 compressed air load data points were then summed in order to calculate the pre-existing annual energy consumption. The difference between the installed and pre-existing annual 8,760 served as the basis for project savings.

EVALUATION RESULTS

The project kWh savings were ultimately calculated by taking the difference between the annual kWh for the baseline and installed periods. The peak demand reduction for each project was taken as the average demand reduction on non-holiday weekdays between 4 P.M and 5 P.M as dictated by the NY Technical Manual (TM). The total evaluated electric savings are listed below in Table 18.

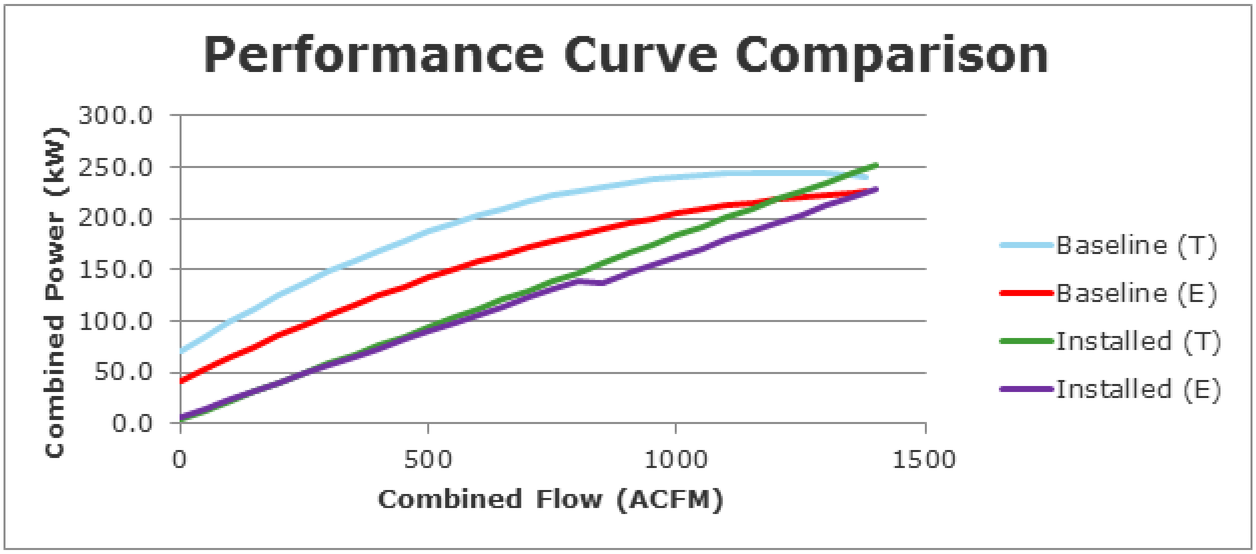
Table 17: Project Savings Summary

Savings Quantity	DNVCA23	DNVCA04	DNVCA07
Tracking Annual Energy Savings (kWh)	799,896	35,095	165,114
Tracking Peak Summer Demand Reduction (kW)	0	11.0	19.4
Evaluated Annual Energy Savings (kWh)	560,896	49,053	94,426
Evaluated Peak Summer Demand Reduction (kW)	68.2	4.9	10
Energy Gross Realization Rate (%)	0.70	1.40	0.57
Peak Demand Gross Realization Rate (%)	NaN	0.44	0.49

Primary Reasons for Savings Discrepancy

Project DNVCA23

1. *Discrepancy #1 (Load Discrepancy)* – The discrepancy between tracking and evaluated savings can be largely attributed to the operating conditions observed during the trending period. The tracking analysis showed the majority of system operation occurring between 400-700 ACFM. Between these loads, the kW reduction was maximized. At loads above 720 A CFM, the kW savings decreased. This inverse relationship between savings and compressed air load is the primary source of discrepancy between the tracking and evaluated savings. At no point during the evaluation did the compressed air demand drop below 600 ACFM. This resulted in a reduction in project savings of 118,918 kWh, an impact of -15%.
2. *Discrepancy #2 (Curve Discrepancy)* – An additional discrepancy was discovered during the course of the evaluation between the tracking compressor performance curves and the evaluated performance curves. The figure below shows the difference between the tracking performance curves and the evaluated performance curves and illustrates that at higher loads (above 800 ACFM) where the majority of the compressor operation occurred, the baseline energy consumption was highly overestimated while the proposed power consumption showed a slight change. The result is a discrepancy of -120,056 kWh, an impact of -15%.



3. *Discrepancy #3 (Peak Demand Calculation Method)* – The tracking calculations claimed 0 peak demand savings. However, the method by which tracking peak demand reduction was calculated is unknown. The evaluated peak demand reduction estimate was calculated by taking the average peak demand between 4PM-5PM on non-Holiday weekdays, as outlined by the New York Technical Manual (TM). The evaluated peak demand was calculated to be 68.2 kW. However, since the tracking methodology to calculate peak demand reduction is unknown, the evaluator cannot attribute discrepancy to a specific factor.

The overall project discrepancy as a result of the load and curve discrepancies was calculated to be -238,973 kWh, resulting in an energy savings realization rate of 70%. The overall peak demand discrepancy as a result of the calculation method was 68.2 kW. However, since no peak demand reduction was reported in the tracking calculations, the peak demand gross realization rate cannot be calculated.

Project DNVCA04

1. *Discrepancy #1 (Calculation Method)* – The discrepancies between the tracking and evaluated savings can be largely attributed to the method by which the initial tracking savings were calculated. The tracking calculations merely utilized a rule of thumb stating that every 2 PSIG reduction in system operating pressure corresponds to a 1% decrease in system power consumption. However, no evidence was collected which verified the 8% reduction in system operating pressure. Furthermore, the applicability of this specific rule of thumb was not verified for the system. As a result, the evaluation determined that the project kWh savings had been underestimated by 13,958 kWh and the demand reduction was overestimated by 6.3 kW, resulting in realization rates of 140% and 44% for kWh savings and demand reduction, respectively.

Project DNVCA07

1. *Discrepancy #1 (Performance Curves)* – During the evaluation, the evaluator discovered discrepancies in the performance curves used to characterize the operation of the pre-existing compressors. The figure above shows the difference in the tracking and evaluated performance

curves for the pre-existing compressed air system. The baseline performance curve generated during the evaluation is slightly steeper in slope than the baseline performance curve utilized in the tracking analysis. Therefore, the updated performance curves resulted in a slight increase in project savings by 15,731 kWh and 2 kW, impacts of 10% and 9%, respectively.

2. *Discrepancy #2 (Calculation Method)* – The calculation methodology is considered a major source of discrepancy between the tracking and evaluated savings. The tracking analysis does not consider the effects of the tank installation on the air leak repair measure. Similarly, the air leak repair was applied to the installed compressors, which double counts the effects of the compressor replacement. During the evaluation, the evaluator applied the air leak repair to the pre-existing system in order to truly isolate the effects of the three measures. The overall calculation method discrepancies lead to a decrease in project savings by -86,419kWh and -11.6 kW, impacts of -52.3% and -60%, respectively.

The overall project discrepancy as a result of the curve and calculation method discrepancies was calculated to be -70,688 kWh and -9.9 kW, resulting in gross realization rates of 57% for energy savings and 49% for peak demand reduction.

SITE ID: DNVCA05

Project Type	Early Replacement and Add-On
Measure Category	Custom Compressed Air

PROJECT DESCRIPTION

This project involved the retirement of one (1) pre-existing air-cooled 25-hp reciprocating compressor and one (1) pre-existing air-cooled 15-hp reciprocating compressor (used for emergency use only). These compressors were replaced with a new 25-hp air-cooled, oil-injected rotary screw compressor with variable speed (VFD) flow controls, an integrated refrigerant air dryer, and a 120 gallon air receiver tank.[10] Table 1 provides the evaluation savings results while Table 2 provides a summary of the discrepancy analysis results.

Table 1: Summary of Evaluation Results

Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
Annual Energy Savings (kWh)	14,135	-5,658	-40%
Peak Demand Reduction (kW)	4.42	-1.7	-39%

Table 2: Discrepancy Analysis Summary

Discrepancy Factor	kWh	kW
Operating Conditions	Discrepancy #1 (Tracking Calculation Error in Operating Conditions): -7,634 (-54%)	Discrepancy #1 (Tracking Calculation Error in Operating Conditions): -2.4 (-54%)
Equipment Specifications	Discrepancy #2 (Proposed Compressor Has Integrated Dryer): -8,409 (-59%)	Discrepancy #2 (Proposed Compressor Has Integrated Dryer): -2.6 (-59%)
Calculation Method	Discrepancy #3 (Different Air Profile & Calculation Method): -3,750 (-27%)	Discrepancy #3 (Different Air Profile & Calculation Method): -1.1 (-26%)
Inappropriate Baseline	N/A	N/A

TRACKING SAVINGS

This section summarizes the methodology and assumptions used to estimate the Tracking savings claimed for the project.

[10] The proposed air storage tank did not have tracking savings associated with it. Only the savings resulting from the compressor replacement were calculated and documented in the tracking data and project documentation

Project Description

The customer had a compressed air system whose demand was met by one (1) pre-existing air-cooled 25-hp reciprocating compressor and one (1) 15-hp reciprocating compressor. These compressors had load/unload controls and were apparently staged such that the 25-hp compressor handled the base load at 100% capacity while the 15-hp compressor handled the uncommon trim load operating around 50% capacity[11]. The pre-existing air storage was documented as 390 gallons – a 240 gallon tank associated with the 25-hp compressor and 150 gallon tank associated with the 15-hp compressor. The pre-implementation inspection demand schedule is listed in the *Pre-existing Condition* section, below. The proposed new VFD compressor handles the entire existing demand with the one of the retired compressors in place and energized only for emergencies. Table summarizes the proposed ECMs.

Table 3: Tracking ECMs

Description of ECM	Quantity
25-hp rotary screw compressor with VFD controls, integrated air dryer and air storage tank	1

Baseline

The pre-existing compressors appeared to have been operating at a common discharge pressure of 160 PSIG but system pressure ranged from 150-160 PSIG. The pre-installation inspection form lists a total of 390 gallons of air storage. The tracking savings calculation method assumes that the pre-existing 25-hp compressor operated fully loaded 60% of the time and unloaded during the remaining 40%[12]. The total annual operating period was estimated to be 3,198 hours, based on the customer's facility hours. The pre-existing compressors and system air demand and compressor load are described in the tables below:

Table 4: Pre-Existing Equipment[13]

Description	hp	Control	Rated PSIG	Operating PSIG	Capacity (ACFM)
Air-cooled reciprocating compressor	25	Load/unload	150-160	160	81
Air-cooled reciprocating compressor	15	Load/unload	150	160	DK

[11] This interpretation is based on the pre-installation site inspection form which has inadequate information to describe the existing system,

[12] The project documentation does not estimate any use from the 15-hp compressor. It is assumed by the evaluator that this compressor was retained in the pre-existing case as an emergency backup and was never operated as a primary compressor. It is also unknown whether the 150 gallon air storage tank associated with this compressor was attached to a common header rather than a stand-alone tank used exclusively by the 15-hp compressor

[13] The table values and demand schedule (next table) come directly from the pre-installation site inspection form

Table 5: Pre-existing Compressed Air Conditions

Demand Schedule	ACFM	Compressor Load (kW)	Hours per year
Fully Loaded	81	22.8	1,918.8
Unloaded	0	2.85	1,279.2
Average	48.6 (60% of 81)	14.8	3,198

The pre-installation site inspection form notes that "moisture or air quality" was an operational issue, the pre-existing compressors were "old", and that there was no pre-existing air dryer. It also noted that the current system pressure at the furthest point from the compressor was 150 PSIG.

Proposed Condition

The proposed scenario presented in the tracking savings method assumes that the proposed average air demand is approximately 39.0 CFM (lower than the pre-existing average air demand of 48.6 CFM) with an estimated 3,198 operating hours (same as pre-existing). The compressor load at 39.0 CFM was estimated to be 10.4 kW, based on a CAGI sheet for the VFD compressor model[14]. The tables below (values come directly from the tracking documents) summarize the proposed case equipment and operating scenario.

Table 6: Proposed Equipment

Manufacturer	hp	Control	Rated PSIG	Operating PSIG	Capacity (ACFM)
VFD screw compressor (with integrated air dryer and 120 gallon tank)	25	VFD	150	140	97.2

Table 7: Proposed Compressed Air Conditions

Demand Schedule	ACFM	Compressor Load (kW)	Hours per year
Average	39.0	10.4	3,198

Tracking Calculation Methodology

The tracking calculation methodology was limited to a hand-written savings estimate using one line calculations. The savings assumptions are derived exclusively from the air compressor replacement measure. The peak demand reduction is calculated by dividing the annual kWh savings by the annual operating hours.

[14] The evaluator believes that the CAGI sheet used by the Utility to estimate tracking savings is the non-integrated dryer model but this could not be confirmed

Assessment of Tracking Methodology and Analysis

There were a couple discrepancies in the tracking savings that are discussed next. The tracking savings assumes that the pre-existing air demand (48.6 CFM) is greater than the proposed air demand (39 CFM). This discrepancy over-estimates the potential average demand reduction due to the compressor replacement measure[15]. When estimating savings due to a compressor replacement the estimated pre-existing and proposed air demand schedules should be equivalent; otherwise, the savings estimate will count savings that are not associated with the compressor measure e.g., capacity or production changes that affect load profile.

The tracking savings also uses a CAGI performance sheet that appears to be the correct proposed base model but does not include the integrated refrigerant air dryer module. The integrated cycling refrigerant air dryer model was the compressor package observed to be installed; its CAGI sheet includes dryer load and flow losses due to the pressure drop across the dryer unit in its packaged input power rating. Since the pre-existing (in situ) scenario *did not* have an air dryer[16] and the proposed scenario selected a compressor with an *integrated* air dryer (i.e., under normal operating conditions the cycling dryer operates when the compressor operates, and the compressor experiences inherent efficiency losses due to pressure drop across the dryer components), the VFD compressor *with integrated air dryer* CAGI sheet should have been used to estimate the proposed *packaged* (compressor + dryer) average load. While this issue may not have been a discrepancy during the pre-implementation phase (because a non-integrated dryer model may have been proposed at first, but was later changed to an integrated dryer model), it could have been mentioned and addressed during the post-implementation phase.

The quality of the tracking savings methodology, documentation retention, and data collection efforts could be better. No pre- or post-implementation measurements were made to verify the savings assumptions used in the tracking methodology. If the "desk review" discrepancies (i.e., Discrepancy #1 and Discrepancy #2 – the discrepancies that could have been discovered through a desk review) were addressed by program implementers in the pre-implementation phase, this project could have been identified as a questionable endeavour with uncertain savings. Custom compressed air energy savings methodologies need to incorporate pre- and post-implementation M&V data collection including comprehensive documentation of the pre-existing and proposed compressed air equipment and operating conditions as well as time-series monitoring of the compressed air system flow, pressure, and/or power for a time period that will capture the facility's typical air demand profile.

EVALUATION METHODOLOGY

The following sub-sections describe project scope and estimated savings based on observed site conditions. The sub-sections go over the pre-existing (baseline) and proposed operating conditions & equipment

[15] This flow rate reduction could be representative of a leak repair measure, but as is, cannot be associated with the compressor replacement measure.

[16] The Evaluation assumed the baseline to be the in situ (pre-existing) equipment i.e., 25 hp compressor and no air dryer. The proposed case is the actual observed equipment i.e., VFD compressor with integrated air dryer. The integrated air dryer "efficiency losses" cannot be removed from the compressor performance because the compressor and dryer are connected such that it would be impractical to have the integrated model but remove the dryer module

informed by the site visit and correspondence with the site contact. The sub-sections also discuss the data collection, analysis, and calculation methodology performed to estimate the evaluated savings.

Measure Verification

The baseline condition was largely determined from the tracking documentation for this project. The facility site contact was only able to escort the evaluator to the compressor location during the site visit, and was not able to provide any useful details about the compressed air system or usage. The site contact could not comment on the pre-existing compressors to confirm some of the tracking assumptions used in the tracking calculation.

No explicit details were given for the pre-existing compressor performances. The pre-existing compressor performance was described as "25-hp, 81 cfm, 22.8 kW @ full load". The pre-installation form notes that there was a total of 390 gallons air storage in the pre-existing scenario; the evaluator observed a total storage of 120 gallons – the integrated tank on the installed compressor - during the site visit.

The project documentation claims that the proposed & installed compressor was a 25-hp air-cooled screw compressor with VFD controls. The compressor performance specifications used in the tracking savings suggest that the installed compressor was the non-integrated-dryer model. The site visit observed that the installed compressor is the model configuration with the integrated cycling refrigerant air dryer.

The VFD compressor was observed to be installed and operational. It was operating at a target pressure of 140 PSIG. The rated operating (discharge) pressure of this compressor is 150 PSIG with a maximum rated operating pressure of 160 PSIG. The pressure regulator showed (during a loading period) a system pressure of approximately 150 PSI and an inlet pressure of approximately 155 PSI.

When the site contact was queried on the pre-existing compressors, they claimed that both the 15-hp and 25-hp reciprocating compressors (along with their associated air storage tanks) were completely removed. The site visit confirmed the removal of the pre-existing compressors and air storage tanks.

The evaluator asked the site contact if there were "production" data available in the form of "number of widgets replaced" or "number of man hours". The site contact did not have that type of data available and suggested that the demand monitored by the power loggers over the planned 3 week period would be representative of "normal" operation throughout the year. Because this facility was a small auto service store, it was not expected for the site contact to have production data that could be analysed to produce a normalized energy savings estimate, but the evaluator confirmed with the site contact that there were no seasonal fluctuations in the store's production that were of notable concern.

Table 8 shows the ECMs and respective quantities installed.

Table 8: Proposed versus Implemented ECMs

Implemented ECMs	Proposed (tracking)	Implemented (evaluated)
25-hp air-cooled rotary screw compressor VFD (with integrated cycling refrigerant air dryer and 120 gallon air storage tank)	Installed	Installed
25-hp reciprocating compressor LNL with 240 gallons air storage	Retire & Retain for emergency use	Retired & Removed
15-hp reciprocating compressor LNL with 150 gallon air storage	Retire & Retain for emergency use	Retired & Removed

Data Collection

The installed VFD compressor was metered for the evaluation. The total package 3-phase true power of the compressor was metered using a DENT Elite Pro SP logger with split core CTs rated 50A. The metering period was approximately 4 weeks (November 18 to December 17, 2013) with a logging interval of 30 seconds. Spot power measurements were taken on each phase to verify that the Elite Pro loggers were recorded power values with reasonable accuracy.

Other data collected during the on site visit included nameplates for the compressor, line (discharge) pressures for the metered compressor, and photographs of the installed ECM. Seasonal operating schedules and observed holiday closures were obtained from the site contact, if any.

The site contact had very limited information regarding the compressed air project under evaluation and the pre-existing operating conditions of the compressors.

Table 9: Evaluation Measurement Summary

Time-Series Data Information	
Measured Parameter	Total packaged True Power (kW) on VFD compressor
Logger Make/Model	DENT Elite Pro SP on VFD compressor
Transducer/Equipment Type	(3x) 50A split-core CTs on VFD compressor
Installation Location	VFD compressor: Power compartment in packaged unit
Observation Frequency	30 second interval
Metering Period	4 weeks (November 18 to December 17, 2013)
Metered By	DNV GL and RISE electrician

Evaluation Savings Analysis

Approximately one month of time-series true power (kW) data was collected for the VFD compressor. These data were used to directly characterize the air demand and performance of the pre-existing and installed compressed air system.

To begin the savings analysis, the metered data had the time stamps formatted for ease of processing. Performance profiles were next generated for the installed and pre-existing compressors:

- *INSTALLED 25-hp air-cooled rotary screw compressor (with integrated air dryer) with VFD flow controls: kW vs. CFM* – This performance curve was generated exclusively from the manufacturer's CAGI sheet for the respective model. Since the compressor is variable-speed, the CAGI sheet lists multiple capacities and their respective packaged input power values at the rated outlet pressure (150 psi in this case). The ACFM vs. kW performance values include the integrated cycling air dryer load. The dryer load increases the specific packaged compressor power above typical variable speed rotary screw compressors of this size (18-22 kW/100 cfm). A manufacturer cut sheet was also obtained that had the compressor model's rated capacity at various rated operating pressures (e.g., 125 psi, 175 psi, etc.); this sheet was used to estimate the installed compressor's capacity (CFM) at the observed discharge pressure of 140 psi. The site contact was unable to confirm if the observed operating pressure (of 140 psi) remains steady throughout facility operation, but mentioned that they "set it and forget it". A quadratic power (kW) vs. capacity (CFM) trend was then formulated using these CAGI and cut sheet performance data.
- *PRE-EXISTING 25-hp air-cooled reciprocating compressor with load/unload controls: kW vs. CFM* – This performance curve was generated from a generic compressor AirMaster+ profile because no detailed (and verified) model specifications or cut sheets could be obtained for this specific model. A cut sheet was obtained that appears to match the pre-existing compressor (770 RPM; 90.1 CFM). Because of its relatively small size (25-hp) and load/unload flow control, a typical 25-hp air-cooled two-stage reciprocating compressor profile with load/unload controls that was similarly rated (110 ACFM at 150 PSIG) to the actual model was considered to be a reasonable proxy for estimating annual energy savings[17]. In order to develop a performance curve for the 25-hp compressor, the default AirMaster+ "Manufacturer Compressor Details" were modified with the specifications found from the manufacturer cut sheet. The rated capacity at full load operating pressure was adjusted from 110 ACFM to the pre-existing compressor capacity of 90.1 ACFM. The operating cut-in and cut-out/unload pressures were changed from 175 and 185 PSIG to 150 PSIG and 160 PSIG, respectively. The total package power input at rated conditions was also adjusted from the AirMaster+ default of 21.7 kW to 22.8 kW, based on the tracking savings estimate. The tracking estimate was used because the manufacturer cut sheet did not have power-related specifications and 22.8 kW was a reasonable value, especially for an aging compressor. The AirMaster+ performance profile graph (kW vs. CFM) was then tabulated in 10% flow increments and their corresponding kW values. From this kW vs. CFM table, a linear power vs. capacity trend was formulated.
- *PRE-EXISTING 15-hp air cooled reciprocating compressor with load/unload controls: kW vs. CFM* – The load profile for this pre-existing compressor was not estimated because it was assumed by the

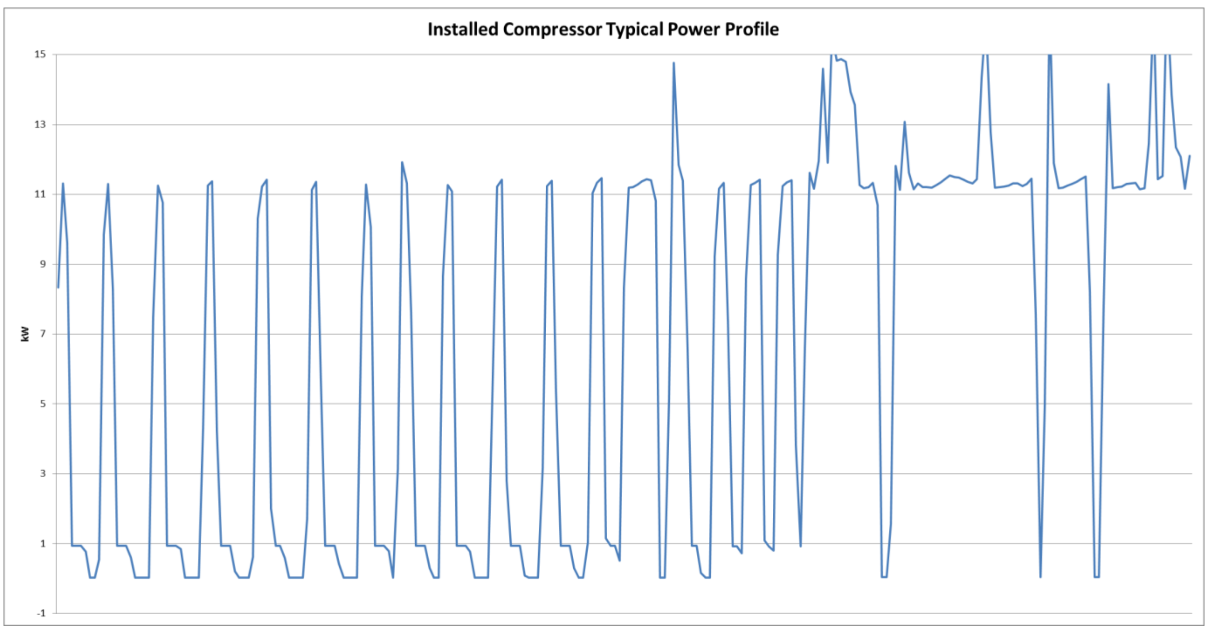
[17] The AirMaster+ compressor that was selected as the proxy for the pre-existing compressor has 26.3 Bhp, 150 PSIG full load operating pressure; 21.7 kW power at rated conditions

evaluator that the compressor saw negligible use compared to the 25-hp compressor. The pre-implementation inspection form doesn't clearly describe how this compressor was used; however, the site contact mentioned that it was "almost never" used. Additionally, the tracking savings calculation does not consider this compressor, suggesting that this compressor was only used as an emergency backup.

Installed Scenario

The performance profile (for the installed compressor) described above was then used to estimate the flow (CFM) corresponding to each time stamp in the metered (kW) data. The installed compressor was assumed to be unloaded (producing 0 CFM) when its recorded power fell below 5 kW. This threshold is different from the unloaded power claimed on the compressor's CAGI sheet (12.3 kW) and was chosen based on the observed power profile of the installed compressor. The installed compressor power generally oscillated between 11 kW and 1 kW with a loaded period of roughly 2- 10 minutes[18]. Unloaded or off periods were shorter, lasting from 30 seconds to 2 minutes. The figure below shows a brief period (125 minutes) of typical compressor usage. The figure's vertical axis (kW) was held to a maximum of 15 kW so that the typical range of 11 kW could be seen with greater clarity.

Figure 1: Installed Compressor Power Profile Sample (~2 hours)



Pre-existing Scenario

To estimate the corresponding performance of the pre-existing compressor, the calculated flow in the installed case and the linear CFM vs. kW trend developed for the 25-hp reciprocating compressor was used. First, the pre-existing compressor air flow (ACFM) for each corresponding time stamp were determined

[18] The instances of lower power around 1 kW is suspected to be the integrated air dryer still operating and shutting down during the sample interval. That operation is observed in the power data as a plateau at 1 kW that drops to zero, then typically spikes back up when the compressor loads up again.

based on the calculated installed air flow and the rated capacity of the pre-existing compressor (90.1 ACFM). Since the rated capacity of the installed compressor is greater than the rated capacity of the pre-existing compressor there was a possibility that the installed compressor could have produced more air during a given time interval than the pre-existing compressor. This did not occur, however, with the maximum calculated flow of 86.9 ACFM. The pre-existing compressor kW vs. CFM trend was then used to calculate the power corresponding to the time-stamp interval flow rates.

The difference between the adjusted pre-existing compressor kW and the installed case compressor kW for each time stamp interval is the calculated average compressor demand reduction for that time interval. An hourly demand reduction profile for each weekday type (Monday through Sunday and holidays) was then developed by averaging the demand reduction corresponding to their respective hour and weekday bins (for a total of 192 hourly bins). Only one demand profile needed to be developed because the facility does not experience any notable seasonal fluctuations in its production output or compressed air demand. Therefore, the Evaluation team considered it reasonable to assume the one month of meter data as representative of the load profile that the facility experiences throughout a typical year. The hourly demand reduction profile was then applied to the New York TM Reference Year (1995) 8,760 profile to calculate the annual electricity savings (kWh)[19]. The peak demand reduction was calculated by averaging the demand reduction for the 4-5 P.M. hour on all non-holiday weekdays.

EVALUATION RESULTS

The total evaluated electric savings was determined to be -5,658 kWh and 0 kW peak demand reduction. The tracking savings are 14,135 kWh and 4.4 kW peak summer demand reduction. The gross realization rates (GRR) comparing the evaluated savings to the tracking savings are -40% for kWh and 0% for kW.

Primary Reasons for Savings Discrepancy

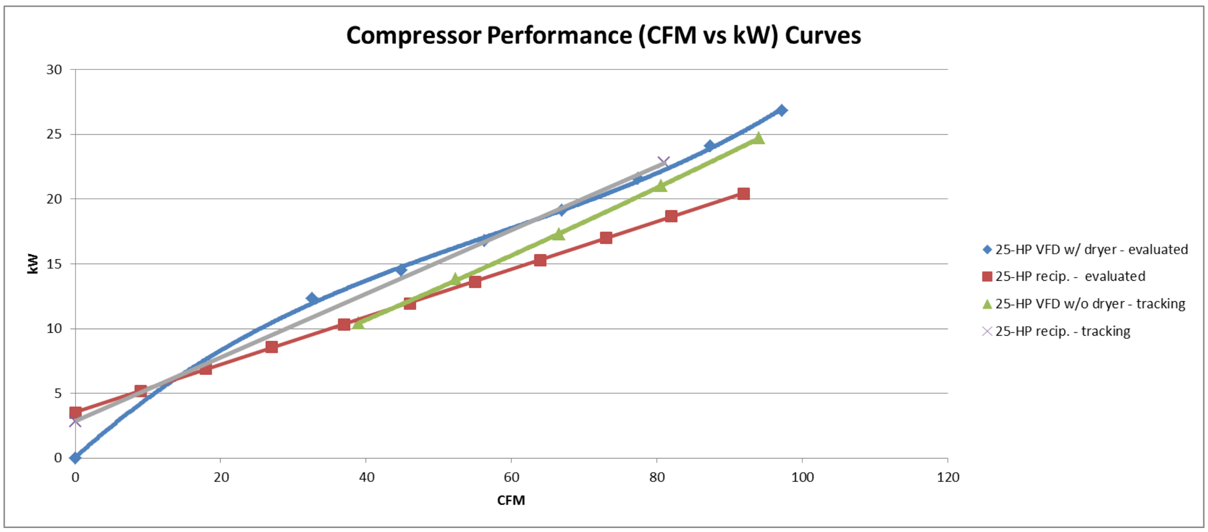
1. *Discrepancy #1 – Tracking Savings Assumed Average Capacity:* The tracking savings method assumes a pre-existing average air demand of 48.6 CFM and a lower average air demand of 39.0 CFM in the proposed scenario. The average air demand of the pre-existing and proposed scenarios should be equivalent when estimated energy savings due to a compressor replacement measure. In the tracking savings, the difference in average compressor load was 4.4 kW (pre-existing compressor = 14.8 kW; proposed compressor = 10.4 kW). Adjusting the proposed average air demand to 48.6 CFM and re-calculating the installed compressor load at that capacity resulted in an average compressor load of 12.8 kW (the difference between the average pre-existing and installed compressor load is now only 2.0 kW) and led to a discrepancy of –7,634 kWh and -2.4 kW or -54% kWh and -54% kW.

2. *Discrepancy #2 – Proposed Compressor has integrated dryer:* The tracking savings calculation uses a CAGI sheet performance curve for the “base” VFD model that does not include an integrated air dryer. However, the actual installed compressor has an integrated refrigerant (cycling) air dryer; the compressor also has inherent efficiency losses due to the pressure drop across the refrigerant-air heat exchanger. The compressor that was observed to be installed was the integrated air dryer model; therefore the appropriate performance curve to use includes the dryer load. The

[19] In order to produce a standardized 8,760 demand reduction profile, 1995 was chosen as the reference year for defining specific holiday and weekday dates.

"compressor-to-compressor" comparison that the tracking savings method uses is inappropriate because the installed dryer is intrinsically tied to the installed compressor load under normal operating conditions. Since the pre-existing scenario (i.e., baseline) did not have an air dryer, the installed air dryer has to be considered as part of the installed load conditions. Adjusting the proposed performance profile to incorporate the dryer load while keeping all other assumptions equivalent to the Discrepancy #1 scenario led to a discrepancy of -8,409 kWh and -2.6 kW or -59% kWh and -59% kW. A comparison of the tracking and evaluated compressor performance curves are presented in Figure 2 below.

Figure 2: Comparison of Tracking and Evaluated Performance Curves



Discrepancy #1 and Discrepancy #2, both issues that could have been addressed in the pre-implementation phase, cause the estimated savings to be negative.

3. *Discrepancy #3 – Air Demand Profile and Calculation Method:* The evaluated calculation method uses a more robust calculation method than the tracking estimate. The evaluated method uses a 24-hour load profile for each weekday (and holiday, resulting in 192 hourly load bins), developed from approximately one month of power data from the installed compressor. The tracking method uses single average compressor loads for the pre-existing and proposed cases and multiplies those loads by the corresponding operating hours to calculate the pre-existing and proposed energy usages. Additionally, the difference between the tracking and evaluated calculation method for determining peak demand reduction contributed to the demand reduction discrepancy. These changes led to a discrepancy of -3,750 kWh and -1.1 kW or -27% kWh and -26% kW. The air demand assumed in the tracking savings estimate (48.6 CFM over the entire 3,198 hour annual operating period) appears to have been significantly overestimated. The air demand that was calculated from the time-interval power data suggests a much lower average flow rate of around 19.8 ACFM; this average covers only periods when the compressor is producing air, so the average flow rate inclusive of unloaded periods would be even smaller.

SITE ID: DNVCA06

Project Type	Early Replacement and Add-on
Measure Category	Custom Compressed Air

PROJECT DESCRIPTION

This project involved the retirement of one 75-hp air-cooled rotary screw compressor with variable displacement (VD) flow controls and the installation of a new 100-hp air-cooled rotary screw compressor with variable speed (VFD) flow controls. The facility produces industrial packaging solutions and has a variety of compressed air end uses including conveyors, lifts, presses, molding processes, and hand tools. Table 1 provides the evaluation results while Table 2 provides a summary of the discrepancy analysis.

Table 1: Summary of Evaluation Results

Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
Annual Energy Savings (kWh)	122,950	57,907	47%
Peak Summer Demand Reduction (kW)	15.3	17.8	116%

Table 2: Discrepancy Analysis Summary

Discrepancy Factor	kWh	kW
Operating Conditions	N/A	N/A
Equipment Specifications	N/A	N/A
Calculation Method	Discrepancy #1 (Different Calculation Method): -65,043 (-53%)	Discrepancy #1 (Different Calculation Method): 2.5 (16%)
Inappropriate Baseline	N/A	N/A

TRACKING SAVINGS

This section summarizes the methodology and assumptions used to estimate the Tracking savings claimed for the project.

Project Description

Note: The tracking project documentation has discrepancies. One pre-installation form stated there were two 75-hp compressors; another pre-installation form states there were two 100-hp compressors and one 75-hp compressor; and the vendor flow analysis document does not describe the compressors with rated input power but with model numbers; the vendor analysis reports three 75-hp compressors. The project *description below takes the position of the vendor savings report describing three 75-hp compressors. This was chosen because the tracking savings uses the vendor report estimate.*

The customer had a compressed air system whose demand was met primarily by two (2) air-cooled 75-hp rotary screw compressors with variable displacement flow controls. An additional 75-hp rotary screw compressor with inlet modulation (IM) flow controls was in place as backup during maintenance of the primary compressors. The project proposed to replace one of the 75-hp compressors with variable displacement controls with a 100-hp rotary screw compressor with VFD flow controls. The proposed compressor sequence intends to use the new VFD compressor as the base compressor. As demand increases, the pre-existing 75-hp compressor with inlet modulation would replace the new VFD compressor as the base compressor and the VFD compressor would handle the trim air demand. The project scope also installed a new 660-gallon vertical air receiver tank and a new flow controller and sequencer downstream of the 660-gallon receiver tank to stabilize system air pressure and control the compressor sequencing. The tank and flow controller equipment were not part of the program scope and thus were not evaluated; however, they were planned to be verified by the evaluator to be installed and functioning as proposed.

The proposed Energy Conservation Measures (ECMs) are shown in Table 3.

Table 3: Tracking ECMs

Description of ECM	Quantity
100-hp air-cooled rotary screw compressor with VFD flow controls	1
660 gallon vertical air receiver tank	1
Pressure/flow & compressor sequence controller	1

Baseline

Based on the tracking documents which had limited savings calculations and context, the customer had a fairly wide range of capacity demand. With an installed capacity of 1,002 cfm, the pre-installation flow analysis report shows an average utilized capacity of 192 cfm with the highest recorded capacity at 461 cfm. The average discharge pressure was measured to be 96 psig. The demand schedules were not documented in a typical day type schedule but the flow analysis report documented an existing system over view that reported each compressor's average percentage of flow and energy. Even though the pre-existing system had three compressors, only two compressors were actually utilized during the pre-installation flow metering period. These two compressors were the equipment that was assessed in the tracking savings calculation. Table 4 describes the pre-existing operating conditions of the compressors while Table 5 summarizes the facility's average air demand and energy profile.

Table 4: Pre-Existing Equipment[20]

Description	hp	Control	Rated PSIG	Operating PSIG	Capacity (acfm)	Manufacturing Year (if known)[21]
(Base) Air-cooled rotary screw compressor	75	Variable Displacement	N/A	96	330	1989
(Trim) Air-cooled rotary screw compressor	75	Variable Displacement	N/A	96	330	1989
(Backup/emergency) Air-cooled rotary screw compressor	75	Inlet Modulation	125	96	320	1989

Table 5: Pre-existing Compressed Air System Overview[22]

Available cfm	Average cfm	Average Capacity %	Average Energy %	Hours per year
1,002	192	19%	30%	5,737

The pre-existing system also had a 400 gallon vertical air receiver tank downstream of a 1,200 cfm refrigerant air dryer. The "compressor age" was documented as being 18 years old; this value did not describe which compressor(s) the age was referring to.

Proposed Condition

The proposed operating conditions require the same demand schedule as the pre-existing scenario, using the new VFD compressor. The tracking documents did not describe the proposed compressor sequence plan other than what was briefly described in the Minimum Requirements Document (MRD): "New compressor becomes the base compressor; as demand increases, the existing 75-hp [compressor] will come on line. The 75-hp compressor then will become the base compressor and the new [100 hp VFD] compressor will become the trim compressor". One of the pre-existing 75-hp compressors was also proposed to be retained as a backup compressor to be used during maintenance and emergency demand situations. The specific capacity ranges and estimated hours of operation for each sequence were not clearly estimated in the tracking documents. Table 6 summarizes the proposed compressed air system based on the tracking documentation.

[20] These table values are directly from the vendor flow analysis summary report

[21] The year 1989 was given by the site contact during the site visit. The pre-installation site inspection form claims that the compressors were 18 years old (making the manufacturing year approximately 1993

[22] The cfm value does not add up to the total capacity using the individual compressor rated capacities (330 + 330 + 320 = 980); but this table is simply reporting what the tracking documentation contains. The operating hours appear to have been estimated based on customer input

Table 6: Proposed Equipment

Description	hp	Control	Rated PSIG	Operating PSIG	Capacity (acfm)
Air-cooled rotary screw compressor	100	VFD	100	96	479
Air-cooled rotary screw compressor	75	Inlet modulation	125	96	320

Tracking Calculation Methodology

The tracking calculation methodology was limited to a vendor report & savings tool print out that documented the existing system, proposed system and respective annual energy costs for the assumed annual air demand profile. The annual energy costs are then converted in to annual energy consumptions by applying a $0.12 / kWh rate. The vendor savings report does not disclose the estimated pre-existing and proposed air demand schedules (e.g., cfm bins, day type air demand profiles); instead, it provides a pre-existing system overview that reports the average capacity demand and subsequent energy usage based on what appears to be 7 days of time-series pressure and flow data. This time-series data was only available in graphical chart form and as such it could not be determined if or how it was used in the derivation of the reported average pressure, flow, power, and cost savings. The pre-existing system and demand overview is then compared to the proposed system; however, the report does not explain how the proposed system is sequenced or how the energy savings are estimated.

Assessment of Tracking Methodology and Analysis

The overall quality of the tracking savings documentation could have been improved. While it appears that adequate pressure and flow data were collected during the pre-installation period, the vendor savings report does not explicitly describe how the reported cost & energy savings were calculated. It also does not appear that any power data was collected during the pre-implementation M&V phase[23]. Without these details, the evaluator cannot completely assess the reasonableness of the tracking methodology and savings estimate. It is recommended that any raw data collected during the pre-implementation M&V phase, whether by the program or by the vendor/auditor, be retained in the tracking project documentation along with the savings report so that evaluators may utilize that data to assess the calculation method and assumptions that fed in to the claimed tracking savings.

That being declared, it appears that the annual energy consumption for the pre-existing and proposed scenarios are calculated by multiplying single average compressor load (kW) values by the estimated annual operating hours. It also appears that the average pre-existing and proposed compressor loads are based on collected flow & pressure data and assumed compressor performance curves. The operating hours may have been extrapolated from the pre-implementation M&V data collection, or simply assumed from the estimated work schedule. While this overall method can be adequate for very steady air demand profiles, it does not accurately estimate for frequent variations in the air demand profile. Additionally, depending on how the performance curves (kW vs. cfm) or specifications were utilized to estimate the pre-existing and proposed compressor loads (kW) corresponding to the measured pressure and air demand profiles, the analysis could

[23] Evaluator could not determine whether power data was collected. It looks like the pressure and flow data was used along with assumed compressor performance curves to estimate the average pre-existing and proposed compressor loads

have benefitted from collecting power measurements. Time series power data or at least spot power measurements could be used so that the pressure, flow, and power data can be utilized to derive a unique compressor system performance curve for the pre-existing system. In compressed air projects where the pre-existing compressors are replaced, it is important to have any information collected about the pre-existing system to be properly documented and retained under the project's tracking record because that information can rarely be re-produced during evaluation.

The tracking documentation should be "self-sufficient" – it should provide all sources, assumptions, calculations, and results that are ultimately used to inform the tracking savings estimate. In the case of this vendor savings report, all proprietary assumptions and calculations should be clearly explained (and provided in a supplementary workbook or savings tool, if possible) in the report. Furthermore, any pressure, flow, or power data that is presented in graphical chart form in the vendor savings report should also be available in a supplemental data file. Information regarding what instrumentation was used and where measurements were taken should also be included in the tracking documentation.

Whenever possible, program implementers should base peak demand reduction on actual regional "peak" definitions. When metering cannot coincide with peak periods, generalizations can be made to assume the coincidental weekdays and hours during the metering as the peak period.

EVALUATION METHODOLOGY

The following sub-sections describe project scope and estimated savings based on observed site conditions. The sub-sections go over the pre-existing (baseline) and proposed operating conditions & equipment informed by the site visit and correspondence with the site contact. The sub-sections also discuss the data collection, analysis, and calculation methodology performed to estimate the evaluated savings.

Measure Verification

During the site visit, the evaluation engineer physically verified the installation of the 100-hp VFD compressor, confirmed the presence of the newly installed 660 gallon air tank and visually verified the installation of the flow pressure controller. The evaluation site visit also collected information regarding the pre-existing compressors and their operating conditions from the facility electrician. Two of the pre-existing compressors (one 75-hp IM and the 75-hp VD) were still commissioned and functional; however, only one of them (the 75-hp IM compressor) was actively being used. The 75-hp VD compressor was retained only for very rare peak usage and during compressor maintenance periods. The proposed 100-hp compressor with VFD controls was installed and sequenced as intended. The VFD compressor target discharge pressure was set at 100 psig while the target pressure for the pre-existing 75-hp compressor was set at 95 psig. The additional 660 gallon air receiver tank and flow & compressor sequence controller were also installed.

The pre-existing compressor models and sequencing conditions were also verified by the site contact. According to the site contact, the third compressor (the 75-hp rotary screw compressor with IM controls) that acted as an emergency or backup (had to be manually engaged) compressor now operates as a primary compressor. Now, during periods of low air demand, the installed VFD compressor satisfies the entire demand. When air demand reaches a particular threshold where the VFD compressor cannot satisfy the entire demand, the pre-existing 75-hp compressor with IM flow controls becomes the base compressor and the VFD compressor switches roles and handles the remaining trim load. One pre-existing 75-hp rotary screw compressor with variable displacement controls was retained to operate as the emergency & backup compressor. The site contact stated that this compressor rarely operated as an emergency source (i.e., to handle maximum peak air demand) and would likely not operate during the metering period. Table 7 shows the ECMs and equipment changes performed in the project scope.

Table 7: Proposed versus Implemented ECMs

Implemented ECMs	Proposed (tracking)	Implemented (evaluated)
75-hp air-cooled rotary screw compressor VFD	Installed	Installed
660 gallon vertical air receiver tank	Installed	Installed
75-hp rotary screw compressor VD	Retired & Removed	Retired & Removed
Flow & compressor sequence controller	Installed	Installed

Data Collection

The installed 100-hp VFD compressor and pre-existing 75-hp compressor with IM flow controls were metered for the evaluation. The VFD compressor had its total package 3-phase true power metered using a DENT Elite Pro SP logger with split core CTs rated at 150A. The 75-hp compressor with IM flow controls had one of its three phase's current metered using a HOBO Microstation with a split core CT rated at 150A. The metering period was approximately 4 weeks (November 20 to December 18, 2013) with a logging interval of 30 seconds (one minute for the Microstation). Spot power measurements were taken on each phase to verify that the loggers were recording power & current values with reasonable accuracy.

Other data collected during the on site visit included nameplates for the compressor, line (discharge) pressures for the metered compressors, and photographs of the installed ECMs. Seasonal operating schedules and observed holiday closures were obtained from the site contact, if any. Table 8 provides the evaluation measurement summary.

Table 8: Evaluation Measurement Summary

Time-Series Data Information	
Measured Parameter	Total packaged True Power (kW) on installed VFD compressor Phase current (A, RMS) on pre-existing 75-hp IM compressor
Logger Make/Model	DENT Elite Pro SP on VFD compressor HOBO Microstation on IM compressor
Transducer/Equipment Type	(3x) 150A split-core CTs on VFD compressor (1x) 150A split-core CT on IM compressor
Installation Location	VFD compressor: Power compartment in packaged unit IM compressor: Power compartment in packaged unit
Observation Frequency	DENT Elite Pro SP: 30 second interval HOBO Microstation: 1 minute interval
Metering Period	4 weeks (November 20 to December 18, 2013)
Metered By	DNV GL and RISE electrician

Evaluation Savings Analysis

Approximately one month of time-series true power (kW) and current (Amps) data were collected for the installed 100-hpVFD compressor and pre-existing 75-hp IM compressor, respectively. These data were used to directly characterize the air demand and performance of the pre-existing and installed compressed air system.

To begin the savings analysis, the metered data had the time stamps formatted for ease of processing. Performance profiles were next generated for the installed and pre-existing compressors:

- *INSTALLED (power metered) 100-hp air-cooled rotary screw compressor with VFD flow controls: kW vs. cfm* – This performance curve was generated exclusively from the manufacturer's CAGI sheet for the respective model. Since the compressor is variable-speed, the CAGI sheet lists multiple capacities and their respective packaged input power values at the rated outlet pressure (100 psig in this case). The capacity at the rated discharge pressure did not need to be adjusted because the actual operating target pressure was equal to the rated operating pressure of the VFD compressor. The site contact was able to confirm that the observed operating pressure (of 100 psig) remains steady throughout facility operation. A quadratic power (kW) vs. capacity (cfm) trend was then formulated using these CAGI sheet performance data.
- PRE-EXISTING (current metered) 75-hp air-cooled rotary screw compressor with inlet modulation and blow down flow controls: kW vs. cfm – This performance curve was generated from a generic compressor AirMaster+ profile because no detailed model specifications or cut sheets could be obtained for this specific model besides nameplate ratings. A typical 75-hp air-cooled rotary screw compressor profile with modulation flow controls that was similarly rated (330 acfm at 125 psig) to the actual model (320 cfm at 125 psig) was considered to be a reasonable proxy for estimating the compressor air flow corresponding to the metered current. In order to develop a performance curve

for the 75-hp compressor, the default AirMaster+ “Manufacturer Compressor Details” were modified with the specifications found from the package’s nameplate, specifically the rated capacity, total package Amps and maximum packaged power based on the total package Amps. The operating cut-in and cut-out/unload pressures were changed from the AirMaster+ profile defaults to 95 psig and 114 psig, respectively. These values were based on the observed operating conditions of the pre-existing 75-hp compressor. The AirMaster+ performance profile graph (kW vs. cfm) was then tabulated in 10% flow increments and their corresponding kW values. From this kW vs. cfm table, a fourth-order polynomial power vs. capacity trend was formulated.

- *PRE-EXISTING (not metered) 75-hp air cooled rotary screw compressor with variable displacement controls: kW vs. cfm* – The performance curve for this compressor needed to be generated for estimating its usage in the pre-existing scenario. This compressor was assumed to be a backup/emergency compressor in the installed scenario and was not metered. The site contact mentioned that he is almost certain that this compressor has not operated for some time (for emergency peak demands) including the metering period. The performance curve was generated from a generic compressor AirMaster+ profile because no detailed model specifications or cut sheets could be obtained for this specific model besides nameplate ratings. A typical 75-hp air-cooled rotary screw compressor profile with variable displacement flow controls that was similarly rated (360 acfm at 100 psig) to the actual model (350 cfm at 100 psig) was considered to be a reasonable proxy for estimating the compressor power corresponding to the assigned air flow (cfm). In order to develop a performance curve for the 75-hp compressor, the default AirMaster+ “Manufacturer Compressor Details” were modified with the specifications found from the package’s nameplate, specifically the rated capacity. The operating cut-in and cut-out/unload pressures were changed from the AirMaster+ profile defaults to 96 psig and 110 psig, respectively. These values were based on the pre-existing operating conditions reported in the tracking documentation. The AirMaster+ performance profile graph (kW vs. cfm) was then tabulated in 10% flow increments and their corresponding kW values. From this kW vs. cfm table, a fourth-order polynomial power vs. capacity trend was formulated.

Installed Scenario

The performance profile for the installed compressor described above was then used to estimate the flow (cfm) corresponding to each time stamp in the metered (kW) data. The installed compressor was assumed to be unloaded (producing 0 cfm) when its recorded power fell below 24.3 kW. This threshold was based on the unloaded power claimed on the compressor’s CAGI sheet and by the load profile observed in the power data of the installed compressor.

In order to use the generated kW vs. cfm performance profile for the 75-hp IM compressor, the current data for the 75-hp IM compressor was first converted to total packaged power (kW) using spot power measurements (voltage, current, true power, and power factor), taken on all three phases during the site visit, as the input values for voltage and power factor. The kW vs. cfm performance profile for the 75-hp IM compressor was then used to estimate the flow (cfm) corresponding to each time stamp in the metered current (Amps) data. The compressor was observed to have a ten minute automatic shutdown timer (i.e., after being unloaded for ten minutes, the compressor shuts down), and an unloading period of less than one minute. The evaluator also observed that the compressor basically operates in two states –fully loaded and unloaded. When fully loaded, the compressor consumed around 60 kW and when unloaded the compressor consumed around 31.4 kW.

Pre-existing Scenario

To estimate the corresponding performance of the pre-existing compressed air system, the total calculated flow in the installed case was used along with the pre-existing compressor sequencing conditions and the cfm vs. kW trends developed for the pre-existing compressors to assign the observed air demand to the pre-existing compressors. First, the loading/sequencing order of the pre-existing compressors was utilized to load the compressors as they would have been in the pre-existing scenario. The two 75-hp variable displacement compressors acted as the primary base and trim compressors while the third 75-hp inlet modulation compressor handled the peak air demand periods i.e., loaded last. The base and trim compressors are loaded to their fully rated capacities (351 cfm, each); any remaining air demand not met by the first two compressors (any time stamp interval where air demand is greater than 702 cfm) was assigned to the third compressor. While this assignment is automatic in the evaluation analysis, the actual pre-existing conditions required that a facility employee manually turn the third compressor on. This automatic loading sequence somewhat exaggerates the pre-existing scenario energy consumption relative to the tracking savings estimate; however, the installed scenario's air demand profile is also generally larger than what was measured during the pre-implementation phase. The pre-existing compressor kW vs. cfm trends were then used to calculate the power corresponding to each of the compressors' assigned time-stamp interval flow rates. A compressor shutoff timer (10 minutes) identical to what was observed in the installed scenario was utilized for the 75-hp inlet modulation compressor (the peak trim compressor).

The difference between the adjusted pre-existing compressor system kW and the installed case compressor system kW for each time stamp interval is the calculated average compressor demand reduction for that time interval. An hourly demand reduction profile for each weekday type (Monday through Sunday and holidays for a total of 192 bins) was then developed by averaging the demand reduction corresponding to their respective hour and weekday bins. Only one demand profile needed to be developed because, per the site contact, the facility does not experience any notable seasonal fluctuations in its production output or compressed air demand. This assertion is supported with the highly consistent air demand observed during the one month metering period. Therefore, the evaluation team considered it reasonable to assume the one month of meter data as representative of the load profile that the facility experiences throughout a typical year. The hourly demand reduction profile was then applied to the New York TM Reference Year (1995) 8,760 profile to calculate the annual electricity savings (kWh).[24] The peak demand reduction was calculated by averaging the demand reduction for the 4-5 P.M. hour on all non-holiday weekdays based on the NY ISO peak period definition.

EVALUATION RESULTS

The total evaluated electric savings was determined to be 57,907 kWh and 17.8 kW peak demand reduction. The tracking savings are 122,950 kWh and 15.3 kW peak summer demand reduction. The gross realization rates (GRR) comparing the evaluated savings to the tracking savings are 47% for kWh and 116% for kW.

[24] The 1995 reference year was used to standardize the 8,760 demand reduction profile's weekday and holiday dates

Primary Reasons for Savings Discrepancy

Discrepancy #1 – Calculation Method and Air Demand Profile: The tracking savings method could not be completely assessed by the evaluator due to lack of tracking documentation describing the calculation method and the assumptions used to generate the tracking savings estimates. It appears, however, that the tracking calculation method uses single average compressor loads (kW) for the pre-existing and proposed compressed air system scenarios and multiplies those loads by the assumed annual operating hours to estimate annual energy consumption for each scenario. The discrepancy analysis does not attempt to "re-create" the tracking analysis in order to determine incremental discrepancies (e.g., difference between tracking and evaluated compressor performance profiles or air demand profiles, difference in equipment specifications, etc.) because assumptions would have to be made by the evaluator that may not have been the same as the vendor savings method. Instead, the table below lists all the known differences between the tracking savings estimates and the evaluated savings estimates. All of these differences including the difference in calculation methods led to a total discrepancy of -65,043 kWh and 2.5 kW or -53% kWh and 16% kW.

Table 9: Notable Discrepancies between Tracking & Evaluated Parameters[25]

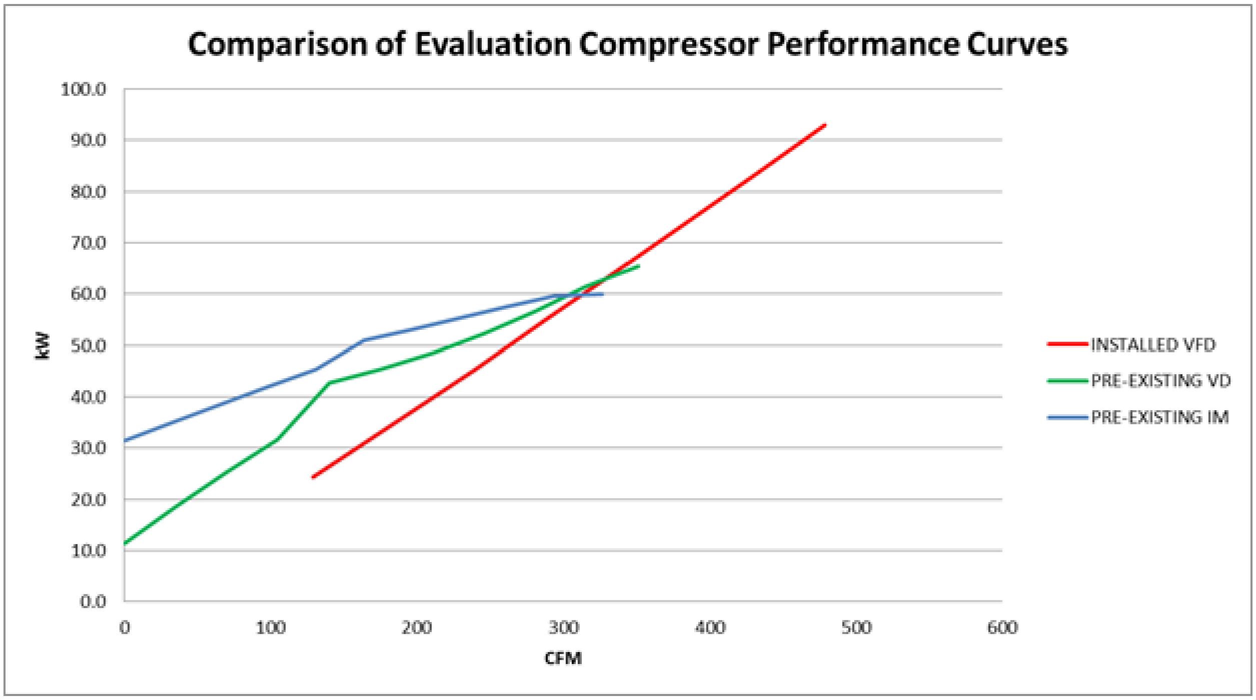
Input Parameter Description	Proposed (tracking)	Implemented (evaluated)
Average Air Capacity	192 cfm	309 cfm
Average Pre-existing Compressed Air System Demand	56.5 kW	75.1 kW
Average Installed Compressed Air System Demand	35.1 kW	61.5 kW
Average Compressed Air System Demand Reduction	21.4 kW	13.6 kW

Without tracking documentation that explains how these capacity and compressor load values were estimated the evaluator cannot assign specific reasons for discrepancy or how those discrepancies could be accounted for in future projects.

Based on the performance curves of the pre-existing and installed compressor models used by the evaluator (see Figure 1 below), it can be argued (if the shape and magnitude of tracking performance curves are similar to those the evaluator used) that the reason for discrepancy may have had to do with the difference between the average capacity estimated in the tracking and evaluated energy savings. The comparison of performance curves show that the potential for larger demand reduction between the installed VFD compressor and the pre-existing VD and IM compressors is largest at low part-loads. As capacity increases, the potential demand reduction decreases. Since the evaluated average capacity was higher than the tracking average capacity, the potential demand reduction and subsequent energy savings are lower than the tracking demand reduction and energy savings.

[25] Note that the average pre-existing and installed compressed air system demand (kW) values listed in the tracking column are based on reverse-calculations performed by the evaluator. The tracking estimate did not explicitly include these values.

Figure 1: Comparison of Compressor Performance Curves



Peak Summer Demand Discrepancy

The tracking peak summer demand reduction was determined using an unknown method. It does not appear that the tracking method has any real association with the facility's compressor demand that is coincident with a defined peak hour or period. The evaluated peak demand reduction estimate was calculated by using the peak period used by the NY ISO which is the 4-5 P.M. hour on non-holiday weekdays.

SITE ID: DNVCA08

Project Type	Retrofit
Measure Category	Custom Compressed Air

PROJECT DESCRIPTION

The customer replaced two pre-existing load/unload, oil-injected rotary screw compressors (one 75 HP and one 60 HP) with one 100 HP VSD single stage air compressor. Table 1 summarizes the savings estimates prior to the retrofit and the revised or evaluated savings values following project implementation. Furthermore, Table 2 summarizes the reasons for discrepancy between the tracking and evaluated savings.

Table 1: Summary of Evaluation Results

Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
Annual Energy Savings (kWh)	153,158	113,045	74%
Peak Demand Reduction (kW)	17.7	27.2	154%

Table 2: Discrepancy Analysis Summary

Discrepancy Factor	kWh	kW
Operating Conditions	Discrepancy #1 (Compressor Performance Curves): -31,385 kWh; -20% Discrepancy #2 (Observed Average Load): 42,587 kWh; 28% Discrepancy #3 (Observed Operating Hours): -51,332 kWh; -34%	Discrepancy #2 (Observed Average Load): 1.2 kW; 7%
Equipment Specifications		
Calculation Method		Discrepancy #4 (Calculation method): 8.3 kW, 47%
Inappropriate Baseline		

TRACKING SAVINGS

This section summarizes the methodology and assumptions used to estimate the Tracking savings claimed for the project.

Project Description

The customer is a fiberglass manufacturer and a supplier to composite manufacturers. The customer's compressed air system, which provides compressed air to actuate pneumatic valves and power pneumatic tools, was surveyed and evaluated to determine opportunities to reduce energy consumption and process expenditures. The implemented ECM involved installation of a single stage, air-cooled, rotary screw 100 hp air compressor with VSD control in place of the two pre-existing 75 hp and 60 hp compressors. The initial energy audit found that a single VSD compressor would allow the system to operate at higher efficiency under part loads. The tracking ECM's are listed in Table 3.

Table 3: Tracking ECMs

Description of ECM	Proposed Quantity
7507V/A 100-HP rotary screw compressor	1

Baseline

Prior to the retrofit, the customer operated two compressors to meet the facility's compressed air load and kept an additional compressor onsite for use as a backup in case of emergency. The specifications of the three compressors are outlined in Table 4. Prior to the retrofit, both primary compressors were used to meet system load. Compressor 1 acted as the primary compressor and met all compressed air loads up to its full capacity. When load exceeded 258 ACFM, compressor 2 came on and was used as a trim compressor to meet rest of the plant air load. Furthermore, the facility had 500 gallons of air storage onsite during the pre-existing period.

Table 4: Pre-Existing Equipment

Description	Stages	HP	Control	Rated PSIG	Operating PSIG	Capacity (ACFM)	Date of Installation
Oil Injected Rotary Screw	1	75	L/NL	100	100	258	1994
Oil Injected Rotary Screw	1	60	L/NL	100	100	300	1995

Proposed Condition

Table 5 summarizes the compressed air system equipment following the compressor retrofit. The two pre-existing primary air compressors were decommissioned and replaced with one VSD compressor. Two additional 500 gallon tanks were also installed onsite during the compressor retrofit. However, the installation of the two tanks was not included in the scope of the compressor retrofit incentive application (ID# DNVCA08).

Table 5: Proposed Equipment

Description	Stages	HP	Control	Rated PSIG	Operating PSIG	Capacity (ACFM)
Oil Injected Rotary Screw	1	100	VSD	100	100	493

Tracking Calculation Methodology

In order to calculate the initial project savings, the vendor fitted the pre-existing compressed air system with pressure and power data loggers for a period of 1 week. The tracking analysis utilized AirMaster+ to generate performance curves exhibiting the relationship between compressed air demand (ACFM) and power consumption (kW) using equipment nameplate information. The performance curves were used in conjunction with the compressor sequence of operations to determine a system kW demand vs. flow relationship which included the kW demand of both pre-existing compressors. Using the vendor power trend data and the AirMaster+ curves, the vendor generated hourly flow profiles for each recorded kW. The calculated compressed air flow was split into 5 separate bins based on compressed air demand. The % time at each load bin was multiplied by 6,578 operating hours to estimate the annual hours at each load bin. The kW demand and annual operating hours at each load bin were multiplied in order to calculate the annual kWh at each load bin.

The installed compressor annual energy consumption was calculated in a similar manner. The % load of the compressor was determined using the load profile used in the baseline calculations. The kW demand for each bin was subsequently determined using AirMaster+ performance curves generated to replicate the compressor performance curves taken from CAGI data sheets. The kW demand and annual operating hours for each bin were multiplied in order to calculate the installed case annual kWh. The kW vs. ACFM data for the pre-existing and proposed compressors as calculated by AirMaster+ is shown below in Table 6.

Table 6: Compressor Performance Data

ACFM	Baseline kW	Installed kW
0	18.54	0.00
35	30.88	10.98
70	43.21	19.33
105	54.97	27.28
140	57.57	33.55
175	60.16	39.81
210	35.76	46.07
245	65.36	52.33
280	89.38	58.59
315	98.87	64.85
350	108.36	71.12
385	116.06	77.38
420	118.07	83.64
455	120.07	89.90
490	122.07	96.16
525	124.06	-

The tracking calculations are shown in their entirety in Table 7. The tracking analysis shows the 5 load bins used to estimate project savings and the number of hours at each bin estimated by the vendor. The difference between the annual Existing and Proposed kWh served as the basis of project savings.

Table 7: Tracking Analysis Methodology

Compressor Average Load Profile					
Load Profile Type	1	2	3	4	5
Annual Hours	2080	2080	1040	1092	286
Average Demand ACFM	160	210	260	285	370
Existing					
Compressor Capacity	% Load				
258 ACFM	0.62	0.82	1	1	1
300 ACFM	0	0	0.01	0.09	0.38
	ACFM				
Compressor 1	160	211.6	258	258	258
Compressor 2	0	0	3	27	114
Total	**160**	**211.6**	**261**	**285**	**372**
System kW	59.1	62.9	76.3	90.7	113.2
System kWh	122,928	130,832	79,352	99,044	32,375
				Total	**464,532**
Proposed					
Compressor Capacity	% Load				
493 ACFM	0.33	0.43	0.53	0.58	0.75
	ACFM				
Compressor 1	162.69	211.99	261.29	285.94	369.75
Compressor 1 kW	35.9	45.2	54.5	59.1	74.9
System kWh	74,714	94,013	56,656	64,554	21,418
				Total	**311,355**

Equations:

1. Individual Load kWh = (kW at Specific Load) x (Number of Hours at Load)
2. Total System kWh = Load 1 kWh + Load 2 kWh +…+ Load 5 kWh
3. kWh Savings = Total System kWh $_{Base}$ – Total System kWh $_{Proposed}$

Assessment of Tracking Methodology and Analysis

1. Trend data which served as the basis of the savings calculations were not provided with the tracking documentation. Additionally, only 1 week of trend data was used to annualize project savings. This trending duration will likely not be sufficient to capture seasonality in load.

2. It is not explained how the tracking calculations used the one week short-term metered data to determine 6,578 annual operating hours.
3. The project documentation does not detail how the peak demand reduction was calculated. The tracking kW reduction is closest to the average kW reduction corresponding to a load of 210 ACFM.

EVALUATION METHODOLOGY

The following sub-sections describe project scope and estimated savings based on observed site conditions. The sub-sections go over the pre-existing (baseline) and proposed operating conditions & equipment informed by the site visit and correspondence with the site contact. The sub-sections also discuss the data collection, analysis, and calculation methodology performed to estimate the evaluated savings.

Measure Verification

The conditions found on site were similar to those outlined in the tracking analysis. The customer’s compressed air system actuates valves and powers pneumatic tools in the machine shop. Furthermore, the evaluator was able to visually verify nameplate information of the pre-existing and installed compressors, as all three compressors were onsite at the time of the evaluation.

Since no time series trend data was available onsite, the evaluator was forced to utilize spot verification to substantiate the system operating pressure claimed in the tracking calculations. During the onsite evaluation, the evaluator observed minor fluctuations in system operating pressure between 98-101 PSIG. This coincides with the tracking calculations assumed operating pressure of 100 PSIG.

Additionally, no control data was available to verify the pre-existing compressor sequence of operations. However, through an interview conducted during the evaluation, the site contact was able to verify that the sequencing used in the tracking analysis was accurate. Table shows the ECMs and respective quantities installed.

Table 8: Proposed versus Implemented ECMs

Implemented ECMs	Proposed (tracking)	Implemented (evaluated)
100 HP VSD rotary screw compressor	Installed	Installed
75 HP LNL rotary screw compressor	Retired & Removed	Retired but retained for backup
60 HP LNL rotary screw compressor	Retired & Removed	Retired but retained for backup
1,000 gallon storage tank	Installed	Installed

Data Collection

An Elite Pro SP kW logger was installed on the VSD compressor for a period of 4 weeks. Table 9 outlines the specifications of the kW data logger installed during the evaluation.

Table 9: Evaluation Measurement Summary

Time-Series Data Information	
Measured Parameter	Total packaged True Power (kW)
Logger Make/Model	DENT Elite Pro SP
Transducer/Equipment Type	(3x) 150A split-core CTs
Installation Location	Power compartment in packaged unit
Observation Frequency	1 minute interval
Metering Period	4 weeks (November 7 to December 4, 2013)
Metered By	DNV GL and RISE electrician

The customer was also asked to provide production data in order to aid the evaluator in annualizing the power trend data collected during the evaluation. The customer informed the evaluator that the facility produced 1.3 million lbs. of fiberglass during the trending period (11/7/13 – 12/4/13) and 12.6 million lbs. of fiberglass in 2012.

Lastly, the evaluator was able to determine normal operating hours through an onsite interview with the customer. The customer noted normal operating hours of 6A – 11P Monday through Friday with occasional production on Saturday depending on load. Additionally, the customer indicated that the facility observed 10 Federal Holiday shutdowns throughout the year.

Evaluation Savings Analysis

The evaluation engineer utilized the power trend data collected during the onsite evaluation along with CAGI performance curves for the installed compressor to develop an 8,760 compressed air load profile. Using the load profile, the evaluator calculated the pre and post retrofit kW demand using AirMaster+ curves for the pre-existing compressors and CAGI performance curves for the installed compressor. The evaluator subsequently calculated the facility's annual operating hours using the production data collected during the onsite evaluation. Further explanation regarding the evaluation methodology is given below.

NOTE: It appears as though the storage tank installation was incentivized under a separate project as the vendor explicitly calculated savings for the storage tank and the tanks were verified to have been installed onsite, but the tracking savings for this project only reflect the savings from the compressor replacement. As a result, the post-retrofit storage capacity of 1,500 gallons was utilized to generate the pre and post-retrofit performance curves in order to eliminate the effects of the tank installation from this evaluation.

Note: The proceeding section contains italicized brackets with the spreadsheet ("Tab") location of the referenced analysis step. The name of the savings analysis workbook is "1428553 Savings Analysis.xlsx".

Installed Scenario

In order to calculate project savings, the evaluator developed an hourly operating profile for the customer's compressed air system. To accomplish this, the evaluator utilized the installed compressor power consumption data collected between 11/7/13 – 12/4/13 and compressor performance curves which outline the relationship between compressed air demand and power consumption and are generated using CAGI performance data *["3- Performance Curves"]*. Using this relationship, the evaluator was able to generate a lookup table which listed the average compressed air demand from the trending period based on hour and day type. This lookup table was used to generate an 8,760 load profile by matching each hour and day type throughout the year to the corresponding average compressed air demand in the lookup table.

Once the compressed air load profile was generated, the corresponding kW demand for each load was calculated based on a performance curve taken from the CAGI data sheet. The 8,760 data points (kW) were summed in order to calculate the annual compressor power consumption for the post-installation period. *["6- 8760 Analysis"]*

Pre-existing Scenario

The pre-existing compressed air system power consumption was determined based on the 8,760 compressed air load profile and performance curves generated in AirMaster+. The AirMaster+ performance curves were generated using the compressor nameplate information and system operating parameters utilized in the tracking analysis and verified on site. AirMaster+ then generates a % Power vs. % Flow curve for the specified compressor. Dummy flows were input into the 'Profile' tab in AirMaster+ which automatically generates a Capacity (ACFM) vs. Power (kW) relationship *["3- Performance Curves"].* Using this relationship, the evaluator was able to calculate the 8,760 kW demand as a function of the 8,760 compressed air demand from the post-installation period. The 8,760 kW were then summed in order to calculate the annual compressor power consumption for the baseline period.

Merely taking the difference between the baseline and post-installation annual power consumption as calculated above would assume 8,760 annual operating hours. Customer-provided production data was used to verify the annual production hour estimate used in the tracking analysis. The tracking analysis assumed 6,578 annual operating hours for savings estimation. Trending period production data was provided alongside 2012 production data. The total production during the trending period was divided by the total operating hours from that same period to determine a pound per hour (PPH) production estimate. The 2012 annual production was divided by the PPH estimate to determine hours per year of operation. This methodology calculated 4,007 annual hours of operation, which shows a large discrepancy between assumed and evaluated operating hours. In order to achieve the correct number of annual operating hours in the 8760 analysis, it was assumed that no production occurred on 10 Federal holidays. Lastly, 8 weeks, 25 days, and 1,653 hours were assumed to have no production in order to achieve the correct number of annual operating hours. A correction factor was used to simulate the reduction in operation hours and is outlined below.

Corrected Savings = Total Savings Pre Correction – Weekly Reduction – Daily Reduction – Hourly Reduction

1. Weekly Reduction = Average Weekly Reduction x Number of weeks
2. Daily Reduction = Average Saturday Reduction x Number of Saturdays
3. Hourly Reduction = Average Hourly Reduction during non-working hours x Number of hours

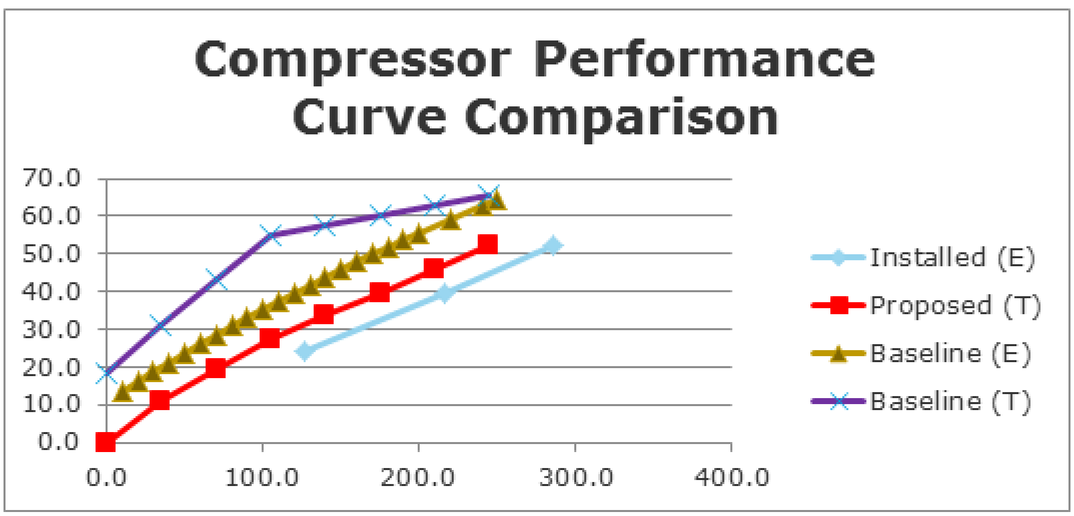
Lastly, the peak demand reduction was calculated in compliance with the NYISO, which states that system peaks generally occur during the hour ending at 5pm on the hottest non-holiday weekday. The New York Technical Manual (TM) states that this peak occurs on Friday, July 21, 1995 between 4 P.M. – 5 P.M. As such, the demand reduction during this time would serve as the project peak demand reduction.

EVALUATION RESULTS

The total evaluated electric savings was determined to be 113,045 kWh and 27.2 kW peak demand reduction. The tracking savings are 153,158 kWh and 17.7 kW peak demand reduction. The gross realization rates (GRR) comparing the evaluated savings to the tracking savings are 0.74 for kWh and 1.54 for kW.

Primary Reasons for Savings Discrepancy

1. *Discrepancy #1 (Compressor Performance Curves)* – Discrepancies between the baseline and installed compressors were observed in the course of the savings evaluation. The figure below shows the differences between the baseline and installed compressors used in the tracking analyses and the evaluation. The AirMaster+ curves for the pre-existing period were generated using operating parameters observed on site. The discrepancy between the tracking and evaluated baseline performance curves shows that the annual baseline energy consumption was underestimated, which in turn overestimated savings. Similarly, the installed compressor performance curve was updated to reflect observed operation. The evaluator's performance curve was taken directly from the CAGI data sheet, while it is unknown how the tracking performance curve was generated. The updated installed compressor performance curve resulted in a reduction in post-installation period power consumption. The baseline curve discrepancy would cause a decrease in savings while the installed compressor performance curve discrepancy would cause an increase in project savings. Since the magnitude of discrepancy of the baseline curve was larger, the net result is a 20% decrease in kWh savings. The total kWh discrepancy as a result of the updated performance curves was calculated to be -31,385 kWh which was -20% impacts on the total project tracking kWh savings.



2. *Discrepancy #2 (Observed Average ACFM Demand)* – The average compressed air load was calculated at 221.5 ACFM in the tracking calculations but was found to be 167.1 through the evaluation. Only one load/unload compressor would be used to meet this load during the baseline period. Since the variable speed compressor is more efficient at part loads, this discrepancy resulted in an increase in project savings. The total discrepancy as a result of the discrepancy in observed average load was calculated to be 42,587 kWh and 1.2 kW, impacts of 28% and 7% respectively.

3. *Discrepancy #3 (Observed Operating Hours)* – The tracking analysis does not specify how the annual operating hours were calculated. The tracking analysis utilized 6,578 annual hours in the calculations but the evaluation yielded 4,007 annual hours. This result was verified by the normal operating hours provided by the customer. The reduction in operating hours resulted in large reduction in project kWh savings. The total discrepancy as a result of the discrepancy in observed operating hours was calculated to be -51,332 kWh, an impact of -34%.
4. *Discrepancy #4 (Calculation Method)* – The tracking analysis does not specify how the peak demand was calculated. The evaluator determined that the tracking analysis likely took the demand reduction at 210 ACFM to represent the peak demand reduction, as both values yield 17.7 kW However, it is not clear from the tracking analysis why that value was chosen to represent the peak demand reduction, as is neither the largest demand nor is it the most frequent demand. In keeping all things constant, the evaluator calculated a peak demand reduction of 26.0 kW in abiding by NYISO protocols for peak demand reduction calculations. The overall discrepancy as a result of the difference in calculation methodology is 8.3 kW, an impact of 47%.

SITE ID: DNVCA09

Project Type	Early Replacement
Measure Category	Custom Compressed Air

PROJECT DESCRIPTION

This project involved the replacement of one (1) pre-existing 200-hp oil injected rotary screw compressor with inlet modulation and blow down flow controls with a new 75-hp rotary screw compressor with variable speed (VFD) flow controls. Compressed air end-uses vary widely in demand, ranging from small air-powered hand tools (e.g., sanders, impact wrenches) to hydraulic lifts and sand blasting containment vessels. Table 1 provides the evaluation results while Table 2 provides a summary of the discrepancy analysis results.

Table 1: Summary of Tracking Savings

Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
Tracking Annual Energy Savings (kWh)	181,038	135,583	75%
Tracking Peak Summer Demand Reduction (kW)	64.2	14.1	22%

Table 2: Discrepancy Analysis Summary

Discrepancy Factor	kWh	kW
Operating Conditions	Discrepancy #1 (Compressor Performance at Observed Operating Conditions): -70,313 (-39%)	Discrepancy #1 (Compressor Performance at Observed Operating Conditions): -25.0 (-39%)
Equipment Specifications	N/A	N/A
Calculation Method	Discrepancy #2 (Different Calculation Method and Air Profile): 24,858 (14%)	Discrepancy #2 (Different Calculation Method and Air Profile): -25.2 (-39%)
Inappropriate Baseline	N/A	N/A

TRACKING SAVINGS

This section summarizes the methodology and assumptions used to estimate the Tracking savings claimed for the project.

Project Description

The customer had a compressed air system whose demand was met by one (1) air-cooled, oil-injected, 200-hp rotary screw compressor and one (1) air-cooled 25-hp rotary screw compressor. Based on the Utility documents, the 25-hp compressor was rarely used and was not involved in the savings calculations. The project documents describe the existing demand being served only by the 200-hp compressor; this compressor had inlet modulation with blow down controls and was operated (on average) below 40% capacity. During pre-M&V monitoring, it was determined that there were four distinct compressed air demand day type schedules or shifts. The demand schedules are listed in the Pre-existing Condition section, below. The new 75-hp VFD compressor handles the entire pre-existing demand without being fully loaded during peak demand. The "Minimum Requirements Document (MRD) also mentions that a flow controller was proposed to be installed downstream of the existing 1,040 gallon air receiver tank to stabilize system pressure. The incremental savings potential from the flow controller, however, was not assessed or claimed in the tracking savings. Table 3 lists the tracking measures (ECMs) described in the project documentation.

Table 3: EEM List

Description of ECM	Quantity
75-hp air-cooled, oil-injected, rotary screw compressor with variable speed (VFD) flow controls	1 (savings claimed)
Flow controller installed downstream of the 1,040 gallon air storage tank	1 (savings not claimed)

The pre-installation documents also mention a non-operating 30-hp compressor as pre-existing equipment. Although the 25-hp and 30-hp compressors were described as being part of the pre-existing system, these compressors were either non-functional or operated rarely enough to have their energy consumptions omitted from the tracking savings calculations (i.e., tracking savings and incentives are based off the replacement of the 200-hp compressor with the proposed 75-hp VFD compressor).

Baseline

According to the pre-installation site inspection form the pre-existing compressed air system appears to have produced air at a nominal pressure of 90 PSIG and an air demand that could be described using four day type schedules or shifts. The pre-existing compressors and demand schedule are listed in the following tables. The pre-existing compressors and demand schedule are listed in Table 4 and Table 5.

Table 4: Pre-existing Equipment[26]

Equipment	HP	Control	Rated PSIG	Operating PSIG	Capacity (ACFM)	Manufactured Year
Air-cooled, oil-injected rotary screw compressor	200	Inlet modulation with blowdown	100	90	900	1995

[26] The equipment details and demand schedule are based on the pre-installation site inspection form included in the project documents

Table 5: Pre-Existing Compressed Air Demand Schedule

Demand Schedule	ACFM	200-hp Compressor Capacity %	Hours per year
1	200	22%	780
2	300	33%	780
3	350	39%	780
4	250	28%	208

The pre-installation inspection form mentions three air receiver tanks – two (2) 120-gallon tanks and one 1,040 gallon tank. It appears the 120 gallon tanks are associated with the 25-hp and 30-hp compressors (i.e., tank mounted compressors) while the 1,040 gallon is the primary storage for the 200-hp compressor. There is no description of other equipment on the compressed air supply side. The annual operating hours were estimated at 2,548 hours; however, it appears that an erroneous estimation of 2,818 hours was used to calculate the peak demand reduction. It appears that these compressor operating hours were based on customer estimates.

Proposed Condition

The proposed operating conditions require the same demand schedule as the pre-existing, using the new 75-hp VFD compressor. Table 6 and Table 7 below summarize the proposed compressor equipment and capacity schedule corresponding to the proposed compressor.

Table 6: Proposed Equipment[27]

Equipment	HP	Control	Rated PSIG	Operating PSIG	Capacity (ACFM)
Air-cooled, oil-injected rotary screw compressor	75	Variable Speed (VFD)	100	90	377

Table 7: Proposed Compressed Air Demand Schedule

Demand Schedule	ACFM	75-hp Capacity %	Hours per year
1	200	53%	780
2	300	80%	780
3	350	93%	780
4	250	66%	208

Tracking Calculation Methodology

The tracking calculation methodology involved a vendor cost savings print out that was converted to energy savings using a $0.13/kWh utility rate. The vendor savings estimate uses four air demand schedules as discussed earlier in this report; the pre-existing and proposed compressor performance profiles appear to be

27 The proposed equipment specifications and schedule are referenced from the tracking savings calculation

based on a supplemental table showing each compressor's load (kW) corresponding to the delivered air flow rate (CFM). Peak demand reduction was estimated by averaging the compressor replacement energy savings over 2,818 annual operating hours (i.e., average demand reduction). The project documentation did not include any M&V data e.g., flow, pressure, or power measurements.

Assessment of Tracking Methodology and Analysis

The details for the pre-existing compressor performance was slightly convoluted and required extra analysis to assess how the reported performance was used in the tracking savings calculation. The tracking savings calculation uses a vendor savings print out that performs a cost savings analysis. The cost savings is then converted in to energy savings using a $0.13/kWh utility rate. The vendor print out is supplemented with two performance (CFM vs kW) curves, one for the pre-existing compressor and one for the proposed compressor. Extra calculations needed to be performed in order to compare the cost savings analysis to the evaluator's reverse-engineered energy analysis using the performance curves; the comparison resulted in essentially equivalent savings (the tracking cost savings analysis estimated 181,038 kWh, the energy analysis using the curves produced 176,311 kWh in savings), with the difference arising possibly from rounding/bucketing errors. Discrepancy analysis and performance curve comparisons that used the curves discussed above are presented later in the report

The tracking savings method appears to use a bin analysis with four demand bins to estimate the annual compressor load profile. In order to use the bin analysis method appropriately it needs to be supplemented with sufficient evidence (e.g., M&V data like power/flow/pressure measurements, sequence logic, compressor specifications) to support the assumed air demand profiles and corresponding compressor loads. Without these supporting data, the evaluator cannot assess the assumptions used to create the air demand profiles and subsequent compressor loads and annual energy consumptions for the pre-existing and proposed scenarios. The evaluator recommends that custom compressed air projects include all sources (complete and unlocked) for savings calculations in the tracking documentation. This would include "working" savings calculations (i.e., the savings calculations are in a format such that the individual savings input variables and equations can be identified and changed) so the evaluator can assess the reasonableness of the individual savings assumptions.

The peak demand reduction calculation erroneously assigns 2,818 annual operating hours; the vendor savings estimate uses 2,548 annual operating hours to calculate cost/energy savings. That error lowered the tracking value for summer peak demand reduction (64.2 kW) below what the demand savings method's estimate would have reported (71.1 kW). The tracking peak demand reduction calculation (average annual energy savings over annual operating hours) should use time-of-use (TOU) M&V data or assumptions to estimate peak demand reduction as defined by the region's utility or ISO. Depending on the specific load profile that the facility experiences, especially nearing the closing time – 5 P.M. - of this facility, air demand (i.e., peak demand reduction) can vary through its potential range. M&V data, as mentioned above, would have helped in determining the peak demand reduction based on the definition stated by the New York ISO.

EVALUATION METHODOLOGY

The following sub-sections describe project scope and estimated savings based on observed site conditions. The sub-sections go over the pre-existing (baseline) and proposed operating conditions & equipment

informed by the site visit and correspondence with the site contact. The sub-sections also discuss the data collection, analysis, and calculation methodology performed to estimate the evaluated savings.

Measure Verification

The baseline condition was largely determined from the tracking documentation. The facility site contact was only able to escort the evaluator to the compressor location during the site visit, and was not able to provide many details about the pre-existing compressed air system.

All of the pre-existing compressors were retained by the customer. Both the 25-hp and 30-hp compressors were completely shut down and appeared to be isolated (valves connecting compressors' air tanks to transmission piping were closed) from the operating compressed air system. This led the evaluator to presume that the remaining air storage is the transmission piping and the 1,040 gallon vertical tank. The 200-hp compressor appeared to be in "standby" mode (compressor was off but user interface panel was illuminated and "Ready"). The customer commented that the 25-hp compressor is used during times that the new 75-hp compressor is down for maintenance but based on site observations it appears the 200-hp compressor is used as the backup. Regardless, based on the customer comments and the maintenance log for the new 75-hp compressor, the annual downtime that the new 75-hp compressor may experience is negligible compared to its operating hours. Therefore, maintenance downtime was not assessed in the evaluated savings analysis.

The proposed flow controller was observed to be installed but a spot reading was not taken because the controller was approximately 20 feet above the ground, installed near the top of the vertical air receiver tank. The installed 75-hp compressor was observed to be functional and operating at a target discharge pressure of 115 PSIG and unload pressure of 125 PSIG. It had a recorded run time of 6,290 hours and a logged start date on December 8, 2011, averaging 3,224 hours per year.

The evaluator observed through inspection and customer input that the facility uses compressed air for many different end-uses, including hydraulic lifts, air-powered hand tools (e.g., sanders, impact wrenches, etc.), and sand blasting vessels. The evaluator asked the site contact if there was production data available but the site contact was reluctant in providing anything concrete (e.g., man-hours, product orders, etc.) and noted that they were expecting "normal" production during the estimated metering period (late November to mid-December). The compressor & compressor inlet are housed inside a fairly drafty high-bay warehouse adjacent to a central, open boiler room; these conditions suggest that the inlet air temperature may not be weather-dominated but rather tempered by its indoor location.

Finally, the age of the pre-existing compressors was determined through the site contact; the 200-hp compressor was manufactured in 1995 and the 25-hp (and 30-hp) compressor was estimated to have been manufactured "25-30 years ago".

Table 8 shows the observed results of the project implementation.

Table 8: Proposed versus Implemented ECMs

Implemented ECMs	Proposed (tracking)	Implemented (evaluated)
75-hp air-cooled, oil-injected rotary screw compressor with VFD	Installed	Installed
Flow controller installed downstream of the 1,040 gallon air storage tank	Installed	Installed
25-hp rotary screw compressor with 120 gallons air storage	Retired & Removed	Retained but effectively retired
200-hp rotary screw compressor inlet modulation with blowdown controls	Retained for backup	Retained for backup

Data Collection

The installed 75-hp compressor was metered for the evaluation. The total package 3-phase true power of the compressor was metered using a DENT Elite Pro SP logger with split core CTs rated 150A. The metering period was approximately 4 weeks (November 19 to December 17, 2013) with a logging interval of 30 seconds. Spot power measurements were taken on each phase to verify that the Elite Pro loggers were recorded power values with reasonable accuracy.

Other data collected during the on site visit included nameplates for the compressor, line (discharge) pressures for the metered compressor, nameplate specifications of the pre-existing EAUSPE compressor, and photographs of the installed ECMs. Observed holiday closures and typical work hours were also obtained from the site contact. Table 9 summarizes the Evaluation team's measurement and verification details.

Table 9: Logger Information

Time-Series Data Information	
Measured Parameter	Total packaged True Power (kW) on 75-hp
Logger Make/Model	DENT Elite Pro SP on 75-hp
Transducer/Equipment Type	(3x) 150A split-core CTs on 75-hp
Installation Location	75-hp: Power compartment in packaged unit; load side just after unit disconnect (includes drive losses)
Observation Frequency	30 second interval
Metering Period	4 weeks (November 19 to December 17, 2013)
Metered By	DNV GL and RISE electrician

Evaluation Savings Analysis

Approximately one month of time-series true power (kW) data was collected for the installed 75-hp compressor. These data were used to directly characterize the air demand and performance of the pre-existing and installed compressed air system.

To begin the savings analysis, the metered data had the time stamps formatted for ease of processing. Performance profiles were next generated for the installed and pre-existing compressors; the sources and assumptions used to generate the compressor performance profiles are bulleted below:

- INSTALLED 75-hp air-cooled, oil-injected, rotary screw compressor with VFD flow control: kW vs. CFM – This performance curve was generated exclusively from the manufacturer's CAGI sheet for the respective model. Since the compressor is variable-speed, the CAGI sheet lists multiple capacities and their respective packaged input power values at the rated outlet pressure (100 PSIG in this case). A manufacturer cut sheet was also obtained that had the compressor model's rated capacity at various rated operating pressures (e.g., 125 PSIG, 175 PSIG, etc.); this sheet was used to estimate the installed compressor's capacity (CFM) at the observed discharge pressure of 115 PSIG. A quadratic power (kW) vs. capacity (CFM) trend was then formulated using these CAGI and cut sheet performance data.
- PRE-EXISTING 200-hp air-cooled rotary screw compressor with inlet modulation and blowdown flow controls: kW vs. CFM – This performance curve was generated from a generic compressor AirMaster+ profile modified with basic manufacturer model specifications taken from the compressor nameplate and a contemporary model cut sheet (the pre-existing model was manufactured in 1995). In order to develop the performance curve for the compressor, the default AirMaster+ "Manufacturer Compressor Details" were modified with the specifications found from the compressor nameplate and manufacturer cut sheet. The operating cut-in and cut-out/unload pressures were changed from 100 and 110 PSIG to 90 PSIG and 100 PSIG, respectively (based on pre-existing conditions). The AirMaster+ performance profile graph (kW vs. CFM) was then tabulated in 10% flow increments and their corresponding kW values. From this kW vs. CFM table, a linear power vs. capacity trend was formulated.

Installed Scenario

The performance profile for the installed compressor described above was then used to estimate the flow (CFM) corresponding to each time stamp in the metered (kW) data. Based on the collected power data, the evaluator determined that the installed compressor has an unloaded power demand of approximately 7.7 kW (the minimum rated input power listed on the CAGI sheet is 19.5 kW). If the measured power was less than this chosen demand threshold, then the compressor was assumed to be unloading and producing no useful air (0 CFM).

Pre-existing Scenario

To estimate the corresponding performance of the pre-existing 200-hp compressor, the calculated flow in the installed case and the linear CFM vs. kW trend developed for the 200-hp compressor were used. First, the pre-existing compressor air flow (CFM) for each corresponding time stamp was determined based on the calculated installed air flow. Since the pre-existing compressor has a higher capacity than the installed compressor there was no possibility of unmet air demand in the pre-existing scenario. If the installed compressor was unloaded during a time stamp the pre-existing compressor was also assumed to be unloaded. The pre-existing compressor kW vs. CFM trend was then used to calculate the power corresponding to the time-stamp interval flow rates.

The difference between the pre-existing compressor load and the installed case compressor load for each time stamp interval is the calculated average compressor demand reduction for that time interval. An hourly demand reduction profile for each weekday type (Monday through Sunday and holidays) was then developed by averaging the demand reduction corresponding to their respective hour and weekday bins. Only one demand profile needed to be developed because the facility does not reportedly experience any notable seasonal fluctuations in its production output or compressed air demand. The collected power data appears to support this claim with its reasonably consistent demand profile. Therefore, the Evaluation team considered it reasonable to assume the one month of meter data as representative of the load profile that the facility experiences throughout a typical year. The hourly demand reduction profile was then applied to the New York TM Reference Year (1995) 8,760 profile to calculate the annual electricity savings (kWh). The peak demand reduction was calculated by averaging the hourly demand reduction for the 4-5 P.M. hour on all non-holiday weekdays as defined by the NY ISO.

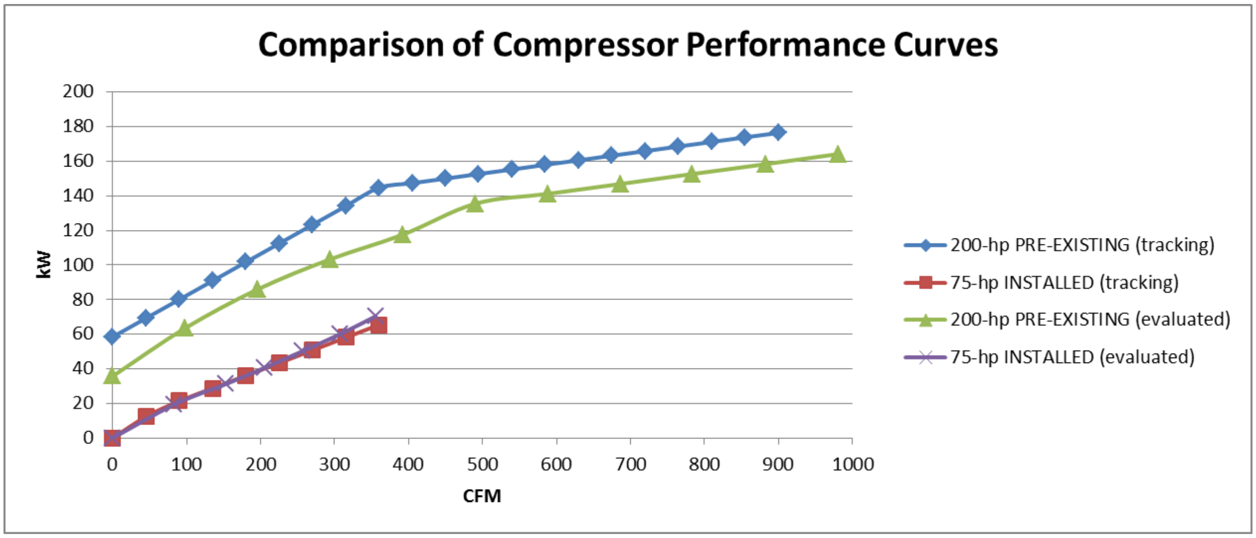
EVALUATION RESULTS

The total evaluated electric savings was determined to be 135,583 kWh and 14.1 kW peak demand reduction. The tracking savings are 181,038 kWh and 64.2 kW peak summer demand reduction. The gross realization rates (GRR) comparing the evaluated savings to the tracking savings are 75% for kWh and 22% for kW.

Primary Reasons for Savings Discrepancy

4. *Discrepancy #1 – Compressor Performance:* Differences between the evaluated and tracking compressor performance curves caused a discrepancy of –70,313 kWh and -25.0 kW or -39% kWh and -39% kW. A comparison of the compressor performance curves can be seen in Figure 1, below. The tracking savings calculation uses a pre-existing average compressor load of 122.0 kW and a proposed average compressor load of 50.9 kW (an average load difference of 71.1 kW). Using the evaluated compressor performance curves while leaving other tracking savings assumptions unchanged estimates a pre-existing compressor load of 99.0 kW and a proposed average compressor load of 55.6 kW (an average load difference of 43.4 kW).

Figure 1: Tracking versus Evaluated Performance Curves



5. *Discrepancy #2 – Air Demand Profile & Calculation Method:* The evaluated air demand profile and calculation method are different from the tracking savings method and estimate. The evaluation metering determined that the average air demand is much lower than what was estimated in the tracking savings. The evaluated average air demand was 94.8 CFM, significantly lower than the tracking savings estimate of 280.6 CFM. However, the estimated annual operating hours were higher in the evaluated savings (3,783) than in the tracking savings (demand savings estimates 2,818 hours, kWh savings estimates 2,548). Finally, the evaluated peak demand reduction method uses one month of power measurements to estimate the coincidental demand reduction during the defined peak period (4-5 P.M. for non-holiday weekdays). The tracking savings does not attempt to estimate coincidental TOU demand reduction; instead, it averages the annual energy savings over the annual operating hours to calculate peak demand reduction. Using the evaluated savings method, assumptions, and demand profile led to a discrepancy (from Discrepancy #1) of 24,858 kWh and -25.2 kW or 14% kWh and -39% kW

SITE ID: DNVCA10

Project Type	Retrofit
Measure Category	Custom Compressed Air

PROJECT DESCRIPTION

This project includes installation of three new compressor units and two pressure regulators to serve plant demand effectively. This project even includes retiring two existing compressors. Table 1 summarizes the initial savings estimates prior to the retrofit and the revised or evaluated savings values following project implementation. Table 2 outlines the reasons for discrepancy between the initial and evaluated project savings.

Table 1: Summary of Tracking Savings

Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
Tracking Annual Energy Savings (kWh)	238,896	188,410	79%
Tracking Peak Summer Demand Reduction (kW)	29.3	21.6	74%

Table 2: Discrepancy Analysis Summary

Discrepancy Factor	kWh	kW
Operating Conditions	Discrepancy #1 (Load Discrepancy): 50,486.10 kWh, -21%	Discrepancy #1 (Load Discrepancy): 7.67 kW, -26%
Equipment Specifications		
Calculation Method		
Inappropriate Baseline		

TRACKING SAVINGS

The following sub-sections describe the project scope and estimated savings based on tracking data. The sub-sections go over the pre-existing (baseline) and proposed operating conditions & equipment, the tracking data collection and analysis, and the tracking calculation methodology.

Project Description

This project is implemented in an industrial manufacturing facility which approximately requires 667 to 698 cfm of compressed air throughout the year. The plant compressed air requirement comprises of high pressure (HP) – 95 psi and low pressure (LP) - 50 psi compressed air. The Customer has completed the installation of two (LP) compressor units; 40 hp, 50 hp, and one (HP) unit 100 hp VSD. The installation of the three new compressors has resulted in retiring two of the LP existing compressors, and programming one HP compressors in back-up mode. The retired compressors are LP 75 hp, and LP 50 hp. The back-up HP compressor is 75 hp.

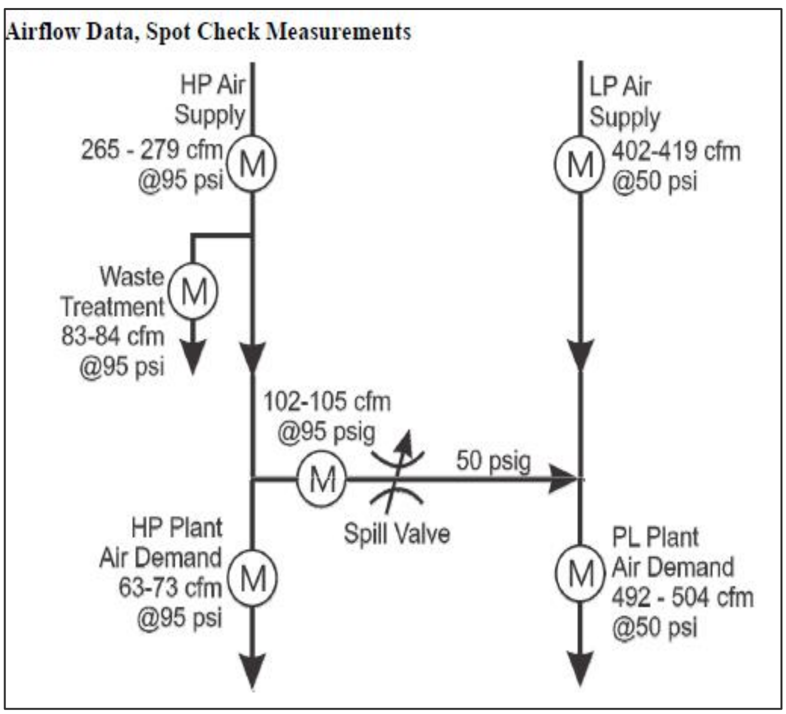
The scope of this project further involves measures to reduce the plant air demand and system optimization. The Customer has installed two pressure regulators to optimize the high pressure air delivered to the waste water treatment plant and to serve the plant demand effectively. The three compressed air end use components are the HP waste treatment plant (83-84 cfm @ 95 psi), HP plant load (63-73 cfm @ 95 psi) and LP plant load (492 -504 cfm @ 50 psi). Additional site air supply and load requirements are provided in Figure 1, which was provided as part of the project submittals. The Customer has estimated that the HP plant load as well as the waste treatment load would be reduced to a supply air pressure of 85 psi.

Table 3 provides a complete list of EEM's associated with this project.

Table 3: EEM List

EEM Type	Quantity	Size/Notes
New LP Compressors	2	40 hp, 50 hp
New HP Compressors	1	100 hp VSD
Pressure Regulators	2	HP plant load and waste treatment load.

Figure1: Pre-existing plant data



Baseline

The plant compressed air equipment includes three oil-free rotary screw compressors. Based on the information available on the project submittals; it is estimated that three of these compressors produce 420-

419 cfm of LP compressed air at 50 psi, and one compressor produces 265-279 cfm of HP compressed air at 95 psi. The pre-existing equipment is shown in Table 4.

Table 4: Pre-existing Equipment

HP	Pressure (PSI)	Quantity	Current Status
75	50	1	Retired
50	50	1	Retired
75	95	1	Back-up

It was mentioned in the project submittal that during the pre-implementation measurement period three air compressors were operating in total; the two units supplying the LP air loop were 75 hp and 50 hp, and the one unit supplying the HP air loop was 75 hp. The submitted project documentation states that the compressor units operate 24/7, 350 days/year totalling 8,400 hours per year. The actual operating hours would be confirmed during the site visit.

Proposed Condition

The customer has installed two new compressors on the LP side, and one new VFD compressor on the HP side. The proposed equipment is summarized in Table 5.

Table 5: Post Equipment

HP	Full Load Pressure (PSI)	Capacity (ACFM)
40	50	178
50	50	228
100	95	331

Two of the existing compressors have been retired, and the 75 hp unit is currently programmed to operate as a back-up unit.

The Customer has installed two pressure regulators, one each on the existing HP Plant Air Supply pipeline and the pipeline that serves the Waste Treatment. Each regulator is set to the lowest optimum supply pressure required by each of the demand sectors, 80 psi.

Air Compressor Sequencing and Control: The project submittal states that manual compressor controls as well as compressor sequencing has been implemented as follows:

<u>Normal plant operation:</u> During the fully loaded operation; the two LP System (50 psig) air compressors will provide 404 cfm of delivered airflow. The HP System will require between 165 cfm and 225 cfm of air supply (80 -100 cfm HP to LP spill flow; 45 cfm HP Plant Air @ 85 psig, and 40 to 80 cfm of air demand in Waste Treatment). The HP VSD air compressor with capacity of 333 cfm will operate between 50% and 68% of full load capacity.

<u>Reduced plant operation:</u> During the reduced plant operation period; one LP (50 hp) unit and the 75 hp HP unit will meet the required load, and the 40 hp LP compressor would be OFF. When the air demand is further reduced the 40 hp LP unit and the 75 hp HP units would operate, and the 50 hp LP unit will be OFF.

During very low demand periods, the 75 hp HP compressor alone would operate to supply the entire compressed air system demand.

Tracking Calculation Methodology

The site energy consultants conducted a comprehensive performance measurement during the normal plant operational period (August 2nd – 15th, 2011). The site measurements included all the operating compressor kW consumption, airflow measurements on the HP and LP compressors, and the HP and LP air demand. The spill over flow from the HP to LP system was also measured at the intermediate control valve. The tracking savings were estimated by utilizing the AirMaster+ software, and the measured plant parameters to establish the plant operational base-line. The measured data were not provided as part of the project submittals. The project report only included the screen shot of the savings estimate from the AirMaster+ software.

<u>LP Compressor Savings Estimation:</u> The manufacture specified full load power draw at 75 psi operating pressure for the 40 hp and 50 hp units are 22.3 and 24.0 kW/100 cfm respectively. The units are operated at 50 psig hence, the power is adjusted by 1% per 2 psig, resulting in 12.5% power reduction for 25 psig reduced discharge pressure. The adjusted compressor performance is 34.7 kW at 178 cfm and 50 psig for the model KNW A0-A/L, and 47.9 kW at 228 cfm and 50 psig for the model KNW A0-B/L air compressor. Total kW for both air compressors operating at full load of 406 cfm and 50 psig discharge pressure is estimated to be 82.6 kW. Performance was modelled in AiRMaster+ software by using the Improve End Use Efficiency EEM considering that 406 cfm of existing air demand will be displaced by low pressure generation. The kW of the "substitute tool" is entered as 82.6 kW.

<u>Pressure regulation savings:</u> The savings with respect to this measure is modelled with the Improve End Use Efficiency EEM by entering a 35 cfm air demand reduction for all operating time periods. This is based on the reported plant air demand reduction from about 80 cfm to 45 cfm with pressure reduced from full line pressure to a target of 80 psig. The artificial demand reduction for the Waste Water sector is unknown and therefore assumed to be zero.

<u>New VSD HP air compressor:</u> The manufacture specified full load power draw of the 100 hp unit is75 kW. This measure is modelled in the AiRMaster+ software using the Reduce Runtime EEM. For this measure the new compressor's performance data is added to the compressor inventory module with the compressor shut-off in the baseline profile module. Then in the EEM module, the existing air compressors are shut down and the new VSD compressor is marked as operating.

Assessment of Tracking Methodology and Analysis

- The site measured compressor flow and kW measurements were recorded for less than 2 weeks, and this trended data is considered inadequate to accurately capture the facility's entire load profile and seasonal/holiday load profiles.
- The project documentation only included the screen shot of the savings estimate from the AirMaster+ software.

EVALUATION METHODOLOGY

The following sub-sections describe project scope and estimated savings based on observed site conditions. The sub-sections go over the pre-existing (baseline) and proposed operating conditions & equipment informed by the site visit and correspondence with the site contact. The sub-sections also discuss the data collection, analysis, and calculation methodology performed to estimate the evaluated savings.

Measure Verification

The Evaluation team conducted a comprehensive site visit to collect all the relevant name plate/equipment information and other controls information with respect to this project. The evaluator documented the base-line condition based on the information collected during the site visit. The EEM's with respect to this project were completed as proposed in the Tracking documentation. The evaluator collected installed equipment details from the equipment name plate, and other operational data were collected from the installed unit's display screen. The evaluator collected pressure and CFM readings from the site installed flow meters.

Data Collection

The installed compressors were installed with elite pro loggers to monitor system operation and true power consumption. The existing/back-up compressors were installed with a HOBO micro station logger. Spot power measurements were taken for all the existing and newly installed compressors to validate the baseline and proposed energy consumption profile. Additional air side data were collected from the site installed flow meters. Table 6 and Table 7 summarize the Evaluation team's measurement and verification details.

Table 6: Proposed Measurement and Verification Summary

Input	Tracking Analysis Variable	Verification Method
Annual Run Hours.	8,400	Elite Logger
HP Baseline (3 new units)	40,50,100 HP	On Site Verification
kW (3 new units)	22.3, 24, 75 kW	Elite Logger
Amperage (existing unit)	60 to 70 A	HOBO Logger
Air Pressure (2 lines)	95, 50 PSI	On Site Verification
Air Capacity (multiple units)	178, 228, 331 CFM	On Site Verification

Table 7: Logger Information

Time-series Data Information	
Measured Parameter	Total Package True Power (kW) and Amperage (A)
Logger Make/Model	New Units: DENT Elite Pro SP kW Logger (3 units), Back-up unit: Onset HOBO Logger (1 unit)
Transducer/Equipment Type	New Units: (3) 50 A, (3) 100 A , and (3) 150 A CTs (9 units in total) Back-up unit: (1) 100 A CT.
Installation Location	Outlet of VSD in Power Compartment
Observation Frequency	15 minute interval
Metering Period	5 weeks (12/11/13 – 1/16/14)
Metered By	DNV GL and RISE electrician

Evaluation Savings Analysis

The measured kW data and the air side cfm data were used to create custom kW/cfm curves, and these curves were used to create the proposed case energy consumption model. The user created proposed case energy consumption model were utilized to estimate the plant CFM profile. The evaluator created a spreadsheet based engineering calculation to evaluate savings with respect to this project.

The evaluation engineer utilized the trend data collected during the onsite evaluation to develop an 8,760 compressed air load profile. Using the load profile, the evaluator calculated the pre and post retrofit kW demand using performance curves generated using baseline trend data for the pre-existing compressors and CAGI performance curves for the installed compressor.

The peak demand reduction was calculated in compliance with the NYISO, which states that system peaks generally occur during the hour ending at 5pm on the hottest non-holiday weekday. The New York Technical Manual (TM) states that this peak occurs on Friday, July 21, 1995 between 4 P.M. – 5 P.M. However, since compressed air load at this facility is not weather dependent, the peak demand reduction was calculated as the average demand reduction between 4 P.M and 5 P.M on all non-holiday weekdays. The customer provided the following holiday information. The customer mentioned that during holidays; the plant is still operating at a reduced load.

Holiday List	Start Date	Full List	Time	ON/OFF
New Year	1/1/1995	1/1/1995		OFF
		1/2/1995	7:00 AM	ON
Easter	4/15/1995	4/15/1995	11:00 PM	OFF
		4/16/1995		OFF
		4/17/1995	7:00 AM	ON
Memorial Day	5/29/1995	5/29/1995	7:00 AM	
		5/30/1995	7:00 AM	ON
Independence Day	7/3/1995	7/3/1995	7:00 AM	OFF
		7/4/1995		
		7/5/1995		
		7/6/1995		
		7/7/1995		
		7/8/1995		
		7/9/1995		
		7/10/1995	7:00 AM	ON
Labor Day	9/4/1995	9/4/1995	7:00 AM	OFF
		9/5/1995	7:00 AM	ON
Thanksgiving	11/23/1995	11/23/1995	7:00 AM	OFF
		11/24/1995		
		11/25/1995		
		11/26/1995	7:00 AM	ON
Christmas	12/24/1995	12/24/1995	7:00 AM	OFF
		12/25/1995		
		12/26/1995		
		12/27/1995		
		12/28/1995		
		12/29/1995		
		12/30/1995		
		12/31/1995		

The evaluator developed an hourly operating profile for the customer's compressed air system. The evaluator utilized the installed compressor time series kW data collected between 12/11/13 – 1/16/14 and compressor performance curves to generate the hourly CFM profiles. CAGI performance data and Generic Curves from the Best Practices for Compressed air Systems were used to create the CFM load profiles. The evaluator then created 2 separate hourly CFM profiles; Normal Day CFM profiles and Holiday CFM Profiles. Figure 2 and Figure 3 shows the kW profiles for the 100 HP VSD compressor during regular working days and holidays respectively. The different color bands indicate the Day Types.

Figure 2: 100 HP VSD Unit kW Profile; Normal Operation

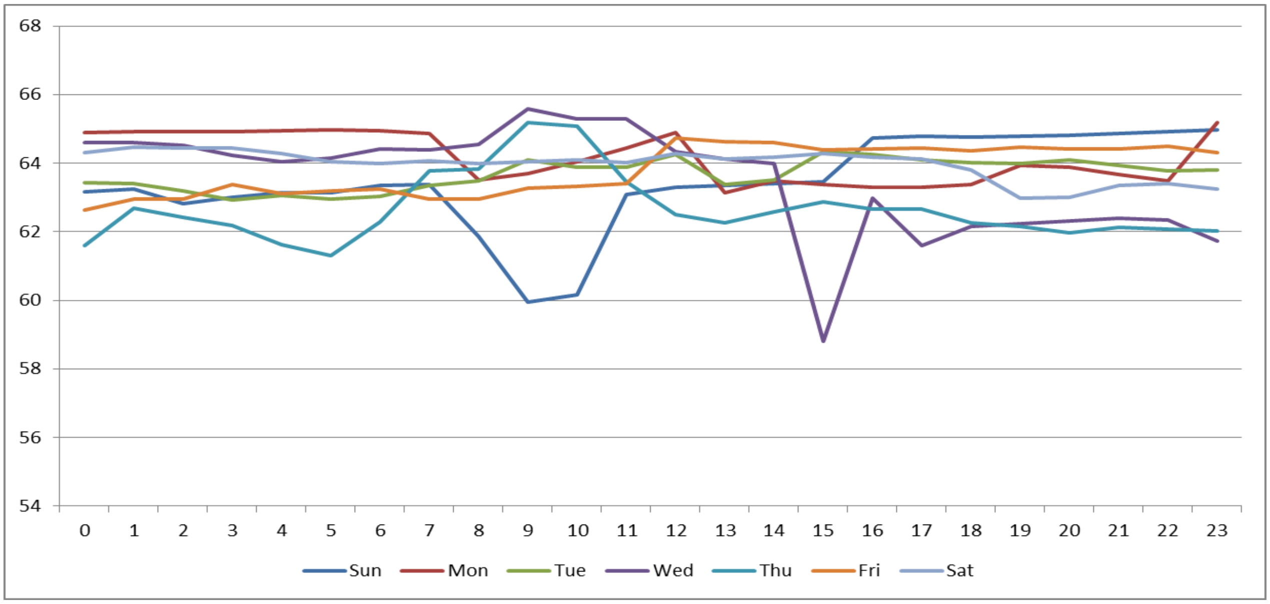
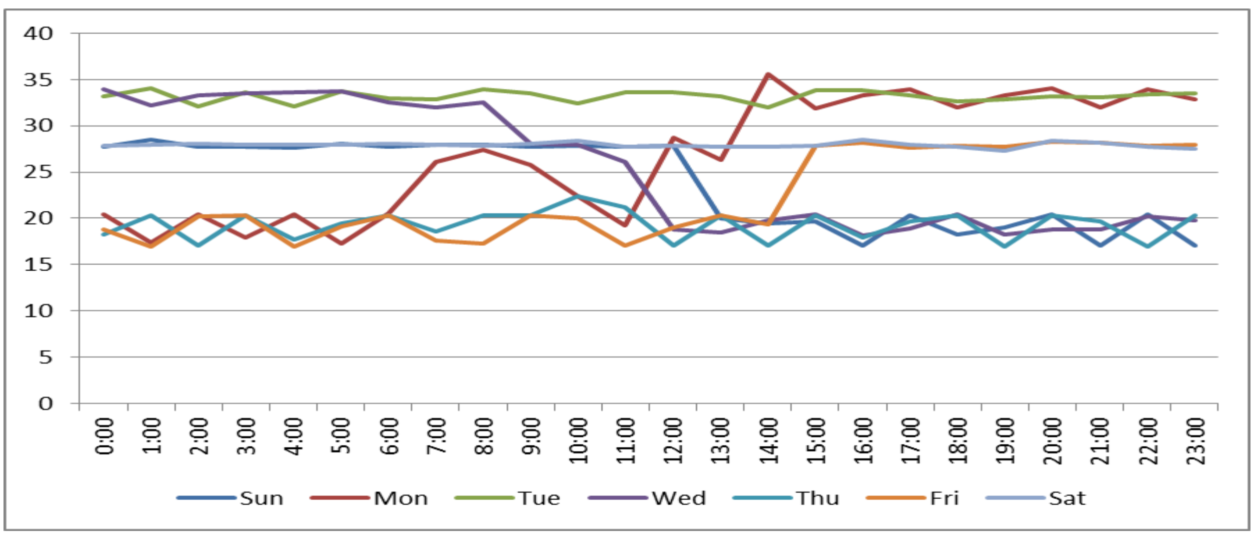


Figure 3: 100 HP VSD Unit kW Profile; Holiday Operation



The evaluator then created a lookup table which listed the average compressed air demand from the trending period based on hour and day type. This lookup table was used to generate an 8,760 load profile by matching each hour and day type throughout the year to the corresponding average compressed air demand in the lookup table. Table 8 summarizes all the compressor curve fit equations created for this project, where 'x' indicates CFM and 'y' indicates kW consumption.

Table 8: Compressor Performance Curve Fitting

Setup	Model	CFM	Type	Size	Equation
Proposed System	KNWAO-D/XL	331	HP	100 HP	$y = 0.1828x + 6.0375$
	KNWA0-A/L	225	LP	40 HP	$y = 0.1389x + 8.2683$
	KNWAO-B/L	178	LP	50 HP	$y = 0.1632x + 12.326$
Base System	ZT 237	226	LP	50 HP	$y = -0.0005x^2 + 0.2103x + 9.245$
	ZT 255	326	LP	75 HP	$y= -0.0004x^2 + 0.2173x + 15.573$
	ZT 55	326	HP	75 HP	$y = -8E-05x^2 + 0.1869x + 15.742$

Pre-existing Scenario

The pre-existing compressed air system power consumption was determined based on the 8,760 compressed air load profile created by the evaluator. The kW consumption and the performance curves are used to estimate the CFM needed to meet the plant load in base-case scenario.

For the LP system; ZT 255 unit is set to operate as the lead unit and ZT 237 acts as the lag unit. The ZT 55 unit provides all the required HP CFM.

The peak demand reduction was calculated in accordance with the guidelines stipulated by the New York Technical Manual (TM), which states that system peaks generally occur between the hours of 4PM and 5PM on non-Holiday weekdays. Therefore, the average demand reduction during these hours served as the basis for the evaluated peak demand reduction.

EVALUATION RESULTS

The difference between the baseline and installed 8,760 hourly load profiles served as the basis for the annual project savings. The total evaluated electric savings were determined to be 188,410 kWh and 21.6 kW peak demand reduction. The tracking savings are 238,896 kWh and 29.3 kW peak demand reduction. The gross realization rates (GRR) comparing the evaluated savings to the tracking savings are 79% for kWh savings and 74% for peak demand reduction.

Primary Reasons for Savings Discrepancy

The discrepancies between the tracking and evaluated savings can be attributed to the following source:

1. Discrepancy #1 (Operating Conditions) – The primary source of discrepancy between the proposed and evaluated savings is due to a discrepancy in Plant load profile. The initial tracking calculations calculated that the pre-existing compressed air system profiles based on 2 weeks of monitored data. However, the evaluator collected kW trend data for 5 weeks, which provides more data points for the calculation of the plant load profile during normal working days and Holidays. The project kWh savings was reduced by 50,486 kWh, -21% and 7.67 kW, -26%.

SITE ID: DNVCA11

Project Type	Retrofit
Measure Category	Custom Compressed Air

PROJECT DESCRIPTION

This manufacturing facility has completed a compressor retrofit project, and this project includes replacing the existing fixed speed rotary screw compressor with a VFD compressor. The existing compressor was operating in modulating mode to satisfy the plant load. The new VFD compressor is currently installed, and the existing compressor is retired. This project even includes replacing the existing receiver with a higher capacity unit. Table 1 summarizes the initial savings estimates prior to the retrofit and the revised or evaluated savings values following project implementation. Table 2 outlines the reasons for discrepancy between the initial and evaluated project savings.

Table 1: Summary of Evaluation Results

Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
Annual Energy Savings (kWh)	204,651	154,530	76%
Peak Summer Demand Reduction (kW)	23.36	12.9	55%

Table 2: Discrepancy Analysis Summary

Discrepancy Factor	kWh	kW
Operating Conditions		
Equipment Specifications		
Calculation Method	Discrepancy #1 (Calculation method): - 50,121 kWh, - 24%	Discrepancy #1 (Calculation method): -10.5 kW, - 45 %
Inappropriate Baseline		

TRACKING SAVINGS

This section summarizes the methodology and assumptions used to estimate the Tracking savings claimed for the project.

Project Description

This project is implemented in an industrial manufacturing facility which has the compressed air system comprising of (1) 100 HP rotary screw compressor with a 240 gallon receiver, and a dryer. Total installed compressor capacity is about 446 cfm. The plant operates 24 hours, seven days per week. The current configuration operates the 100-HP unit in modulating mode. The existing compressor is operated at high discharge pressure and all the compressed air generated at the plant is supplied to the plant shops at an average of 85 PSI.

The scope of this retrofit project is to increase the plant compressed air capacity, and to retire the existing compressor, and receiver with a new VFD compressor and a 660 gallon receiver, and continue using the existing dryer. The new VSD compressor is currently installed along with the receiver. The existing compressor, as well as the receiver are decommissioned and retired from service. Refer Table 3 below for the complete list of EEM's associated with this project.

Table 3: EEM List

EEM Type	Quantity	Size/Notes
Install new VSD compressor	1	100 HP VSD unit is installed
Install new Receiver	1	660 gallon receiver installed

Baseline

The plant compressed air equipment includes one compressor unit. Based on the information available on the project submittals; the site is equipped with one fixed rotary screw compressor operating in modulating mode. The plant has the following compressor:

Table 4: Pre-Existing Equipment

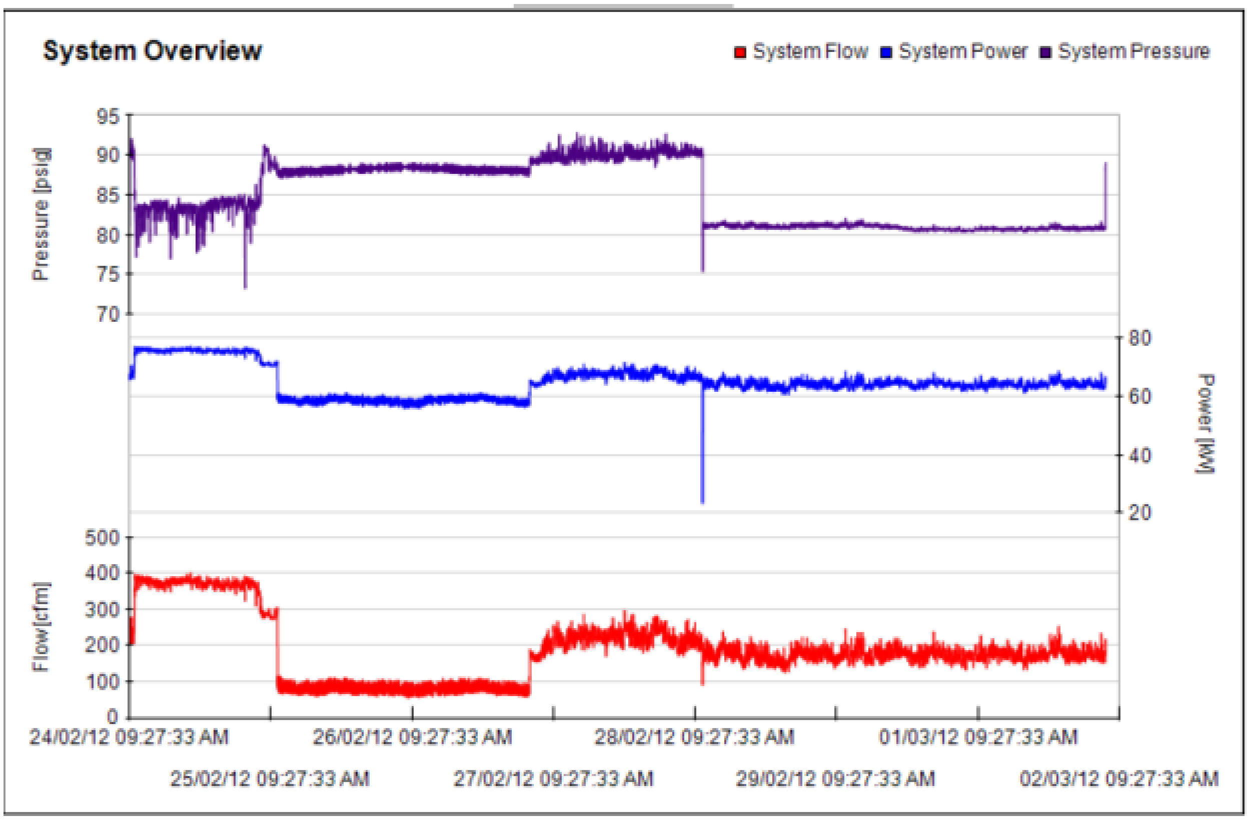
Unit	HP	Pressure (PSI)	Control	Current Status
Unit 1	100	85 (Avg)	Modulating	Retired.

It was mentioned in the project submittal that during the pre-implementation measurement period the existing compressor was operating continuously during the normal production period, Monday through Sunday, 24 hours a day. The actual operating hours would be confirmed during the site visit. Table 5 shows the existing equipment power draw and CFM values. Please refer Figure 1 for the plant equipment power, pressure and flow measurements provided in the project submittal.

Table 5: Pre-Existing Equipment Operating Data

Unit	Size (HP)	Capacity (CFM)	PSIG	Measured Power
Unit-1	100	446	85 (AVG)	64.9 kW (AVG)

Figure 1: Plant Equipment System Power, Flow and Pressure



Proposed Condition

The new 100 HP VFD compressor along with the new 660 gallon receiver have been installed, and the existing compressor and receiver have been retired. The post equipment's configurations and control scheme are summarized in Table 6 below.

Table 6: Post Equipment

Unit	HP	Pressure (PSIG)	Control	Status
New Unit	100	100	VFD	Installed
Old Unit	100	85 (Avg)	Modulating	Retired

The project submittal states that the VFD units would operate all the time to meet the varying plant load, including holidays.

Tracking Calculation Methodology

The project submittal mentioned that the site energy consultants conducted a comprehensive site operational data collection for one week, February 24th to March 2nd, 2012. The site measurements included the operating compressor power reading, airflow, and pressure measurements. The tracking savings were estimated by the consultants by utilizing the measured plant parameters to establish the plant base-line energy consumption.

Base-line profile creation: Based on the plant measured data, the power consumption of the base-line compressor was estimated. The base-line energy consumption is estimated based on the measured average compressed air kW. The base-line energy consumption is calculated by multiplying the average compressor energy consumption times the plant operating hours.

64.87 kW x 8,758 hours/year = 568,091 kWh/yr

Energy Savings:

The VFD savings has been calculated based on an estimated reduction in the compressor kW consumption. The project submittal has no details regarding how the savings were estimated. The project submittal mentions that the VFD compressor and receiver installation would result in a 26 kW power reduction.

Assessment of Tracking Methodology and Analysis

1. The savings for this project are calculated based on the plant data, which was collected for a week's period of time. It is deemed that it is difficult to capture the dynamic nature of the plant load in one week's monitoring period.
2. There are not details regarding the demand savings calculation. The project submittal reports 26 kW energy reductions, and the tracking savings documentation reports 23.36 kW demand savings.
3. The measured data was not provided as part of the submittal.
4. The base-line energy consumption was estimated based on the average plant compressor power draw.

EVALUATION METHODOLOGY

The following sub-sections describe project scope and estimated savings based on observed site conditions. The sub-sections go over the pre-existing (baseline) and proposed operating conditions & equipment informed by the site visit and correspondence with the site contact. The sub-sections also discuss the data collection, analysis, and calculation methodology performed to estimate the evaluated savings.

Measure Verification

The Evaluation team conducted a comprehensive site visit to collect all the relevant name plate/equipment information and other controls information with respect to this project. The evaluator documented the base-line condition based on the information collected during the site visit. The EEM's with respect to this project were completed as proposed in the Tracking documentation. The evaluator collected installed equipment details from the equipment name plate, and other operational data were collected from the installed unit's display screen. The evaluator collected pressure and CFM readings from the site installed flow meters. Table 7 shows the ECMs and respective quantities installed.

Table 7: Proposed versus Implemented ECMs

Implemented ECMs	Proposed (tracking)	Implemented (evaluated)
100 HP unit	Retired	Retired
New 660 Gallon Receiver	Installed	Installed
New 100 HP VFD unit	Installed	Installed

Data Collection

The newly installed compressor was installed with elite pro loggers to monitor system operation, Amperage and true power consumption. Spot power measurements were taken for the newly installed compressor to validate the proposed energy consumption profile. During the site inspection it was recorded that the new VFD unit was operating continuously to satisfy the plant load. The operating personnel mentioned that the compressor would experience low loads during weekends. Additional air side data were collected from the site installed flow meters. Table 8 and 9 summarizes the Evaluation team's measurement and verification details.

Table 8: Proposed Measurement and Verification Summary

Input	Tracking Analysis Variable	Verification Method
Annual Run Hours.	8,760	Elite Logger
Unit HP	100 HP	On Site Verification
kW	93 kW	Elite Logger
Air Capacity	479.3 CFM	On Site Verification

Table 9: Logger Information

Time-Series Data Information	
Measured Parameter	Total Package True Power (kW) and Amperage (A)
Logger Make/Model	DENT Elite Pro SP kW Logger,
Transducer/Equipment Type	100 A CT's (3 units in total)
Installation Location	Outlet of VSD in Power Compartment
Observation Frequency	15 minute interval
Metering Period	5 weeks (12/13/13 – 1/21/14)
Metered By	DNV GL and RISE electrician

Evaluation Savings Analysis

The measured kW data and the air side cfm data were used to create custom kW/cfm curves, and these curves were used to create the proposed case energy consumption model. The user created proposed case energy consumption model were utilized to estimate the plant CFM profile. The evaluator created a spreadsheet based engineering calculation to evaluate savings with respect to this project.

The evaluation engineer utilized the trend data collected during the onsite evaluation to develop an 8,760 compressed air load profile. Using the load profile, the evaluator calculated the pre and post retrofit kW demand using CAGI performance curves.

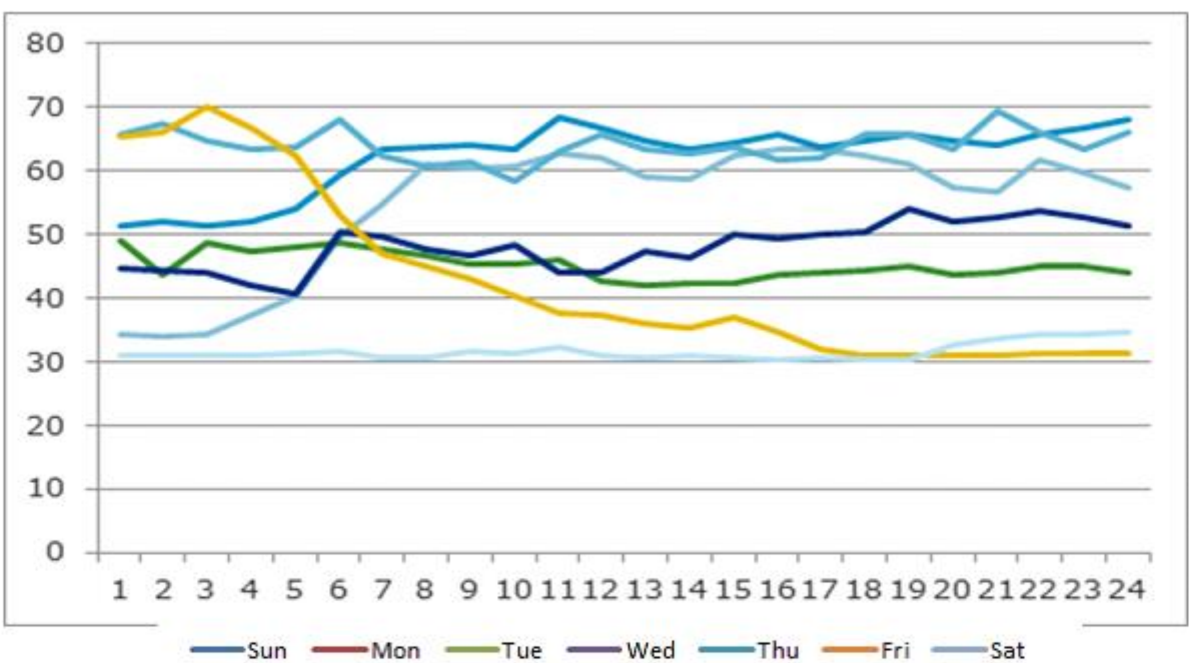
The peak demand reduction was calculated in compliance with the NYISO, which states that system peaks generally occur during the hour ending at 5pm on the hottest non-holiday weekday. The New York Technical Manual (TM) states that this peak occurs on Friday, July 21, 1995 between 4 P.M. – 5 P.M. However, since compressed air load at this facility is not weather dependent, the peak demand reduction was calculated as the average demand reduction between 4 P.M and 5 P.M on all non-holiday weekdays. The customer mentioned the compressors operate 24/7 throughout the year to meet the plant load and the compressors are shut down only during holidays.

Based on the monitored data it is determined that the new VSD operates continuously Monday through Sunday, 24 hours a day and experiences lower loads during Saturday and Sunday.

Installed Scenario

The evaluator developed an hourly operating profile for the customer's compressed air system. The evaluator utilized the installed compressor time series kW data collected between 12/13/13 – 1/21/14 and compressor performance curves to generate the hourly CFM profiles. CAGI performance data and Generic Curves from the Best Practices for Compressed air Systems were used to create the CFM load profiles. The evaluator then created hourly CFM profile for Normal Day operation. Figure 2 shows the kW profiles for the VSD compressor. The different color bands indicate the Day Types.

Figure 2: (100) HP VSD unit kW profile.



The evaluator then created a lookup table which listed the average compressed air demand from the trending period based on hour and day type. This lookup table was used to generate an 8,760 load profile by matching each hour and day type throughout the year to the corresponding average compressed air demand in the lookup table. Table 10 summarizes all the compressor curve fit equations created for this project.

Table 10: Compressor Performance Curve fitting

		CFM	Type	Size	Equation
Proposed System	VFD Unit	479.3	VFD	100	$CFM= -0.0152x^2 + 7.1101x - 48.817$
Base System	Base-unit	446	Modulation	100	$kW= -1E-05x^2 + 0.0575x + 52.925$

The post compressed air system power consumption was determined based on the 8,760 compressed air load profile created by the evaluator. The kW consumption and the performance curves are used to estimate the CFM needed to meet the plant load in the base-case scenario.

Pre-existing Scenario

The evaluator utilized the kW consumption and the performance curves to estimate the CFM needed to meet the plant load.

In the base-case scenario the 100-HP unit operates continuously in modulation mode to meet the plant load.

The peak demand reduction was calculated in accordance with the guidelines stipulated by the New York Technical Manual (TM), which states that system peaks generally occur between the hours of 4PM and 5PM on non-Holiday weekdays. Therefore, the average demand reduction during these hours served as the basis for the evaluated peak demand reduction.

EVALUATION RESULTS

The difference between the baseline and the installed kW served as the basis for the annual project savings. The total evaluated electric savings were determined to 154,530 kWh and 12.9 kW peak demand reduction. The tracking savings are 204,651 kWh and 23.36 kW peak demand reduction. The gross realization rates (GRR) comparing the evaluated savings to the tracking savings are 76% for kWh savings and 55% for peak demand reduction.

Primary Reasons for Savings Discrepancy

The discrepancies between the tracking and evaluated savings can be attributed to the following source:

1. Discrepancy #1 (Calculation Method) – The primary source of discrepancy is the calculation method. The tracking savings are estimated based on plant consumption data collected for a week's period. It is deemed that it is difficult to capture the dynamic nature of the plant load in one week's monitoring period. There are no details provided regarding the estimated demand savings for this project. The tracking savings are calculated based on the plant average energy consumption data. There are no details provided regarding how the proposed case energy consumption estimation. The reviewer utilized the actual compressor power consumption to estimate the post retrofit energy consumption, and utilized the plant user generated plant CFM profiles to estimate the energy savings for this project. The project kWh savings was reduced by 50,121 kWh, - 24% and the kW savings was reduced by 10.5 kW, - 45%.

SITE ID: DNVCA12

Project Type	Retrofit
Measure Category	Custom Compressed Air

PROJECT DESCRIPTION

The customer replaced the pre-existing 100 HP single stage, rotary screw load/unload (LNL) compressor with a 100 hp single stage, rotary screw VSD compressor. By installing a VSD air compressor, the customer was able to reduce compressor power consumption at lower loads as the VSD compressor has greater part load efficiency. Table 1 summarizes the savings estimates prior to the retrofit and the revised or evaluated savings values following project implementation. Table 2 summarizes the discrepancies between the tracking and evaluated savings.

Table 1: Summary of Evaluation Results

Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
Annual Energy Savings (kWh)	223,463	154,045	69%
Peak Demand Reduction (kW)	27.7	26.1	94%

Table 2: Discrepancy Analysis Summary

Discrepancy Factor	kWh	kW
Operating Conditions	Discrepancy #1 (Compressor Performance at Observed Operating Conditions): -128,900 kWh; -58% Discrepancy #2, (Updated load profile): 59,481 kWh; 27%	Discrepancy #1 (Compressor Performance at Observed Operating Conditions): -17.8 kW; -64% Discrepancy #2, (Updated load profile): 16.1 kW; 58%
Equipment Specifications		
Calculation Method		
Inappropriate Baseline		

TRACKING SAVINGS

This section summarizes the methodology and assumptions used to estimate the Tracking savings claimed for the project.

Project Description

The customer's facility utilizes their compressed air system to actuate pneumatic valves and power pneumatic hand tools. The customer replaced the pre-existing 100 hp oil-injected compressor with load/unload controls with one 100 hp oil-injected compressor with VSD control. With the installation of a VSD air compressor, the customer was able to reduce the compressor power consumption at lower loads as the VSD compressor has greater part load efficiency. Table shows the ECM's installed as a result of the retrofit.

Table 3: Tracking ECMs

Description of ECM	Quantity
100 hp single stage, rotary screw variable speed compressor	1

Baseline

Prior to the retrofit, the customer operated two compressors to meet the facility's compressed air load. The specifications of the pre-existing compressor are outlined in Table 4.

Table 4: Pre-Existing Equipment

Description	HP	Control Method	Rated PSIG	Operating PSIG	Capacity (ACFM)	Date of Installation
Rotary screw	100	Load/No Load	105	96	465	

Proposed Condition

As a result of the retrofit, the customer installed one 100 hp VSD compressor to meet the facility's compressed air load. The specifications for the installed compressor are outlined in Table 5.

Table 5: Proposed Equipment

Description	HP	Control	Rated PSIG	Operating PSIG	Capacity (ACFM)
Rotary Screw	100	VSD	102	96	519

Tracking Calculation Methodology

In order to calculate the initial project savings, the pre-existing compressed air system was fitted with pressure and flow data loggers for a period of one week. The flow data collected was split into 34 separate bins based on compressed air demand. The % time at each load bin was multiplied by the assumed 6,000 annual operating hours to calculate the annual hours at each load bin based on one week of trend data. The tracking analysis utilized AirMaster+ to generate performance curves characterizing the relationship between compressed air demand (ACFM) and power consumption (kW) based on compressor nameplate information. The initial vendor calculations modified the performance of an inlet modulating compressor in order to replicate the CAGI performance data for the variable speed compressor. The air demand vs. kW relationship developed by AirMaster+ for both the baseline and proposed compressors is shown below in Table 6. The performance curves were used to calculate system power consumption based on the observed system demand. The kW demand and annual operating hours for each load bin were multiplied in order to calculate the annual kWh for each load bin. The kWh for all 34 load bins was summed in order to calculate the annual baseline system power consumption.

Table 6: Compressor Performance Data

ACFM	Existing kW	Proposed kW
0	59.9	5.6
50	65.5	14.2
100	70.6	22.8
150	75.3	31.5
200	59.4	40.1
250	83.0	78.8
300	86.2	57.4
350	88.8	66.0
400	90.9	74.7
450	92.6	83.3
500	-	92.0

The installed compressor annual power consumption was calculated in a similar manner. The % load of the compressor was determined using the load profile used in the baseline calculations. The kW demand for each bin was subsequently determined using the *Installed kW* data in Table 6. The kW demand and annual operating hours for each load profile bin were multiplied in order to calculate the annual kWh for each bin. The annual kWh for all 34 bins was summed to calculate the installed case annual kWh.

Equations:

1. Individual Load kWh = (kW at Specific Load) x (Number of Hours at Load)
2. Total System kWh = Load 1 kWh + Load 2 kWh + …+ Load 34 kWh
3. kWh Savings = Total System kWh_{Base} – Total System $kWh_{Proposed}$

Assessment of Tracking Methodology and Analysis

1. The tracking analysis utilized only one week of trend data in order to determine annual project savings. This may introduce error if the data was taken during periods of either high or low load due to the seasonality of the customer's compressed air demand.
2. The tracking analysis utilized AirMaster+ to generate performance curves for the proposed VSD compressor. Currently, AirMaster+ does not have the capability to model variable speed compressors. However, it appears that the tracking analysis modified the inlet modulation performance curve in AirMaster+ to model the variable speed compressor's operating parameters. No details on this modification were discussed in the tracking analysis. As such, the proposed compressor AirMaster+ performance curves must be compared with the proposed compressor CAGI performance curves to verify accuracy.
3. The project documentation does not provide any details on how the peak demand reduction was calculated for this compressor replacement project.

EVALUATION METHODOLOGY

The following sub-sections describe project scope and estimated savings based on observed site conditions. The sub-sections go over the pre-existing (baseline) and proposed operating conditions & equipment informed by the site visit and correspondence with the site contact. The sub-sections also discuss the data collection, analysis, and calculation methodology performed to estimate the evaluated savings.

Measure Verification

The conditions found on site were similar to those outlined in the tracking analysis. The customer's compressed air system is used to actuate pneumatic valves and operate pneumatic hand tools in the machine shop. Furthermore, the evaluator was able to visually verify nameplate information of the pre-existing and installed compressors, as all three compressors were onsite at the time of the evaluation. Table 7 shows the ECMs and respective quantities installed.

Since no time series trend data was available onsite, the evaluator utilized spot verification to substantiate the system operating pressure claimed in the tracking calculations. During the onsite evaluation, the evaluation team verified the claimed operating pressure of 100 PSIG through a pressure gauge installed on compressed air system.

Table 7: Proposed versus Implemented ECMs

Implemented ECMs	Proposed (tracking)	Implemented (evaluated)
100 HP VSD rotary screw compressor	Installed	Installed
100 HP LNL rotary screw compressor	Retired & Removed	Retired & Removed
1x 400 gallon compressed air storage tank	Retained	Retained

Data Collection

An ElitePro SP kW logger was installed on the VSD Compressor for a period of 4 weeks. This time series kW logger data was used to create an hourly compressed air system operating profile. Table 8 outlines the specifications of the data logger installed during the onsite evaluation.

Table 8: Evaluation Measurement Summary

Time-Series Data Information	
Measured Parameter	Total packaged True Power (kW) on VSD Compressor
Logger Make/Model	DENT Elite Pro SP kW logger
Transducer/Equipment Type	(2x) 150A, (1x) 200A split-core CTs
Installation Location	Power compartment in packaged unit
Observation Frequency	1 minute interval
Metering Period	4 weeks (November 7 to December 3, 2013)
Metered By	DNV GL and RISE electrician

The customer provided payroll hours for one year encompassing the evaluator's trending period. The payroll hour provided shows man hours billed in weekly increments. Therefore, the payroll hours for the trending period span from 11/4/2013 – 12/6/2013, the hours for fiscal weeks 45-49. Additionally, the customer provided normal operating hours for the facility. The front office usually operates between 6A-2:30P Monday through Friday. However, production hours are dependent on load as their production is based on customer orders. The operational data collected during the onsite evaluation was used to verify the operating hours utilized in the tracking analysis.

Evaluation Savings Analysis

The evaluation engineer utilized the trend data collected during the onsite evaluation to develop an 8,760 compressed air load profile. Using the load profile, the evaluator calculated the pre and post retrofit kW demand using AirMaster+ curves for the pre-existing compressors and CAGI performance curves for the installed compressor.

The peak demand reduction was calculated in compliance with the NYISO, which states that system peaks generally occur during the hour ending at 5pm on the hottest non-holiday weekday. The New York Technical Manual (TM) states that this peak occurs on Friday, July 21, 1995 between 4 P.M. – 5 P.M. However, because compressor operation at this facility is not weather dependent, the peak demand reduction was calculated as the average demand reduction for all non-holiday weekdays between the hours of 4 P.M and 5 P.M.

Installed Scenario

In order to calculate project savings, the evaluator developed an hourly operating profile for the customer's compressed air system. To accomplish this, the evaluator utilized the installed compressor power consumption data collected between 11/7/13 – 12/3/13 and compressor performance curves which outline the relationship between compressed air demand and power consumption and are generated using CAGI performance data. Using this relationship, the evaluator was able to generate a lookup table which listed the average compressed air demand from the trending period based on hour and day type. This lookup table was used to generate an 8,760 load profile by matching each hour and day type throughout the year to the corresponding average compressed air demand in the lookup table. However, merely annualizing the average compressed air load assumes 8,760 hours of operation.

In order to verify the annual operating hours used in the tracking analysis, payroll data was collected. It was initially believed that payroll data would quantify any seasonality in the customer's load. However, the evaluator does not believe that the payroll data quantifies the variation in compressed air demand brought about by variations in production. This conclusion was reached because no variability was seen in the payroll data between the trending period and on an annual basis. The trending period payroll data showed 8,056 hours worked in 4 weeks. The annual payroll data showed 93,233 hours worked in 52 weeks. 4 weeks accounts for approximately 8% of the 52 week annual payroll period. Similarly, the man hours worked during the 4 week trending period accounted for approximately 9% of the 52 week trending period, which suggests that the variability in load based on customer orders is not captured in the payroll data. Since the trend data showed that production occurred 24/7 during the trending period, the evaluator assumed high load due to seasonality. Since the man hour data collected during the onsite evaluation does not accurately characterize the seasonality of compressed air load, the tracking annual hours – which were calculated from tracking period trend data – were assumed to be correct.

In order to obtain 6,000 annual hours of operation, the evaluator first assumed no production during 20 major Federal Holidays, as indicated by the site contact during an onsite interview. Additionally, the evaluation team assumed no power consumption for 13 weeks and 4 days throughout the year in order to obtain the correct number of annual operating hours. The average kW reduction per day and per week were calculated and multiplied by 13 weeks and 4 days, respectively. These savings were subtracted from the total kWh savings to simulate the effects of the shutdowns.

Pre-existing Scenario

The pre-existing compressed air system power consumption was determined based on the corrected 8,760 compressed air load profile which reflects 6,000 annual hours of operation and performance curves generated in AirMaster+. The AirMaster+ performance curves were generated using the compressor nameplate information and system operating parameters utilized in the tracking analysis and verified on site. AirMaster+ then generates a % Power vs. % Flow curve for the specified compressor. Dummy flows were input into the 'Profile' tab in AirMaster+ which automatically generates a Capacity (ACFM) vs. Power (kW) relationship*.* Using this relationship, the evaluator was able to calculate the 8,760 kW demand as a function of the 8,760 compressed air demand from the pre-installation period. The 8,760 kW were then summed in order to calculate the annual compressor power consumption for the pre-installation period.

EVALUATION RESULTS

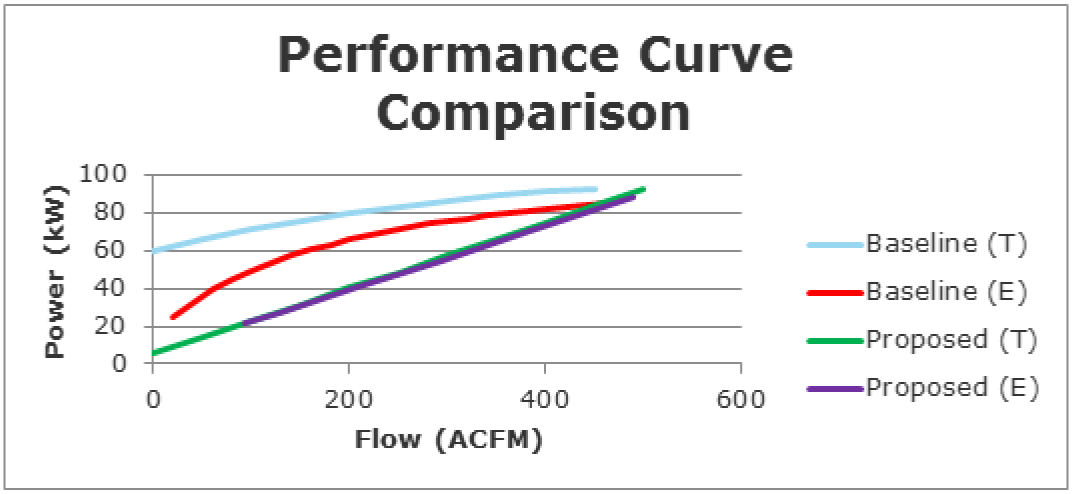
The savings were subsequently calculated by simply taking the difference between the pre-existing kW and the post-retrofit kW. The total evaluated electric savings were determined to be 154,045 kWh and 26.0 kW peak demand reduction. The tracking savings are 223,463 kWh and 27.7 kW peak demand reduction. The gross realization rates (GRR) comparing the evaluated savings to the tracking savings are 69% for kWh savings and 94% for peak demand reduction.

Primary Reasons for Savings Discrepancy

1. Operating Conditions [-69,418 kWh, -31%] [-1.7 kW, -6%]

    a. Updated Performance Curves [-128,900 kWh, -58%] [-17.8 kW, -64%]

        i. The baseline compressor performance curve used in the tracking analysis did not reflect the operation of a load/unload compressor but reflected the operation of an inlet modulating compressor. The baseline curve discrepancy resulted in a decrease in savings of 140,712 kWh and 19.2 kW, -63% and -69% reductions in kWh and kW savings, respectively. Additionally, a discrepancy was discovered between the proposed (tracking) and installed (evaluated) compressor performance curves. The performance curve for the proposed compressor was taken from the CAGI sheet in the tracking analysis. However, during the site evaluation it was determined that the compressor operates at a pressure of 100 PSIG, while the CAGI sheet outlined the compressor rated performance characteristics at 125 PSIG. Compressor performance data at lower pressures was obtained from the manufacturer, showing a slight decrease in total power at full capacity when operating pressure is decreased from 125 PSIG to 100 PSIG. The result was a slight increase in project savings, 11,813 kWh and 1.42 kW, corresponding to a 5% increase in both kWh savings and demand reduction. The figure shown below illustrates the differences in the tracking and evaluated performance curves for the baseline and installed compressors and can be found in '3- Performance Curves' in the calculation spreadsheet. The net impact of the performance curve discrepancies is listed above at 128,900 kWh (-58%) and -17.8 kW (-64%).



b. Updated Load Profile [59,481 kWh, 27%] [16.1 kW, 58%]

i. The annual load profile differed between the tracking and evaluated savings calculations. The tracking analysis calculated an average load of 219 ACFM while the evaluation yielded an average demand of approximately 125 ACFM. Since the variable speed compressor can operate at higher efficiency at lower loads than the pre-existing compressor, this lead to an increase in project savings However, since the updated performance curves accounted for a larger negative impact on savings, the overall project realization rate was calculated to be 69% for kWh savings and 94% for peak demand reduction.

SITE ID: DNVCA13

Project Type	Early Replacement and Add-On
Measure Category	Custom Compressed Air

PROJECT DESCRIPTION

This project involved the retirement of one (1) pre-existing 300-hp air-cooled, oil-injected rotary screw compressor with load/unload controls and the installation of a new 300-hp air-cooled, oil-injected rotary screw compressor with variable displacement flow controls. Additionally, a new 2,000 gallon vertical air receiver tank was installed. The installed compressor is the only compressor serving the compressed air demand of the facility. Table 1 provides the evaluation savings results while Table 2 provides the discrepancy analysis summary.

Table 1: Summary of Evaluation Results

Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
Annual Energy Savings (kWh)	237,276	13,854	6%
Peak Demand Reduction (kW)	38.00	-0.1	-0.2%

Table 2: Discrepancy Analysis Summary

Discrepancy Factor	kWh	kW
Operating Conditions	Discrepancy #1 (Compressor Performance at Observed Operating Conditions): -186,891 or -79%	Discrepancy #1 (Compressor Performance at Observed Operating Conditions): -30 or -79%
Equipment Specifications	N/A	N/A
Calculation Method	Discrepancy #2 (Different Calculation Method): -36,530 or -15%	Discrepancy #2 (Different Calculation Method): -8.2 or -21%
Inappropriate Baseline	N/A	N/A

TRACKING SAVINGS

This section summarizes the methodology and assumptions used to estimate the Tracking savings claimed for the project.

Project Description

Based on the tracking documentation, the pre-existing compressed air demand was met using one 300-hp air-cooled rotary screw compressor using load/unload flow controls. A pre-existing 660 gallon air storage tank was also documented. The pre-existing compressor was replaced by one 300-hp variable displacement rotary screw compressor. One 2,000 gallon vertical air receiver tank was also installed. Note that while the 2,000 gallon air receiver tank was noted in the post-installation inspection form and the "Minimum Requirements Document" (MRD), its incremental savings potential was not addressed in the tracking savings methodology nor was it claimed in the tracking savings. Therefore, the incremental savings associated with the additional 2,000 gallon tank will not be evaluated. Table shows the efficiency measures installed per the tracking documentation.

Table 3: Tracking ECMs

Description of ECM	Quantity
300-hp air-cooled, single-stage, variable displacement rotary screw compressor	1
2,000 gallon vertical air receiver tank	1

Baseline

The compressed air system demand was met using one 300-hp air-cooled rotary screw compressor, operating at a discharge pressure of around 120 - 125 psig. The compressor was documented as having a capacity of 1,285 acfm at the operating pressure which was presumed by the evaluator to be 125 psig. The pre-existing flow controls were documented as load/unload. The pre-existing demand schedule and compressor sequencing were modelled in the tracking savings analysis with 3,120 annual hours operating at 1,085 acfm, 1,560 annual hours at 850 acfm, and 1,560 annual hours at 675 acfm. The tracking documents do not explain how these operating hours were estimated but the evaluator believes they may have been estimated using customer input. The compressor's manufactured date was not documented and it could not be determined from project documentation if the compressor was replaced because of age or performance degradation issues. Table 4 summarizes the pre-existing compressor based on the tracking documentation.

Table 4: Pre-Existing Equipment[28]

Equipment	hp	Control	Rated psig	Operating psig	Capacity (acfm)	Manufactured Year (if known)
Air-cooled, two-stage, oil-injected rotary screw compressor	300	Load/unload	140	125	1,285	1995[29]

The proposed vendor savings calculation includes seven charts of daily pre-installation compressed air pressure (psig) and flow (scfm) with average and maximum values listed for each day. Those values are listed in Table 5 below. Note that the averages include data points when the compressor was unloaded or off,

28 The table values are directly from the pre-installation site inspection form

29 The site contact claimed that the manufactured year was 1993. The 1995 year was given on the pre-installation site inspection form

so the average pressure is not representative of the normal operating pressure, but the flow values may be seen as reasonably representative of the average flow during that period.

Table 5: Pre-existing Daily Average Flow and Pressure (Vendor Measurements)

Date	Maximum Flow (scfm)	Average Flow (scfm)	Maximum Pressure (psig)	Average Pressure (psig)
10/27/2011 – 10/28/2011	1288.26	790.79	130.8	119.05
10/28/2011-10/29/2011	1279.69	560.31	130.9	58.53
10/30/2011-10/31/2011	1281.89	151.35	131.4	53.28
10/31/2011-11/1/2011	1280.44	425.81	131.0	93.36
11/1/2011-11/2/2011	1288.12	1253.75	123.4	121.74
11/2/2011-11/3/2011	1279.58	1239.65	123.1	121.49
10/27/11-11/3/2011	**1281.55**	**643.98**	**131.4**	**80.86**

Proposed Condition

The project proposed to replace the pre-existing compressor with one new 300-hp air-cooled rotary screw compressor (rated 270.9 kW delivering 1,330 acfm at 125 psig, according to the MRD). The compressor's flow control uses a spiral valve to allow variable displacement control so that flow can be modulated based on observed demand. Note that the MRD describes the installed compressor as having variable speed control, but the vendor savings sheet describes it as having variable displacement control. A new 2,000 gallon vertical air receiver tank was also proposed to be installed to provide more buffer from any large air demand spikes as well as to provide a more consistent delivery of air to the process. The MRD describes the proposed operating pressure at 125 psi.

Table 6: Proposed Equipment

Equipment	hp	Control	Rated psig	Operating psig	Capacity (acfm)
Air-cooled, oil-injected, rotary screw compressor	300	Variable Displacement	125	125	1,330
2,000 gallon vertical air receiver tank	N/A	N/A	150	N/A	2,000 gallons

Tracking Calculation Methodology

The project documentation did not clearly explain how the tracking savings were estimated; however, the evaluator was able to perform reverse calculations on the tracking savings to determine key input parameter values. The included vendor "System Comparison Report" uses a proprietary savings approach and performs a cost savings calculation rather than an explicit energy savings calculation. The final claimed tracking savings never actually references to the vendor savings calculation, so the evaluator had no obvious way of knowing how the tracking savings were arrived to. Using the claimed tracking savings, the vendor cost savings calculations, and the assumed air demand schedules described in the pre-existing condition section, the evaluator was able to arrive to the savings input values assumed by the vendor savings estimate, as shown in Table 7. The claimed tracking peak demand reduction was calculated by dividing the kWh savings by the estimated annual hours (6,240).

Table 7: Vendor (Tracking) Savings Calculation Input Parameters

Demand Schedule Annual Hours	cfm	Pre-kW	Pre-kWh	Post-kW	Post-kWh	Savings kWh
3,210	1,085	217.3	677,961	197.1	615,051	62,910
1,560	850	214.3	334,323	167.6	261,495	72,828
1,560	675	210.7	328,752	145.7	227,214	101,538
Total: 6,240	**-**	**-**	**1,341,036**	**-**	**1,103,760**	**237,276**

Assessment of Tracking Methodology and Analysis

The assumed savings input values could not be completely assessed by the evaluator because the vendor savings estimate uses a proprietary calculation tool. It appears the three demand schedules were based off the flow data that was included with the vendor savings estimate, but other sources for input values like the assumed base and proposed case compressor load and operating pressure were not available for assessment.

The evaluator believes that metering pre and post kW to cover each period would have given better understanding of the air demand profile of the compressor system. Further, this data should be retained (in its raw form) with the project documentation so that it may be used during program evaluation. The vendor savings estimate should have the energy savings calculation explicitly documented so that the evaluator may link all of the project data sources, input assumptions, and claimed tracking savings values together efficiently. The assumed tracking pre-existing and proposed compressor loads are critical for determining the reasonableness in the tracking savings estimate.

EVALUATION METHODOLOGY

The following sub-sections describe project scope and estimated savings based on observed site conditions. The sub-sections go over the pre-existing (baseline) and proposed operating conditions & equipment informed by the site visit and correspondence with the site contact. The sub-sections also discuss the data collection, analysis, and calculation methodology performed to estimate the evaluated savings.

Measure Verification

All of the proposed energy conservation measures listed in Table 3 were verified to be installed and operating as intended. The tank size could not be directly verified because the nameplate was at the top of the vertical tank. The tank appeared to be of size comparable to a typical 2,000 gallon tank and a cut sheet of the tank was also provided in the project documentation verifying the claimed capacity. The discharge pressure of the compressor was verified to be set and operating at 124 psig.

The baseline condition was largely determined from the tracking project documentation. The facility site contact was unable to verify pre-existing compressor specifications, compressor flow controls, or operating pressure. However, the site contact was able to comment that the pre-existing production process had not changed so was therefore confident that the pre-existing baseline conditions recorded in the project documentation is likely accurate. The site contact (the facility technician) did mention that the pre-existing compressor "ran full out" when the main air demand process was operating, and also that the pre-existing system had a smaller air storage tank (contact was uncertain on size but appeared around 660 gallon as indicated in the documentation) before the 2,000 gallon tank was added. The project documentation did not describe any other supply side equipment, but the site visit observed a pre-existing 1,900 scfm refrigerant air dryer. The MRD mistakenly describes the installed compressor as having variable speed control; the compressor motor does not modulate shaft speed and does not have a variable speed drive.

The exact pre-existing compressor model and specifications could not be verified with the site contact. The only information regarding the pre-existing compressor were (1) the MRD describes as "air-cooled 300-hp XXXXXXXX"; (2) the vendor savings estimate describes as "XXXXXXX with load/unload"; and (3) the pre-installation site inspection form describes as "XXXXXXX – L/NL".[30] Based on this information, the evaluator was led to assume that the pre-existing compressor was an air-cooled, oil-lubricated two-stage 300-hp rotary screw compressor. The exact model number description as documented on the manufacturer website is "XXXXXX 2-stage air-cooled, 300 hp, 140 psig". When the CAGI sheet was obtained for this compressor model, the rated specifications from the CAGI sheet were different from those that were partially provided in the project documentation. The table below shows the difference between the known tracking compressor rated specifications and those used by the evaluator to determine the evaluated savings estimate.

[30] Manufacturer & model names have been withheld in the report

Table 8: Comparison of Tracking and Evaluated Pre-existing Compressor Specifications

Pre-existing Scenario	Pre-existing Compressor Description	Rated Specification	Flow Controls
Tracking	Air-cooled, 300-hp, manufactured in 1995	220.7 kW delivering 1,285 acfm at 125 psig[31]	Load/unload
Evaluated	Two-stage, air-cooled, 300-hp, oil-lubricated	270.4 kW delivering 1,428 acfm at 140 psig	Load/unload

Production data was requested during and after the site visit but the customer eventually claimed that the production data is considered proprietary information and cannot be disclosed in further detail. The site contact commented that 2013 production was "extremely soft...We only ran the XXXXXX process 44 days in 2013. A typical year is 180 – 220 days. We ran only 1or 2 shifts most of the year".[32]

The site contact was able to send the holidays and facility closure periods that were observed in 2013. These dates were incorporated in to the annual savings analysis so that the holiday and closure dates are appropriately binned as "Facility closed or holiday" days.

Table 9 shows the ECMs and respective quantities installed.

Table 9: Proposed versus Implemented ECMs

Implemented ECMs and Modifications	Proposed (tracking)	Implemented (evaluated)
New 300-hp air-cooled rotary screw compressor with variable displacement flow controls	Installed	Installed
2,000 gallon vertical air receiver tank	Installed	Installed
Pre-existing 300-hp air-cooled rotary screw compressor with load/unload controls	Retired & Removed	Retired & Removed

Data Collection

The installed compressor's total packaged input power was metered for the evaluation. The total 3-phase true power of the packaged compressor was metered using a DENT Elite Pro SP logger with split core CTs rated at 600A and 800A (two 600A CTs and one 800A CT). The metering period was approximately 4 weeks (November 21 to December 18, 2013) with a logging interval of 30 seconds. Spot current measurements were taken on each phase to cross verify that the Elite Pro SP loggers were recording power values with reasonable accuracy.

Other data collected during the on site visit included nameplate specifications for the installed compressor, line (discharge) operating pressure, and photographs of the installed ECMs (compressor and tank) and other

[31] Based on reverse analysis of the vendor savings estimate, the pre-existing compressor consumes 217.3 kW delivering 1,085 acfm (84% of rated capacity ~ 1,292 acfm) at an assumed pressure of 125 psig. Using a linear fit, the compressor consumes 220.7 kW delivering 1,285 acfm at 125 psig (based on vendor assumptions)

[32] The name of the production process was suppressed for reporting purposes

supply side equipment (pre-existing air dryer, 660 gallon air tank). Holidays and facility closure periods for 2013 were also collected from the site contact through e-mail correspondence. The typical number of production days was also collected from the site contact (see the *Site Findings* section). The site contact had very limited information regarding the compressed air project under evaluation and the pre-existing compressor & operating conditions.

Table 10: Evaluation Measurement Summary

Time-Series Data Information	
Measured Parameter	Total packaged True Power (kW) on installed 300-hp
Logger Make/Model	DENT Elite Pro SP on installed 300-hp
Transducer/Equipment Type	(2x) 600A & (1x) 800A split-core CTs on installed 300-hp
Installation Location	Installed 300-hp: Local disconnect for packaged unit
Observation Frequency	30 second interval
Metering Period	November 21 to December 18, 2013
Metered By	DNV GL and RISE electrician

Evaluation Savings Analysis

Approximately one month of 30-second interval true power (kW) data was collected for the installed 300-hp compressor. These data were used to directly characterize the air demand and performance of the pre-existing and installed compressed air system.

To begin the savings analysis, performance profiles were next generated for the pre-existing and installed compressor models which are described in the bullets below:

- *INSTALLED 300-hp air-cooled rotary screw compressor with variable displacement flow controls: kW vs. cfm* – The performance curve of the installed compressor was generated using a combination of the AirMaster+ program's compressor performance inventory and the manufacturer's CAGI sheet for the respective model. Since the compressor is variable displacement and not variable speed, the CAGI sheet lists only the full rated packaged power at the delivered capacity and the rated power at zero flow. In order to develop a performance curve for the installed compressor, a similarly sized (in rated hp, acfm, and full load pressure) single-stage rotary screw compressor with variable displacement flow controls was selected from the AirMaster+ compressor database. The default "Manufacturer Compressor Details" were then modified with the specifications found from the manufacturer's CAGI sheet (267.2 kW delivering 1,330 acfm at 125 psig). The full load (cut-in) discharge pressure was then modified from the AirMaster+ default (125 psig for the selected compressor) to the observed discharge air pressure of 124 psig. The AirMaster+ performance profile graph (% full load kW vs. % flow) was then tabulated in 10% flow increments with their corresponding % full load kW values. From this % kW vs. % flow table, a cubic power % vs. capacity % trend was formulated.
- *PRE-EXISTING 300-hp air-cooled rotary screw compressor with load/unload flow controls: kW vs. cfm* – The performance curve of the pre-existing compressor was also generated from two sources:

(1) AirMaster+; and (2) the manufacturer CAGI sheet. The evaluator's determination of the pre-existing compressor was based primarily on the pre-installation site inspection form which describes the compressor ambiguously. The closest corresponding model found on the manufacturer website was a two-stage, air-cooled rotary screw compressor, rated to consume 270.4 kW delivering 1,428 acfm at 140 psig. In order to develop a performance curve for the pre-existing compressor, a similarly sized (in rated hp, acfm, and full load pressure) two-stage rotary screw compressor with load/unload flow controls was selected from the AirMaster+ compressor database. The default "Manufacturer Compressor Details" were then modified with the specifications found on the model's CAGI sheet. The full load shaft power entered in AirMaster+ was adjusted to 349 bhp to reflect the (CAGI) rated full load package power of 270.4 kW. The unloaded power was changed from the default of 89.3 kW to the CAGI rated unloaded package power of 89.8 kW. The full load (cut-in) discharge pressure was then modified from the AirMaster+ default (140 psig for the selected compressor and identical to the pre-existing compressor rated pressure) to the pre-existing discharge air pressure of 125 psig. The AirMaster+ performance profile graph (% full load kW vs. % flow) was then tabulated in 10% flow increments and their corresponding % full load kW values. From this kW vs. flow table, linear power vs. capacity trends (one equating % capacity as a function of % full load kW, and one equating kW as a function of acfm) were formulated.

Installed Scenario

The performance profile described above was used to estimate the flow (cfm) corresponding to each time stamp in the metered (kW) data. If the metered kW value was below the observed unloaded "zero flow" compressor power (59.4 kW, based on observed trends in power data), the corresponding flow rate for that time stamp period was assumed to be zero.

Pre-existing Scenario

To estimate the corresponding performance of the pre-existing compressed air system, the calculated total flow in the installed case was used as the direct input for the pre-existing flow estimate. This step was considered to be reasonable because the base and proposed case air demand scenarios were assumed to be identical. There were no time stamp periods where the calculated installed flow exceeded the maximum capacity of the pre-existing compressor; this was expected because the pre-existing compressor has a larger rated capacity (1,428 acfm based on the manufacturer CAGI sheet) at the observed operating pressure than the installed compressor (rated 1,330 acfm). The pre-existing compressor power corresponding to the pre-existing flow was then calculated using the kW vs. cfm trend for the pre-existing compressor.

The difference between the pre-existing compressor load and the installed compressor load for each time stamp interval is the calculated demand reduction for that time interval. An hourly demand reduction profile for each weekday type (Monday through Sunday plus observed holidays and facility closures) was then developed by averaging the demand reduction corresponding to their respective hour and weekday bins (for a total of 192 bins). The hourly demand reduction profile was then applied to the New York TM Reference Year (1995) 8,760 profile to calculate the annual electricity savings (kWh).[33] The peak demand reduction was calculated by averaging the 4-5 P.M. hour on all non-holiday weekdays based on the NY ISO holiday schedule.

[33] The 1995 reference year was used to standardize the 8,760 hour demand reduction profile

The average weekly compressor savings profile was not normalized to any sort of production data or "typical" annual operating hours. Actual production data was requested from the site contact but was not forthcoming due to the confidential nature of the data. Instead, the site contact stated that 2013 was "extremely soft…we only ran the [main air demand] process…44 days in 2013…a typical year is 180 – 220 days". At the same time, another site contact (the facility technician) had stated that production does not have any seasonal pattern and is very dependent on order rate – the facility produces only after the order is received. The contact also mentioned (anecdotally) that they will be running at a reduced level of production for the foreseeable future. Without being able to reasonably substantiate a "typical" production year, the evaluation team decided to estimate typical annual savings using the observed production levels during the monitoring period (11/21/2013 through 12/18/2013). The weekly compressor savings profile was categorized by day type (Monday through Sunday, and holidays/closures) and by hour (for a total of 192 hourly bins); this profile was then extended to the 1995 calendar year in order to estimate standardized annual savings.

EVALUATION RESULTS

The total evaluated electric savings was determined to be 13,854 kWh with a peak demand reduction of -0.1 kW. The tracking savings are 237,276 kWh and 38.0 kW peak demand reduction. The gross realization rates (GRR) comparing the evaluated savings to the tracking savings are 6% for kWh and -0.2% for kW.

Primary Reasons for Savings Discrepancy

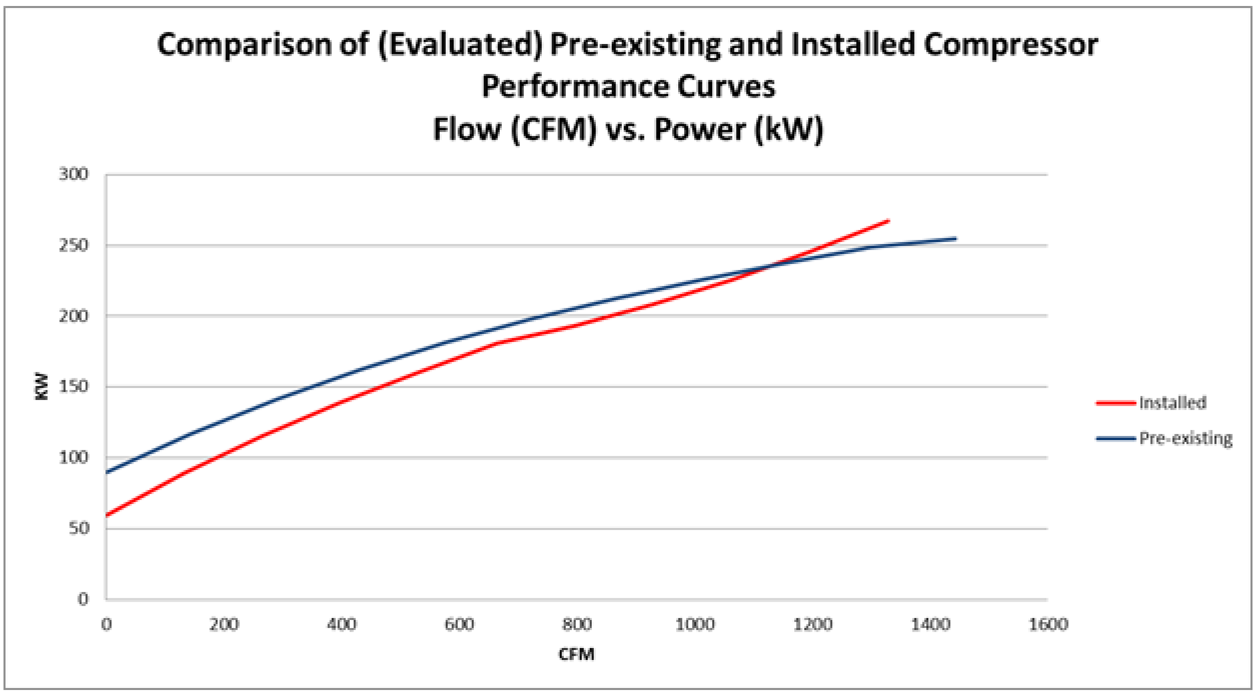
1. *Discrepancy #1 (Compressor Performance)* - The primary reason for discrepancy between the tracking and evaluated savings estimates was the difference between the assumed compressor performance profiles. The tracking savings estimate (documented as a proprietary, hard-coded, vendor savings calculation tool print out) assumes three different average demand schedules and estimates annual hours and compressor load corresponding to the respective schedule's average demand (cfm). The following table presents the tracking and evaluated compressor load assumed for each demand schedule scenario. The average evaluated pre-existing and installed compressor loads were calculated for each average demand schedule by using the corresponding average air demand and the flow (cfm) vs. power (kW) curves developed for the respective compressors. This approach allows a direct comparison between tracking and evaluated compressor performance estimates.

Table 11: Comparison of Tracking and Evaluated Compressor Performances

Demand Schedule Annual Hours	Average Capacity (cfm)	Tracking Pre-existing Compressor kW	Tracking Installed Compressor kW	Tracking Demand Reduction (kW)	Evaluated Pre-existing Compressor kW	Evaluated Installed Compressor kW	Evaluated Demand Reduction (kW)
3,120	1,085	217.3	197.1	**20.2**	232.9	229.7	**3.2**
1,560	850	214.3	167.6	**46.7**	211.9	200.1	**11.7**
1,560	675	210.7	145.7	**65.1**	192.7	178.5	**14.2**

The table above shows that when using the evaluated compressor performance curves the installed compressor operates slightly less efficiently than the pre-existing compressor when air demand is high and only slightly more efficiently when air demand is lower. The visual superimposition (Figure 1 shown below) of the evaluated pre-existing and installed compressor performance curves (cfm vs. kW) illustrates that the pre-existing compressor operates more efficiently when assuming that the supplied air flow from the load/unload compressor follows the optimal performance curve (i.e., the loading/unloading time is ignored). This assumption becomes less reasonable as the frequency of unloading/loading increases. The sampling period of the measured power also has a significant impact on how much error is introduced in to the calculated air flow; having a finer resolution in power measurements increases the accuracy of the calculated installed flow for the corresponding sampling period. The evaluator chose to have a relatively small measurement interval (30 seconds) to increase the accuracy of the calculated flow (and corresponding pre-existing compressor load) values. The differences between compressor performance profiles led to a discrepancy of -186,891 kWh (-79%) and -30 kW (-79%).

Figure 1: Comparison of Evaluated Compressor Performance Curves[34]



2. *Discrepancy #2 (Air Demand Profile and Calculation Method)* – The evaluated method developed hourly load profiles categorized by weekday. This method increases the resolution of the load profile and can increase the accuracy of annual extrapolations when estimating savings. The evaluated metering period also observed air demand that was substantially lower than the demand profiles estimated in the tracking savings calculation. For example, the tracking savings estimate assumes a

34 The pre-existing compressor curve is based on a discharge pressure of 125 psig while the installed curve is based on a discharge pressure of 124 psig

weighted hourly average air demand of 939 cfm. The evaluated air demand schedule has an average hourly average air demand of only 283 cfm. This discrepancy was calculated to be -36,530 kWh (-15%) and -8.2 kW (-21%).

More Comments on Compressor Performance

Based on the information collected from the site contact, the facility's main production process requires high air flow for continuous periods when in production mode. A particular production batch will consume a fairly consistent volumetric rate of air so the compressor often operated near full load. The suspected reason for replacing the pre-existing load/unload compressor with a variable displacement compressor and installing an additional 2,000 gallons of air storage was to reduce the frequency of compressor unloading instances and to generally "ride" the air demand curve with greater accuracy.

The compressor replacement and additional air storage appears to have remedied that issue, based on discussions with the site contact. The installed compressor appears to show savings during these transitional periods where production begins, ends, and transitions in to the next batch. Unfortunately, during high, constant demand periods (which occurred more frequently than the transitional periods), the pre-existing compressor performs more efficiently than the installed compressor. The periods of high demand required the full capacity of the installed compressor (267 kW producing 1,330 acfm at 124 psig); near full capacity the pre-existing compressor can deliver the air more efficiently (254.5 kW producing 1,444 acfm at 125 psig).

SITE ID: DNVCA14

Project Type	Retrofit
Measure Category	Custom Compressed Air

PROJECT DESCRIPTION

This manufacturing facility has completed a compressor retrofit project, the retrofit includes replacing (3) fixed speed rotary screw compressors with (1) VFD compressor. Table 1 summarizes the initial savings estimates prior to the retrofit and the revised or evaluated savings values following project implementation. Table 2 outlines the reasons for discrepancy between the initial and evaluated project savings.

Table 1: Summary of Tracking Savings

Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
Annual Energy Savings (kWh)	256,061	149,763	58%
Peak Summer Demand Reduction (kW)	24.30	35.0	144%

Table 2: Discrepancy Analysis Summary

Discrepancy Factor	kWh	kW
Operating Conditions	Discrepancy #1 (Operating hours): 81,008 kWh, 32%	N/A
Equipment Specifications		
Calculation Method	Discrepancy #2 (Calculation method): 25,290.51 kWh, 10%	Discrepancy #1 (Calculation method): 3.7 kW, 15%
Inappropriate Baseline		

TRACKING SAVINGS

This section summarizes the methodology and assumptions used to estimate the Tracking savings claimed for the project.

Project Description

This project is implemented in an industrial manufacturing facility which has the compressed air system comprising of (3) air compressors. The existing compressors include (2) 25 HP rotary screw compressors operating in load/unload mode and (1) 40 HP rotary screw compressor operating in modulation mode. Total installed compressor capacity is about 419 cfm. The plant operates in two 8-hr shifts, 7am to 12 am five days per week. The current configuration operates (1) compressor unit in modulating mode and the other (2) units operates in load/unload mode. The existing compressors are operated at high discharge pressure and all the compressed air generated at the plant is supplied to the plant shops at around 80 to 125 PSI.

The scope of this retrofit project is to reduce the plant compressed air capacity, and replace the existing compressors with (1) new 67-HP VSD compressors. The new VSD compressor is currently installed as the lead unit, and the plant load can be satisfied by operating only one compressor. The existing (2) 25 HP compressor has been retired and decommissioned. The 40-hp compressor is retained as a back-up unit. Refer Table 3 below for the complete list of EEM's associated with this project.

Table 3: EEM List

EEM Type	Quantity	Size/Notes
Install new VSD compressor	1	67 HP VSD units are installed

Baseline

The plant compressed air equipment includes three compressor units. Based on the information available on the project submittals; the site is equipped with 3 rotary screw compressors. The plant has the following compressors:

Table 4: Pre-Existing Equipment

Unit	HP	Pressure (PSI)	Control	Phase 1 Status
Unit 1	40	125	Modulating	Retained as back-up
Unit 2 & 3	25	145	Load/Unload	Retired

It was mentioned in the project submittal that during the pre-implementation measurement period all the three compressors were operating continuously during the normal production period, Monday through Friday, 7am to 12 am. The actual operating hours would be confirmed during the site visit. Table 5 shows the existing equipment power draw and CFM values.

Table 5: Pre-Existing Equipment Operating Data

Unit	Size (HP)	Capacity (CFM)	PSIG	Measured Amperage
Unit-1	40	160	125	65.6 (Max), 37.2 (Avg)
Unit-2	25	100	145	47.8 (Max), 13 (Avg)
Unit-3	25	100	145	31.0 (Max), 16.2 (Avg)

Proposed Condition

The new 67-HP VFD compressor have been installed, and the (2) existing 25-HP compressors have been retired, and the 40-HP compressor is retained as back-up. The post equipment's configurations and control scheme are summarized in Table 6 below.

Table 6: Post Equipment

Unit	HP	Pressure (PSIG)	Control	Status
New Unit 1	67	100	VFD	Lead Unit
Old Unit 1	40	160	Load/Unload	Back-up unit
Old Unit 1	100	145	N/A	Retired
Old Unit 2	100	145	N/A	Retired

The project submittal states that the VFD units would operate all the time to meet the plant load, and the back-up unit will be operated during maintenance.

Tracking Calculation Methodology

The site energy consultants recorded the plant compressors operational data for a week. The site measurements included the operating compressor amperage reading, airflow, and pressure measurements on all the compressors units. The tracking savings were estimated by the consultants by utilizing the measured plant parameters to establish the plant base-line average energy consumption.

Base-line profile creation: Based on the measured data the average power consumption of the base-line compressor is estimated as 43.9 kW. The base-line energy consumption is calculated based on the average energy consumption and annual operating hours of around 8,400 hours.

Energy Savings:

The VFD savings has been calculated based on an estimated reduction in compressor kW consumption. The estimated average VFD compressor power is 13.5 kW. The energy and demand savings are estimated as follows: (43.9 kW – 13.5 kW) x 8,423 hours/year = 256,061 kWh/yr. The peak demand savings are calculated as 80 % of average kW consumption and that value results as 24.3 kW.

Assessment of Tracking Methodology and Analysis

1. The savings for this project are calculated based on the plant average consumption data.
2. The operating hours used to calculate the energy savings are very high compared to the actual operating hours of 16 hrs/day x 5 days/week x 52 weeks/year
3. The demand savings were calculated as 80 % of the average base-line energy consumption.

EVALUATION METHODOLOGY

The following sub-sections describe project scope and estimated savings based on observed site conditions. The sub-sections go over the pre-existing (baseline) and proposed operating conditions & equipment

informed by the site visit and correspondence with the site contact. The sub-sections also discuss the data collection, analysis, and calculation methodology performed to estimate the evaluated savings.

Measure Verification

The Evaluation team conducted a comprehensive site visit to collect all the relevant name plate/equipment information and other controls information with respect to this project. The evaluator documented the base-line condition based on the information collected during the site visit. The EEM's with respect to this project were completed as proposed in the Tracking documentation. The evaluator collected installed equipment details from the equipment name plate, and other operational data were collected from the installed unit's display screen. The evaluator collected pressure and CFM readings from the site installed flow meters. Table 7 shows the ECMs and respective quantities installed.

Table 7: Proposed versus Implemented ECMs

Implemented ECMs	Proposed (tracking)	Implemented (evaluated)
(2) 25 HP units	Retired & Removed	Retired & Removed
(1) 40 HP unit	Retired & Removed	Retained as back-up
(1) New VFD unit	Installed	Installed

Data Collection

The newly installed compressor was installed with elite pro logger to monitor system operation and true power consumption. Spot power measurements were taken for the newly installed compressor to validate the proposed energy consumption profile. Additional air side data were collected from the site installed flow meters. Table 8 and 9 summarizes the Evaluation team's measurement and verification details.

Table 8: Evaluation Measurement and Verification Summary

Input	Tracking Analysis Variable	Verification Method
Annual Run Hours.	4,300	Elite Logger
Unit HP (1 units)	67 HP	On Site Verification
kW (1 units)	18 - 65.6 kW	Elite Logger
Air Capacity (2 units)	69.8 - 348 CFM	On Site Verification

Table 9: Logger Information

Time-Series Data Information	
Measured Parameter	Total Package True Power (kW) and Amperage (A)
Logger Make/Model	DENT Elite Pro SP kW Logger
Transducer/Equipment Type	100 A CT's (3 units in total)
Installation Location	Outlet of VSD in Power Compartment
Observation Frequency	15 minute interval
Metering Period	5 weeks (12/12/13 – 1/15/14)
Metered By	DNV GL and RISE electrician

Evaluation Savings Analysis

The measured kW data and the air side cfm data were used to create custom kW/cfm curves, and these curves were used to create the proposed case energy consumption model. The user created proposed case energy consumption model were utilized to estimate the plant CFM profile. The evaluator created a spreadsheet based engineering calculation to evaluate savings with respect to this project.

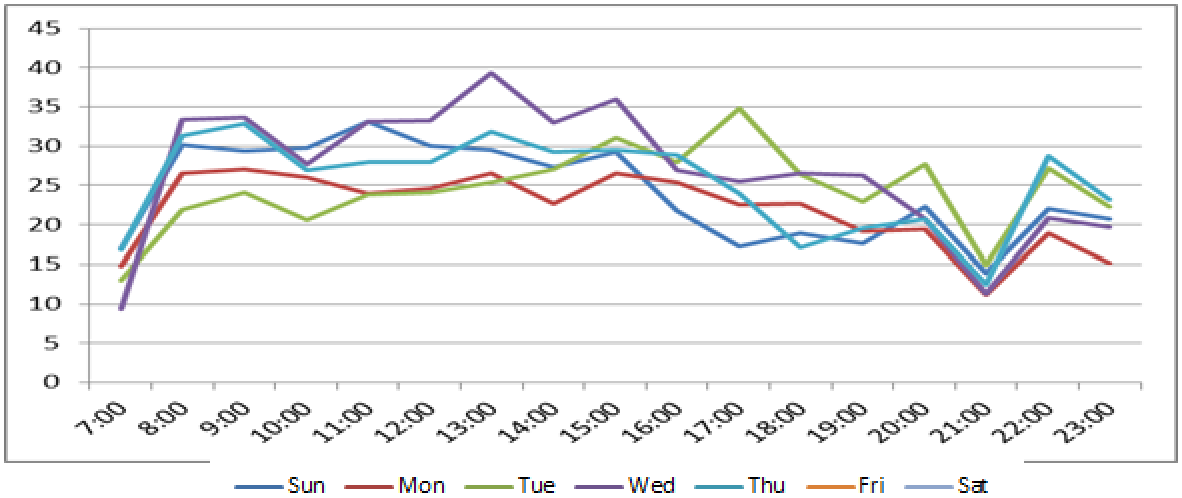
The evaluation engineer utilized the trend data collected during the onsite evaluation to develop an 8,760 compressed air load profile. Using the load profile, the evaluator calculated the pre and post retrofit kW demand using CAGI performance curves.

The peak demand reduction was calculated in compliance with the NYISO, which states that system peaks generally occur during the hour ending at 5pm on the hottest non-holiday weekday. The New York Technical Manual (TM) states that this peak occurs on Friday, July 21, 1995 between 4 P.M. – 5 P.M. However, since compressed air load at this facility is not weather dependent, the peak demand reduction was calculated as the average demand reduction between 4 P.M and 5 P.M on all non-holiday weekdays. The customer mentioned the compressors operate 24/7 throughout the year and the compressors are not shut down during holidays.

Installed Scenario

The evaluator developed an hourly operating profile for the customer's compressed air system. The evaluator utilized the installed compressor time series kW data collected between 12/12/13 – 1/15/14 and compressor performance curves to generate the hourly CFM profiles. CAGI performance data and Generic Curves from the Best Practices for Compressed air Systems were used to create the CFM load profiles. The evaluator then created hourly CFM profile for Normal Day operation. Figure 1 and 2 shows the kW profiles for the VSD compressor. The different color bands indicate the Day Types.

Figure 1: (67) HP VSD unit kW profile.



The evaluator then created a lookup table which listed the average compressed air demand from the trending period based on hour and day type. This lookup table was used to generate an 8,760 load profile by matching each hour and day type throughout the year to the corresponding average compressed air demand in the lookup table. Table 10 summarizes all the compressor curve fit equations created for this project, where 'x' indicates CFM and 'y' indicates kW consumption.

Table 10: Compressor Performance Curve fitting

		CFM	Type	Size	Equation
Proposed System	VFD Unit	65.6	348	VFD	CFM = 5.7927 x kW - 24.314
Base System	Unit1	36.2	179	Modulating	kW = 0.0607 x CFM + 25.847
	Unit 2	23.3	120	Load/Unload	kW = -0.0009x CFM^^{2} + 0.2461x CFM + 6.924
	Unit 3	23.3	120	Load/Unload	kW = -0.0009x CFM^^{2} + 0.2461x CFM + 6.924

The post compressed air system power consumption was determined based on the 8,760 compressed air load profile created by the evaluator. The kW consumption and the performance curves are used to estimate the CFM needed to meet the plant load in the base-case scenario.

Pre-existing Scenario

The evaluator utilized the kW consumption and the performance curves to estimate the CFM needed to meet the plant load.

In the base-case scenario the 40-HP and the (2) 25 HP units operates continuously in modulating mode and load/unload mode respectively to meet the plant load.

The peak demand reduction was calculated in accordance with the guidelines stipulated by the New York Technical Manual (TM), which states that system peaks generally occur between the hours of 4PM and 5PM on non-Holiday weekdays. Therefore, the average demand reduction during these hours served as the basis for the evaluated peak demand reduction.

EVALUATION RESULTS

The difference between the baseline and the installed kW served as the basis for the annual project savings. The total evaluated electric savings were determined to be 149,763 kWh and 35.0 kW peak demand reduction. The tracking savings are 256,061 kWh and 24.3 kW peak demand reduction. The gross realization rates (GRR) comparing the evaluated savings to the tracking savings are 58% for kWh savings and 144% for peak demand reduction.

Primary Reasons for Savings Discrepancy

The discrepancies between the tracking and evaluated savings can be attributed to the following source:

1. Discrepancy # 1 (Operating Conditions) – The primary source of discrepancy between the proposed and evaluated savings is the high operating hours (8,423) utilized in the tracking savings. The project kWh savings was reduced by 81,008 kWh, 32%.
2. Discrepancy #2 (Calculation Method) – The other source of discrepancy is the calculation method. The tracking savings are estimated based on an average plant consumption data, and the evaluated savings are based on actual plant operating data. The project kWh savings was reduced by 24,708.37 kWh, 10 % and 3.6 kW, 15%.

SITE ID: DNVCA15

Project Type	Retrofit
Measure Category	Custom Compressed Air

PROJECT DESCRIPTION

This manufacturing facility has completed a compressor retrofit project, the retrofit includes replacing (2) 100 HP fixed speed rotary screw compressors to (2) 50 HP VFD compressors. Table 1 summarizes the initial savings estimates prior to the retrofit and the revised or evaluated savings values following project implementation. Table 2 outlines the reasons for discrepancy between the initial and evaluated project savings.

Table 1: Summary of Tracking Savings

Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
Annual Energy Savings (kWh)	262,800	284,620	108%
Peak Summer Demand Reduction (kW)	30.0	32.2	107%

Table 2: Discrepancy Analysis Summary

Discrepancy Factor	kWh	kW
Operating Conditions		
Equipment Specifications		
Calculation Method	Discrepancy #1 (Calculation method): 21,820 kWh, 8%	Discrepancy #1 (Calculation method): 2.2 kW, 7%
Inappropriate Baseline		

TRACKING SAVINGS

This section summarizes the methodology and assumptions used to estimate the Tracking savings claimed for the project.

Project Description

This project is implemented in an industrial manufacturing facility which has the compressed air system comprising of (2) air compressors. The existing compressors include (2) 100 HP rotary screw compressors operating in modulating mode. Total installed compressor capacity is about 936 cfm. The plant experiences a constant production load which operates 24/7 throughout the year. The current configuration operates (1) compressor unit in modulating mode and the other unit operates as back-up. The existing compressors are operated at high discharge pressure and all the compressed air generated at the plant is supplied to the plant shops at around 85 to 90 PSI.

The scope of this retrofit project is to reduce the plant compressed air capacity, and replace the existing compressors with (2) new 50-HP VSD compressors. The (2) new 50-HP VSD compressors are currently installed in redundancy mode, and the plant load can be satisfied by operating only one compressor. The existing (2) 100 HP compressor has been retired and decommissioned. Refer Table 3 below for the complete list of EEM's associated with this project.

Table 3: EEM List

EEM Type	Quantity	Size/Notes
Install new VSD compressor	2	50 HP VSD units are installed

Baseline

The plant compressed air equipment includes two compressor units. Based on the information available on the project submittals; the site is equipped with 2 rotary screw compressors. The compressors are manually operated with one compressor in stand-by control mode. The plant has the following compressors:

Table 4: Pre-Existing Equipment

Unit	HP	Pressure (PSI)	Control	Phase 1 Status
Unit 1	100	90	Modulating	Retired
Unit 2	100	90	Modulating	Retired

It was mentioned in the project submittal that during the pre-implementation measurement period one of the 100-HP air compressors were operating, and the other 100-HP unit in the plant was OFF. The submitted project documentation states that the compressor units operate 24/7, 365 days/year totalling 8,760 hours per year. The actual operating hours would be confirmed during the site visit. Table 5 shows the existing equipment power draw and CFM values.

Table 5: Pre-Existing Equipment Operating Data

Unit	Size (HP)	Capacity (CFM)	Avg SCFM	PSIG	Measured Amperage
Unit-1/2	100	468	103	90	123.9 (Max), 80.8 (Avg)

Proposed Condition

The (2) new 50-HP VFD compressors have been installed, and the (2) existing 100-HP compressors have been retired. The post equipment's configurations and control scheme are summarized in Table 6 below.

Table 6: Post Equipment

Unit	HP	Pressure (PSIG)	Control	Status
New Unit 1	50	90	VFD	Lead Unit
New Unit 2	50	90	VFD	Back-up unit
Old Unit 1	100	90	N/A	Retired
Old Unit 2	100	90	N/A	Retired

The project submittal states that the one of the VFD units would operate all the time to meet the plant load, and the other unit will be operated in redundancy mode.

Tracking Calculation Methodology

The site energy consultants recorded the plant compressors operational data for a week. The site measurements included the operating compressor amperage reading, airflow, and pressure measurements on all the compressors units. The tracking savings were estimated by the consultants by utilizing the measured plant parameters to establish the plant base-line average energy consumption. The measured data were not provided as part of the project submittals.

Base-line profile creation: Based on the measured data the average power consumption of the base-line compressor is estimated as 50.2 kW. The base-line energy consumption is calculated as 50.2 kW x 8,760 hours/year = 439,752 kWh/yr

Energy Savings:

The VFD savings has been calculated based on an estimated reduction in compressor kW consumption. The estimated average VFD compressor power is 20 kW. The energy and demand savings are estimated as follows: (50.2 kW - 20 kW) x 8,760 hours/year = 176,952 kWh/yr and 30.2 kW

Assessment of Tracking Methodology and Analysis

1. The savings for this project are calculated based on the plant average consumption data.
2. The project submittals didn't include the measured data.

EVALUATION METHODOLOGY

The following sub-sections describe project scope and estimated savings based on observed site conditions. The sub-sections go over the pre-existing (baseline) and proposed operating conditions & equipment informed by the site visit and correspondence with the site contact. The sub-sections also discuss the data collection, analysis, and calculation methodology performed to estimate the evaluated savings.

Measure Verification

The Evaluation team conducted a comprehensive site visit to collect all the relevant name plate/equipment information and other controls information with respect to this project. The evaluator documented the base-line condition based on the information collected during the site visit. The EEM's with respect to this project were completed as proposed in the Tracking documentation. The evaluator collected installed equipment details from the equipment name plate, and other operational data were collected from the installed unit's display screen. The evaluator collected pressure and CFM readings from the site installed flow meters. Table 7 shows the ECMs and respective quantities installed.

Table 7: Proposed versus Implemented ECMs

Implemented ECMs	Proposed (tracking)	Implemented (evaluated)
(2) 100 HP units	Retired & Removed	Retired & Removed
(2) New VFD units	Installed	Installed

Data Collection

The two new installed compressors were installed with elite pro loggers to monitor system operation and true power consumption. Spot power measurements were taken for all the newly installed compressors to validate the proposed energy consumption profile. Additional air side data were collected from the site installed flow meters. Table 8 and 9 summarizes the Evaluation team's measurement and verification details.

Table 8: Proposed Measurement and Verification Summary

Input	Tracking Analysis Variable	Verification Method
Annual Run Hours.	8,760	Elite Logger
Unit HP (2 units)	50 HP	On Site Verification
kW (2 units)	20 - 46.9 kW	Elite Logger
Air Capacity (2 units)	60 - 235 CFM	On Site Verification

Table 9: Logger Information

Time-Series Data Information	
Measured Parameter	Total Package True Power (kW) and Amperage (A)
Logger Make/Model	DENT Elite Pro SP kW Logger (2 units),
Transducer/Equipment Type	75 A CT's (6 units in total)
Installation Location	Outlet of VSD in Power Compartment
Observation Frequency	15 minute interval
Metering Period	5 weeks (12/10/13 – 1/15/14)
Metered By	DNV GL and RISE electrician

Evaluation Savings Analysis

The measured kW data and the air side cfm data were used to create custom kW/cfm curves, and these curves were used to create the proposed case energy consumption model. The user created proposed case energy consumption model were utilized to estimate the plant CFM profile. The evaluator created a spreadsheet based engineering calculation to evaluate savings with respect to this project.

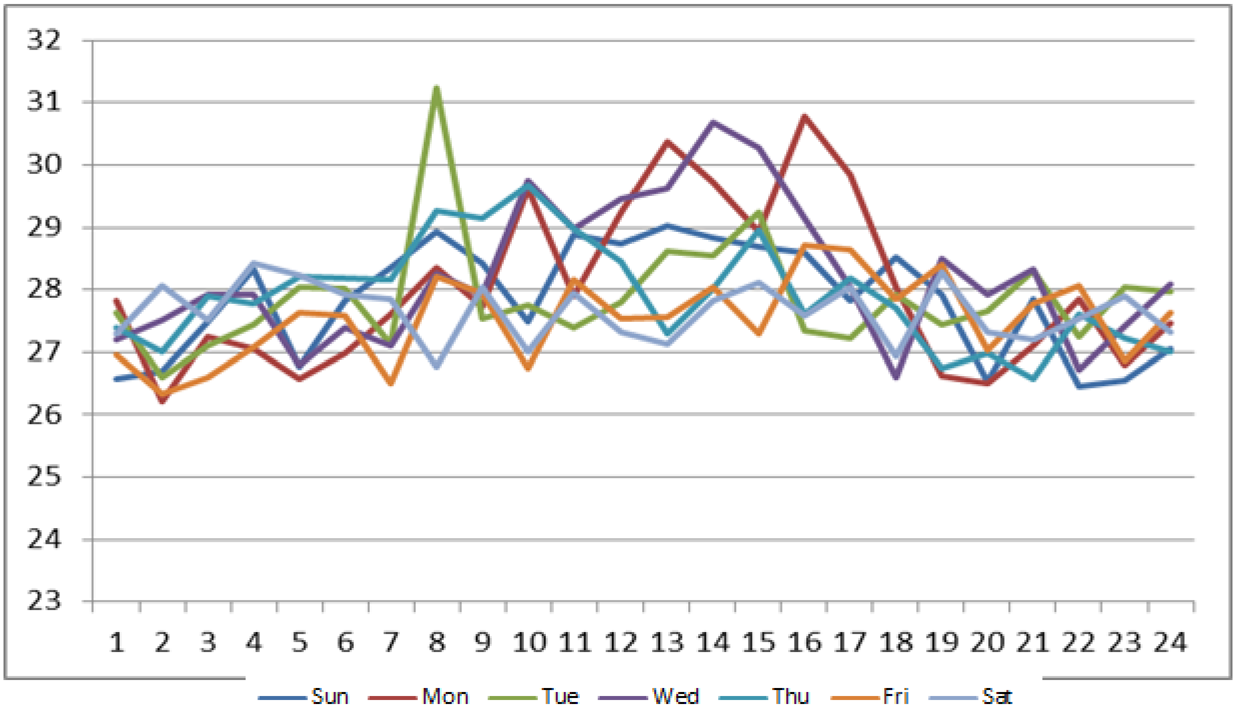
The evaluation engineer utilized the trend data collected during the onsite evaluation to develop an 8,760 compressed air load profile. Using the load profile, the evaluator calculated the pre and post retrofit kW demand using CAGI performance curves.

The peak demand reduction was calculated in compliance with the NYISO, which states that system peaks generally occur during the hour ending at 5pm on the hottest non-holiday weekday. The New York Technical Manual (TM) states that this peak occurs on Friday, July 21, 1995 between 4 P.M. – 5 P.M. However, since compressed air load at this facility is not weather dependent, the peak demand reduction was calculated as the average demand reduction between 4 P.M and 5 P.M on all non-holiday weekdays. The customer mentioned the compressors operate 24/7 throughout the year and the compressors are not shut down during holidays.

Installed Scenario

The evaluator developed an hourly operating profile for the customer's compressed air system. The evaluator utilized the installed compressor time series kW data collected between 12/10/13 – 1/15/14 and compressor performance curves to generate the hourly CFM profiles. CAGI performance data and Generic Curves from the Best Practices for Compressed air Systems were used to create the CFM load profiles. The evaluator then created 2 separate hourly CFM profiles; Normal Day CFM profiles and Holiday CFM Profiles. Figure 1 and 2 shows the kW profiles for the 50 HP VSD compressors. The different color bands indicate the Day Types.

Figure 1: 50 HP VSD unit kW profile.



The evaluator then created a lookup table which listed the average compressed air demand from the trending period based on hour and day type. This lookup table was used to generate an 8,760 load profile by matching each hour and day type throughout the year to the corresponding average compressed air demand in the lookup table. Table 10 summarizes all the compressor curve fit equations created for this project, where 'x' indicates CFM and 'y' indicates kW consumption.

Table 10: Compressor Performance Curve fitting

		CFM	Type	Size	Equation
Proposed System	VFD Unit	235	VFD	50 HP	CFM = 5.0343x + 1.2722
Base System	EP 100	468	Modulation	100 HP	kW = 0.0481x + 53.55

The post compressed air system power consumption was determined based on the 8,760 compressed air load profile created by the evaluator. The kW consumption and the performance curves are used to estimate the CFM needed to meet the plant load in the base-case scenario.

Pre-existing Scenario

The evaluator utilized the kW consumption and the performance curves to estimate the CFM needed to meet the plant load.

In the base-case scenario the 100-HP units operates continuously in modulating mode to meet the plant load. Based on the project submittal it is estimated that only one of the (100) HP compressor will turn ON at a time and hence, only one compressor is programmed to operate in the Analysis.

The peak demand reduction was calculated in accordance with the guidelines stipulated by the New York Technical Manual (TM), which states that system peaks generally occur between the hours of 4PM and 5PM on non-Holiday weekdays. Therefore, the average demand reduction during these hours served as the basis for the evaluated peak demand reduction.

EVALUATION RESULTS

The difference between the baseline and the installed kW served as the basis for the annual project savings. The total evaluated electric savings were determined to be 284,620 kWh and 32.2 kW peak demand reduction. The tracking savings are 262,800 kWh and 30.2 kW peak demand reduction. The gross realization rates (GRR) comparing the evaluated savings to the tracking savings are 108% for kWh savings and 107% for peak demand reduction.

Primary Reasons for Savings Discrepancy

The discrepancies between the tracking and evaluated savings can be attributed to the following source:

1. Discrepancy #1 (Calculation Method) – The primary source of discrepancy between the proposed and evaluated savings is due to the calculation method. The tracking savings are estimated based on an average plant consumption data, and the evaluated savings are based on actual plant operating data. The project kWh savings was increased by 21,820 kWh, 8 % and 2.2 kW, 7%.

SITE ID: DNVCA16

Project Type	Retrofit
Measure Category	Custom Compressed Air

PROJECT DESCRIPTION

This manufacturing facility has completed a compressor retrofit project, and this project includes replacing the existing fixed speed rotary screw compressor with a VFD compressor. The existing compressor was operating in modulating mode to satisfy the plant load. The new VFD compressor is currently installed, and the existing compressor is retired. This project even includes replacing the existing dryer and receiver with higher capacity units. Table 1 summarizes the initial savings estimates prior to the retrofit and the revised or evaluated savings values following project implementation. Table 2 outlines the reasons for discrepancy between the initial and evaluated project savings.

Table 1: Summary of Tracking Savings

Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
Tracking Annual Energy Savings (kWh)	251,410	172,575	69%
Tracking Peak Summer Demand Reduction (kW)	0.0	18.2	N/A

Table 2: Discrepancy Analysis Summary

Discrepancy Factor	kWh	kW
Operating Conditions		
Equipment Specifications		
Calculation Method	Discrepancy #1 (Calculation method): - 78,835 kWh, - 31%	Discrepancy #1 (Calculation method): +18.2 kW, N/A
Inappropriate Baseline		

TRACKING SAVINGS

This section summarizes the methodology and assumptions used to estimate the Tracking savings claimed for the project.

Project Description

This project is implemented in an industrial manufacturing facility which has the compressed air system comprising of (1) 100 HP rotary screw compressor with a 660 gallon receiver and a 450 cfm desiccant dryer. Total installed compressor capacity is about 490 cfm. The plant operates 24 hours, seven days per week. The current configuration operates the 100-HP unit in modulating mode. The existing compressor is operated at high discharge pressure and all the compressed air generated at the plant is supplied to the plant shops at 105 PSI to 115 PSI.

The scope of this retrofit project is to increase the plant compressed air capacity, and to retire the existing compressor, receiver and dryer with a new two stage VFD compressor with a 1,060 gallon receiver, and a 800 cfm desiccant dryer. The new VSD compressor is currently installed along with the new dryer and receiver. The existing compressor, as well as the dryer and the receiver are decommissioned and retired from service. Refer Table 3 below for the complete list of EEM's associated with this project.

Table 3: EEM List

EEM Type	Quantity	Size/Notes
Install new VSD compressor	1	125 HP VSD unit is installed
Install new Dryer	1	800 CFM Dryer installed
Install new Receiver	1	1,060 gallon receiver installed

Baseline

The plant compressed air equipment includes one compressor unit. Based on the information available on the project submittals; the site is equipped with one fixed rotary screw compressor operating in modulating mode. The plant has the following compressor:

Table 4: Pre-Existing Equipment

Unit	HP	Pressure (PSI)	Control	Current Status
Unit 1	100	115	Modulating	Retired.

It was mentioned in the project submittal that during the pre-implementation measurement period the existing compressor was operating continuously during the normal production period, Monday through Sunday, 24 hours a day. The actual operating hours would be confirmed during the site visit. Table 5 shows the existing equipment power draw and CFM values. Please refer Figure 1 and 2 for the plant equipment power and flow measurements provided in the project submittal.

Table 5: Pre-Existing Equipment Operating Data

Unit	Size (HP)	Capacity (CFM)	PSIG	Measured Power
Unit-1	100	490	115	90 kW (Max)

Figure 1: Plant Equipment System Power

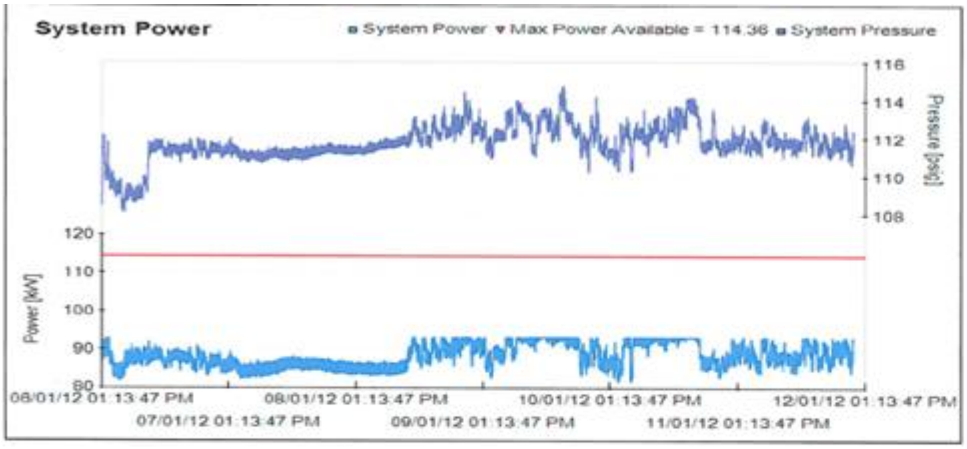
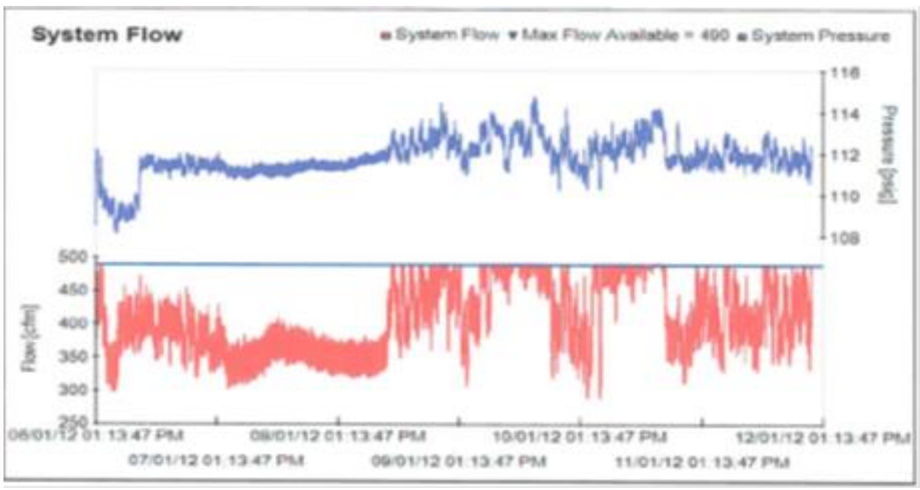


Figure 2: Plant Equipment System Flow



Proposed Condition

The new 125 HP VFD compressor along with the new 1,060 gallon receiver and the 800 CFM dryer have been installed, and the existing compressors, dryer, and receiver have been retired. The post equipment's configurations and control scheme are summarized in Table 6 below.

Table 6: Post Equipment

Unit	HP	Pressure (PSIG)	Control	Status
New Unit	125	100	VFD	Installed
Old Unit	100	115	Modulating	Retired

The project submittal states that the VFD units would operate all the time to meet the varying plant load, including holidays.

Tracking Calculation Methodology

The project submittal mentioned that the site energy consultants conducted a comprehensive site operational data collection for 214 days, June 2012 to December 2012. The site measurements included the operating compressor power reading, airflow, and pressure measurements on the existing compressor unit. The tracking savings were estimated by the consultants by utilizing the measured plant parameters to establish the plant base-line energy consumption.

Base-line profile creation: Based on the plant measured data, the power consumption of the base-line compressor was estimated. The base-line energy consumption is estimated based on the measured compressed air flow demand profiles. The vendor monitored both electrical demand and air flow data, and separated the plant load profile into 10 different load bands. This data was then normalized for the rest of the year, resulting in an over-all operation of 8,760 hours throughout the year.

Energy Savings:

The VFD savings has been calculated based on an estimated VFD compressor performance data and the report didn't provide any source for this performance data. The post-retrofit energy consumption was estimated based on the plant load profile and the VFD compressor performance data.

Assessment of Tracking Methodology and Analysis

1. There was no demand savings submitted with this project.
2. The project submittal didn't provide any details regarding the VFD compressor performance data.

EVALUATION METHODOLOGY

The following sub-sections describe project scope and estimated savings based on observed site conditions. The sub-sections go over the pre-existing (baseline) and proposed operating conditions & equipment informed by the site visit and correspondence with the site contact. The sub-sections also discuss the data collection, analysis, and calculation methodology performed to estimate the evaluated savings.

Measure Verification

The Evaluation team conducted a comprehensive site visit to collect all the relevant name plate/equipment information and other controls information with respect to this project. The evaluator documented the base-line condition based on the information collected during the site visit. The EEM's with respect to this project were completed as proposed in the Tracking documentation. The evaluator collected installed equipment details from the equipment name plate, and other operational data were collected from the installed unit's display screen. The evaluator collected pressure and CFM readings from the site installed flow meters. Table 7 shows the ECMs and respective quantities installed.

Table 7: Proposed versus Implemented ECMs

Implemented ECMs	Proposed (tracking)	Implemented (evaluated)
New Receiver	Installed	Installed
New Dryer	Installed	Installed
(1) New 125 HP VFD unit	Installed	Installed

Data Collection

The newly installed compressor was installed with elite pro logger to monitor system operation, Amperage and true power consumption. Spot power measurements were taken for the newly installed compressor to validate the proposed energy consumption profile. Additional air side data were collected from the site installed flow meters. Table 8 and 9 summarizes the Evaluation team's measurement and verification details.

Table 8: Proposed Measurement and Verification Summary

Input	Tracking Analysis Variable	Verification Method
Annual Run Hours.	8,760	Elite Logger, HOBO Logger.
Unit HP	125 HP	On Site Verification
kW	104 kW	Elite Logger
Air Capacity (4 units)	664 CFM	On Site Verification

Table 9: Logger Information

Time-Series Data Information	
Measured Parameter	Total Package True Power (kW) and Amperage (A)
Logger Make/Model	DENT Elite Pro SP kW Logger
Transducer/Equipment Type	200 A CT's (3 units in total)
Installation Location	Outlet of VSD in Power Compartment
Observation Frequency	15 minute interval on Elite and 1 minute interval on HOBO
Metering Period	5 weeks (1/17/14 – 3/4/14)
Metered By	DNV GL and RISE electrician

Evaluation Savings Analysis

The measured kW data and the air side cfm data were used to create custom kW/cfm curves, and these curves were used to create the proposed case energy consumption model. The user created proposed case energy consumption model were utilized to estimate the plant CFM profile. The evaluator created a spreadsheet based engineering calculation to evaluate savings with respect to this project.

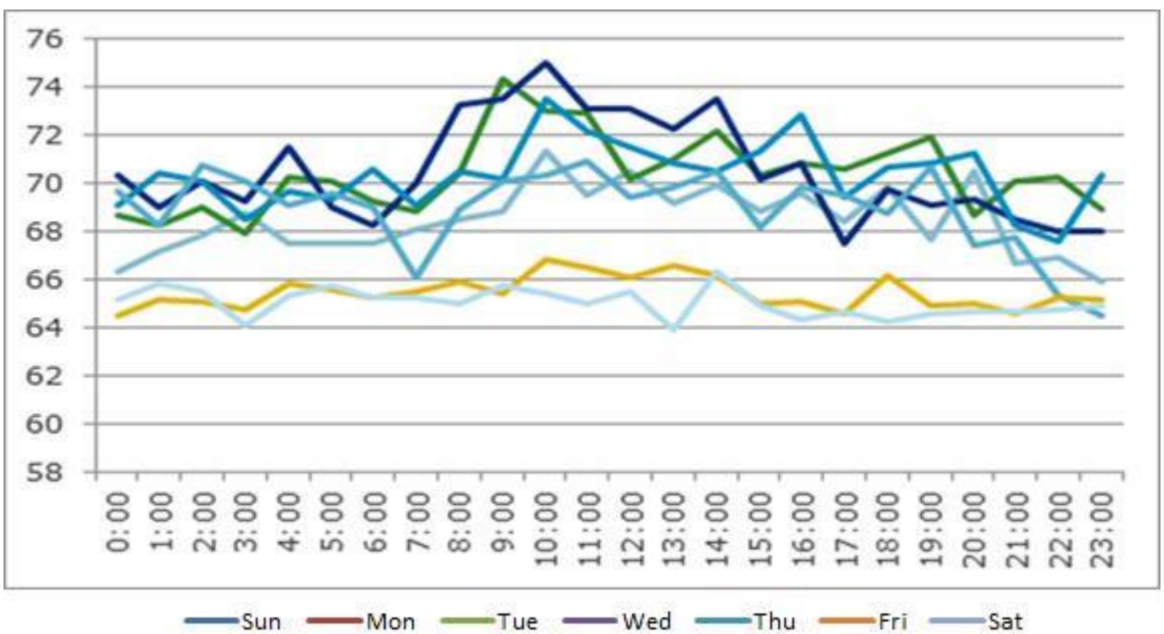
The evaluation engineer utilized the trend data collected during the onsite evaluation to develop an 8,760 compressed air load profile. Using the load profile, the evaluator calculated the pre and post retrofit kW demand using CAGI performance curves.

The peak demand reduction was calculated in compliance with the NYISO, which states that system peaks generally occur during the hour ending at 5pm on the hottest non-holiday weekday. The New York Technical Manual (TM) states that this peak occurs on Friday, July 21, 1995 between 4 P.M. – 5 P.M. However, since compressed air load at this facility is not weather dependent, the peak demand reduction was calculated as the average demand reduction between 4 P.M and 5 P.M on all non-holiday weekdays. The customer mentioned the compressors operate 24/7 throughout the year to meet the plant load and the compressors operate during holidays as well.

Installed Scenario

The evaluator developed an hourly operating profile for the customer's compressed air system. The evaluator utilized the installed compressor time series kW data collected between 1/17/14 – 3/4/14 and compressor performance curves to generate the hourly CFM profiles. CAGI performance data and Generic Curves from the Best Practices for Compressed air Systems were used to create the CFM load profiles. The evaluator then created hourly CFM profile for Normal Day operation. Figure 3 shows the kW profiles for the VSD compressor. The different color bands indicate the Day Types.

Figure 3: (125) HP VSD unit kW profile.



The evaluator then created a lookup table which listed the average compressed air demand from the trending period based on hour and day type. This lookup table was used to generate an 8,760 load profile by matching each hour and day type throughout the year to the corresponding average compressed air demand in the lookup table. Table 12 summarizes all the compressor curve fit equations created for this project, where 'x' indicates kW and 'y' indicates CFM consumption.

Table 10: Compressor Performance Curve fitting

		CFM	Type	Size	Equation
Proposed System	VFD Unit	664	VFD	125	y = -0.0097x2 + 8.1261x - 95.758
Base System		490	Modulating	125	y = 4E-06x2 + 0.0549x + 65.366

The post compressed air system power consumption was determined based on the 8,760 compressed air load profile created by the evaluator. The kW consumption and the performance curves are used to estimate the CFM needed to meet the plant load in the base-case scenario.

Pre-existing Scenario

The evaluator utilized the kW consumption and the performance curves created in the vendor calculation to estimate the base-case energy consumption. The CFM profile estimated in the post-case scenario was used in the base-case flow profile as well.

In the base-case scenario the 100-HP unit operates continuously in modulating mode to meet the plant load.

The peak demand reduction was calculated in accordance with the guidelines stipulated by the New York Technical Manual (TM), which states that system peaks generally occur between the hours of 4PM and 5PM on non-Holiday weekdays. Therefore, the average demand reduction during these hours served as the basis for the evaluated peak demand reduction.

EVALUATION RESULTS

The difference between the baseline and the installed kW served as the basis for the annual project savings. The total evaluated electric savings were determined to be 172,575 kWh and 18.2 kW peak demand reduction. The tracking savings are 251,410 kWh and 0 kW peak demand reduction. The gross realization rates (GRR) comparing the evaluated savings to the tracking savings are 69% for kWh savings and N/A for peak demand reduction.

Primary Reasons for Savings Discrepancy

The discrepancies between the tracking and evaluated savings can be attributed to the following source:

1. Discrepancy #1 (Calculation Method) – The primary source of discrepancy is the calculation method. The post-case energy consumption was estimated based on an estimated VFD compressor performance profile, and there were no details regarding the source of validity of this performance profile. There was no demand savings submitted with this project. The evaluator utilized the monitored kW consumption data to estimate the post-case energy consumption profile, and demand savings are approved for this project. The project kWh savings was reduced by - 78,835 kWh, - 31% and the kW savings was increased by 18.2 kW, N/A.

SITE ID: DNVCA17

Project Type	Retrofit
Measure Category	Custom Compressed Air

PROJECT DESCRIPTION

This project involved the installation of two 94 hp variable speed air compressors to replace two pre-existing inlet modulating air compressors, one 125 hp and the other 75 hp. The existing compressors were retained as backup units in case of emergency. Additionally, two 500 gallon compressed air storage tanks and a pressure/flow controller were installed as part of this project to stabilize the delivered air pressure. However, the savings as a result of the storage tank installation were not incentivized. Therefore, this evaluation does not credit any savings due to the storage tank installation to the project. Table 1 displays the results of the evaluation against the initial tracking savings estimates. Furthermore, Table 2 outlines the primary reasons for discrepancy between the tracking and evaluated savings.

Table 1: Summary of Evaluation Results

Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
Annual Energy Savings (kWh)	270,315	134,281	50%
Peak Summer Demand Reduction (kW)	31.0	8.2	26%

Table 2: Discrepancy Analysis Summary

Discrepancy Factor	kWh	kW
Operating Conditions	Discrepancy #1 (Load Discrepancy): -213,826 kWh; -79%	Discrepancy #1 (Load Discrepancy): -28.9 kW, -93%
Equipment Specifications		
Calculation Method	Discrepancy #2 (Calculation Method): 77,793 kWh, 29%	Discrepancy #2 (Calculation Method): 6.1 kW, 20%
Inappropriate Baseline		

TRACKING SAVINGS

This section summarizes the methodology and assumptions used to estimate the Tracking savings claimed for the project.

Project Description

The customer is a specialty food product manufacturer that receives raw product, processes it, and packages the product on site. The facility replaced its existing compressor plant (two fixed-speed, inlet modulating compressors) with two variable speed compressors. Additionally, two compressed air receivers and a pressure/flow controller were installed as part of this project. The existing compressors were retained as backup units for use in case of emergency. A water cooled, digital scroll refrigerated air dryer was also proposed but was not installed as the payback period did not meet National Grid Requirements to receive incentives. Table 3 outlines the ECM's reported in the tracking data.

Table 3: Tracking ECMs

Description of ECM	Quantity
Install 94 hp Variable Speed Compressor	2
Install 500 Gallon Compressed Air Receiver	2
Install Pressure/Flow Controls	1

Baseline

The existing compressed air plant consisted of the two baseline compressors described in Table 2 and a 720 gallon received located in the compressor room. The compressor plant operated at approximately 120 PSIG to maintain the point-of-use pressure at about 100 PSIG. A minimum pressure of 90 PSIG is required to support critical end uses. Compressors were turned on and off manually and are not centrally controlled. For six days per week, both compressors operated at nearly full load; on Sundays the larger compressor was turned off and the smaller compressor satisfied the full demand. Table 4 outlines the pre-existing equipment specifications.

Table 4: Pre-Existing Equipment

Description	hp	Control	Rated PSIG	Operating PSIG	Capacity (ACFM)	Date of Installation
Air Cooled Rotary Screw	125	Inlet Modulation	125	120	320	2004
Air Cooled Rotary Screw	75	Inlet Modulation	125	120	530	2002

Proposed Condition

As a result of the retrofit, two 94 hp variable speed compressors were installed in place of the pre-existing compressors. The pre-existing compressors became backup units upon installation of the two proposed compressors listed in Table 2. These compressors were controlled to maintain system pressure such that at low demand, a single compressor would operate. At loads greater than 80% of one compressors capacity, the second compressor would come on line to share the load equally. After the second compressor was turned on, it would operate only until flow had returned to less than 70% capacity of a single compressor. The compressors would alternate as lead units to evenly distribute operating hours.

Additionally, a new pressure/flow controller was installed as a result of the retrofit. During the baseline period, the compressed air system did not operate with pressure control. The pressure/flow controller supplies 100 PSIG compressed air to the distribution system. In order to maintain a reasonable pressure drop across the control valve, the installed compressors and compressed air receivers would operate at 110 PSIG. Table 5 outlines the proposed equipment installed as a result of the compressed air system retrofit.

Table 5: Proposed Equipment

Description	HP	Control	Rated PSIG	Operating PSIG	Capacity (ACFM)
Water Cooled Rotary Screw	94	VSD	125	110	420

Tracking Calculation Methodology

The customer's vendor performed a supply side audit of the compressed air system, monitoring supply-side pressure and electrical current to each compressor at 20-second intervals from December 20, 2011 through January 3, 2012. A Fluke 1735 three-phase power logger was used to determine the power factor at the disconnect for each compressor and the dryer. Clamp-on current transducers and data loggers were used to simultaneously measure the current flowing to each compressor. Air flow was not logged, but spot readings of the site's meter showed flows from 275 to over 500 ACFM.

Table 6: Baseline Compressor Performance Data

Equipment	EAQ99Q	EBM99F
Power Factor	0.82	0.80
Max. Demand (kW)	96	58
Avg. Demand (kW)	75	50
Avg. Load (hp)	92.1	61.8
Avg. % Loading	74%	82%

The 336 hours of sub-metering that was performed was then extrapolated to 8,760 hours per year of plant operation. The baseline summary is shown in Table 7.

Table 7: Baseline Compressor Power Consumption

Equipment	EAQ99F	EAQ99Q	Total
Average Air Flow	-	-	175
Max. Demand (kW)	60.1	102.7	-
15 Minute Peak Demand	-	-	135
Avg. Demand (kW)	47.7	65.3	69.1
Avg. Load (hp)	60.2	82.8	143
Avg. % Loading	60.2	82.8	143
Submetering Period			
Total Consumption	8,866	14,348	23,214
Hours of Operation	186	220	336
Annual Operation			
Total Consumption	231,150	374,049	605,199
Hours of Operation	4,843	5,730	8,760

In order to determine the proposed period energy consumption, the vendor utilized the specifications of the proposed compressors to determine a relationship between required air flow rate and electrical demand. This relationship was applied to the air demand profile collected during the sub-metering period. The primary 125 hp unit was assumed to cover all compressed air loads up to 338 CFM, 80% of its rated capacity. For loads above this point, the two compressors were assumed to share the load equally. The decrease in supply side pressure from 120 PSIG to 110 PSIG is assumed to have minimal effects on the total amount of air that must be compressed. A decrease in pressure would normally be expected to decrease demand side leakage and unregulated usage. However, in this case, the pressure decrease is being limited to the supply side; therefore, no change in flow is anticipated.

Table 8: Proposed Compressor Performance Data

Equipment	VSD 1	VSD 2	Total
Average Air Flow	-	-	175
Max. Demand (kW)	66.0	56.5	-
15 Minute Peak Demand	-	-	91
Avg. Demand (kW)	32.7	30.0	38.2
Avg. Load (hp)	41.9	38.3	51
Avg. % Loading	44.5%	38.5%	-
Submetering Period			
Total Consumption	10,993	1,853	12,845
Hours of Operation	336	662	336
Annual Operation			
Total Consumption	285,584	48,299	334,884
Hours of Operation	8,760	1,613	8,760

The estimated energy savings were calculated based on the annual energy consumption from the baseline and proposed periods. The energy savings summary is shown in the table below.

Table 9: Summary of Compressor Energy Savings

	Existing Compressors	Proposed Compressors	Savings
Average Demand	69	38	31
15 Minute Peak Demand	135	91	44
Estimated Annual Consumption	605,199	334,884	270,315

Equations:

1. Individual Load kWh = (kW at Specific Load) x (Number of Hours at Load)
2. kWh Savings = Total System kWh_{Base} – Total System $kWh_{Proposed}$

Assessment of Tracking Methodology and Analysis

1. The energy savings calculations in the tracking analysis were simply based on an average pre and post kW demand multiplied by the number of operating hours. The tracking analysis should have developed a load profile and applied it to the pre-existing and installed compressor performance data to calculate annual energy consumption. The tracking analysis should have used the same air demand both in pre and post scenario to compare the incremental energy savings of the VSD compressors to the constant speed pre-existing compressor.
2. The average load was 175 ACFM during the trending period; however, the tracking analysis stated that during the trending period evaluators saw loads between 200-500 ACFM. By merely taking the

average kW demand, the tracking analysis ignores any seasonality or changes in load that was observed during the trending period.

EVALUATION METHODOLOGY

The following sub-sections describe project scope and estimated savings based on observed site conditions. The sub-sections go over the pre-existing (baseline) and proposed operating conditions & equipment informed by the site visit and correspondence with the site contact. The sub-sections also discuss the data collection, analysis, and calculation methodology performed to estimate the evaluated savings.

Measure Verification

The conditions found on site were similar to those outlined in the tracking analysis. The customer's compressed air system is used to process raw product in the customer's manufacturing facility. During the site visit, the evaluator visually verified the installation of the pressure/flow controller and confirmed the installation of the two 94 hp water-cooled VSD compressors and the two 500 gallon air storage tank. The evaluator also collected the nameplate information of the installed equipment to verify the size and capacity of the equipment. Table 10 shows the ECMs and respective quantities installed.

Table 10: Proposed versus Implemented ECMs

Implemented ECMs	Proposed (tracking)	Implemented (evaluated)
125 hp Inlet Modulation Compressor	Retained as Backup	Retained as Backup
75 hp Inlet Modulation Compressor	Retained as Backup	Retained as Backup
94 hp Variable Speed Compressor (2x)	Installed	Installed
500 Gallon Compressed Air Storage Tank (2x)	Installed	Installed
Pressure/Flow Controller	Installed	Installed

Data Collection

Data loggers were installed on the two 94 hp variable speed compressors for a period of 4 weeks in order to generate an hourly operating profile for the facility. Table 11 outlines the specifications of the data loggers installed during the onsite evaluation

Table 11: Evaluation Measurement Summary

Time-Series Data Information	
Measured Parameter	Total packaged True Power (kW)
Logger Make/Model	DENT Elite Pro SP
Transducer/Equipment Type	(3x) 100A split-core CTs
Installation Location	Outlet of VSD's
Observation Frequency	1 minute interval
Metering Period	4 weeks (Nov 5, 2013 to Jan 3, 2014)
Metered By	DNV GL and RISE electrician

Evaluation Savings Analysis

The evaluation engineer utilized power and current trend data collected during the onsite evaluation along with CAGI performance curves for the newly installed variable speed compressors and AirMaster+ curves for the pre-existing inlet modulating compressors to develop an 8,760 compressed air load profile. The retrofit savings were calculated by applying the as-built 8,760 load profile to the pre-existing compressed air system. AirMaster+ performance curves were subsequently developed for the pre-existing compressed air system. The difference between the pre and post-retrofit 8,760 kW served as the basis for the project savings.

Installed Scenario

In order to calculate project savings, the evaluator first developed an hourly operating profile for the customer's compressed air system. To accomplish this, the evaluator utilized the installed compressor time series kW data collected between 11/5/13 – 1/3/14 and CAGI compressor performance curves which outline the relationship between compressed air demand and power consumption.

To begin the analysis, the obtained CAGI performance curve of the VSD compressor was adjusted to reflect the actual performance of the compressor at 110 psig from the rated operating pressure of 125 psig. This CAGI performance curve (kW vs. ACFM) along with the time series VSD compressor kW was used to estimate the air demand of the compressed air system for each metered interval. Subsequently, this time series air demand data along with the pre-existing compressor performance curve (ACFM vs. kW) was used to estimate the pre-existing kW of each metering interval. The performance curve for the inlet modulation pre-existing compressor system was obtained from the AirMaster+ simulation tool.

Using this relationship, the evaluator was able to generate a lookup table which listed the average compressed air demand from the trending period based on hour and day type. This lookup table was used to generate an 8,760 load profile by matching each hour and day type throughout the year to the corresponding average compressed air demand in the lookup table. The load met by each individual compressor was determined using the sequence of operations collected during the onsite evaluation, which dictated that one compressor would be used to meet all loads up to 80% capacity. Past this point, both compressors would operate and would share the load equally. Lastly, the 8,760 hourly kW corresponding to the individual compressor demand were summed in order to calculate the proposed period annual kWh.

Pre-existing Scenario

The pre-existing compressed air system power consumption was determined based on the 8,760 compressed air load profile generated earlier, and performance curves generated in AirMaster+. The pre-existing system utilizes the pre-existing compressors but maintains the same storage capacity as the proposed period. The 8,760 kW based on the 8,760 compressed air load were then summed in order to calculate the pre-existing annual energy consumption.

The project savings were calculated by taking the difference between the pre and post-retrofit annual energy consumption. Additionally, the summer peak demand reduction was calculated in compliance with the NYISO, which states that system peaks generally occur during the hour ending at 5pm on the hottest non-holiday weekday. The New York TRM states that this peak occurs on Friday, July 21, 1995 between 4 P.M. – 5 P.M. However, since compressed air system operation at this facility is not weather dependent, the peak demand reduction was calculated as the average demand reduction for all non-holiday weekdays between 4 P.M and 5 P.M.

EVALUATION RESULTS

The total evaluated electric savings was determined to be 134,281 kWh and 8.2 kW peak demand reduction. The tracking savings are 270,315 kWh and 31.0 kW peak demand reduction. The gross realization rates (GRR) comparing the evaluated savings to the tracking savings are 0.50 for kWh and 0.27 for kW.

Primary Reasons for Savings Discrepancy

1. *Discrepancy #1 (Load Discrepancy)* – The primary source of discrepancy between the tracking and evaluated project savings is a result of the discrepancy between the tracking and evaluated average compressed air load. The tracking analysis stated that both compressors would only operate in rare instances when the system load surpassed 80% of the installed compressor's rated capacity, roughly 338 ACFM. However, during the trending period, the smallest observed load was approximately 370 ACFM. At loads between 370 ACFM and 420 ACFM both of the installed compressors would have to operate to meet the facility's load, but only compressor #1 would need to operate during the baseline period. The facility operated in this range approximately ¼ of the year, or 2,100 hours which lead to a significant decrease in project realization rate. The result of the load discrepancy is a 213,826 reduction in kWh savings and a 28.9 kW reduction in peak demand savings. The impact of the load discrepancy is -79% on the kWh GRR and -93% on the demand reduction GRR.
2. *Discrepancy #1 (Calculation Method and Operating Conditions)* – Additionally, the evaluator discovered a discrepancies in the project savings due to the calculation method employed in the tracking analysis. The tracking analysis utilizes an average kW demand approach to calculate project savings. However, no load profile was developed which characterizes system operation throughout the year. . The evaluation utilized trend data collected over a period of 4 weeks to determine a system operating profile. The load profile was subsequently used in conjunction with performance curves either generated by AirMaster+ or obtained from CAGI data sheets to determine the pre and post-retrofit annual power consumption. Using this methodology increased the project savings as the average hourly kW reduction [at the tracking average load of 175 ACFM] was found to be 39.7 kW rather than 31 kW calculated in the tracking analysis. This discrepancy lead to an increase in project savings of 77,793 kWh and 6.1 kW, impacts of 29% and 20%, respectively.

SITE ID: DNVCA18

Project Type	Early Replacement
Measure Category	Custom Compressed Air

PROJECT DESCRIPTION

This project involved the retirement of two (2) of the four (4) pre-existing rotary screw compressors and the installation of a 150-HP VSD-controlled rotary screw compressor. Table 1 provides the evaluation results and Table 2 summarizes the discrepancies between the tracking and the evaluated savings.

Table 1: Summary of Savings

Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
Annual Energy Savings (kWh)	593,700	551,590	93%
Peak Summer Demand Reduction (kW)	68.19	63.7	93%

Table 2: Discrepancy Analysis Summary

Discrepancy Factor	kWh	kW
Operating Conditions	Discrepancy #1 (Compressor Performance Profiles): 573,833 or 97% Discrepancy #2 (Air Demand Profile): 227,900 or 38%	Discrepancy #1 (Compressor Performance Profiles): 66.0 or 97% Discrepancy #2 (Air Demand Profile): 26.2 or 38%
Equipment Specifications	N/A	N/A
Calculation Method	Discrepancy #3 (Hourly Air Profile by Day Type): -843,843 or -142%	Discrepancy #3 (Hourly Air Profile by Day Type): -96.7 or -142%
Inappropriate Baseline	N/A	N/A

TRACKING SAVINGS

This section summarizes the methodology and assumptions used to estimate the Tracking savings claimed for the project.

Project Description

Based on the project documentation provided in the tracking documents, the pre-existing compressed air demand was met using four (4) identical 100-HP single-stage oil-injected (and water-cooled) rotary screw compressors using inlet modulation flow controls and sequenced to share the load equally for all demand periods. Details regarding the compressor sequencing and flow controls were not provided in the project documentation. The project intended to retire and discard one of the four pre-existing compressors, and to retire another pre-existing compressor but leave it connected to operate as a backup during maintenance of the main compressors. The two retired 100-HP compressors were replaced by one 150-HP oil-injected (and water-cooled) rotary screw compressor with variable speed (VFD) flow controls that would act as a trim compressor to the two pre-existing 100-HP compressors. The three main compressors (two pre-existing 100-HP compressors and the new 150-HP) would be sequenced such that the two pre-existing compressors would act as base compressors while the new VFD compressor would handle trim demand. If demand fell below a designated threshold (that was not described in the project documents), one of the base compressors would unload and turn off, while the remaining base and trim compressors would handle the reduced demand. Finally, during low demand periods, the pre-existing compressors would unload and the new VFD compressor would handle the entire air demand. A 2,560 gallon air receiver tank and a submersible mass flow meter were also installed with the intention of buffering the supply side from erratic air demand. The tank and flow meter, however, were not claimed in the tracking savings so their gross incremental savings impacts were not evaluated. Table 3 shows the ECMs and respective quantities installed.

Table 3: EEM List

Description of ECM	Quantity
150-HP liquid cooled rotary screw compressor with VFD controls	1
2,560 gallon horizontal air receiver tank	1
Thermal Mass Submersible Flow Meter	1

Baseline

The compressed air system demand was met using four (4) identical 100-HP water-cooled rotary screw compressors. Their operating conditions and general specifications are listed in Table 4.

Table 4: Pre-existing Equipment

Equipment	HP	Control	Rated PSIG	Operating PSIG	Capacity (ACFM)
Water-cooled, oil-injected single-stage, rotary screw compressor	100	IM w/ blowdown	100	100	490
Water-cooled, oil-injected single-stage, rotary screw compressor	100	IM w/ blowdown	100	100	490
Water-cooled, oil-injected single-stage, rotary screw compressor	100	IM w/ blowdown	100	100	490
Water-cooled, oil-injected single-stage, rotary screw compressor	100	IM w/ blowdown	100	100	490

The total rated system capacity was 1,960 ACFM and the pre-existing sequencing was described as “load sharing” in the savings calculations. The pre-existing demand schedule and compressor sequencing was modelled in the savings analysis such that the four compressors were always loaded, with all four compressors loaded at 36% capacity (706 ACFM system total) during the lowest demand period. During the highest demand period, all four compressors are estimated to be 72% loaded (1411 ACFM system total). The compressors' manufactured dates were documented as 1978, 1979, and 1990. According to the project documentation, the pre-existing compressors were all operating adequately; however, the pre-installation site inspection form mentions that there was "inadequate air pressure" and the minimum air pressure on the demand side furthest from the compressors was observed to be 78 psi (This was also documented as the minimum operating pressure required for the demand side equipment).

The pre-existing supply side of the compressed air system also had a storage capacity of approximately 660 gallons (not including transmission pipe capacity) using a single vertical tank, and a 1,500 CFM capacity refrigerant air dryer.

Proposed Condition

The project proposed to replace two of the four pre-existing compressors with one new 150-HP VFD ("rated 134.7 kW delivering 800 ACFM", per project documentation) water-cooled rotary screw air compressor. The compressor's flow control uses a variable speed drive to modulate flow based on observed demand. The "Minimum Requirements Document" describes the proposed sequence of operation as having the pre-existing 100-HP compressors handling the base load at the lower operating pressure band of 95-100 psi while the new VFD compressor would handle the trim load at the higher operating pressure band of 100-105 psi. A pre-existing 100-HP compressor that was replaced by the new VFD compressor would operate only as backup for periods of maintenance downtime for the primary compressors. The post equipment configurations and control scheme are summarized in Table 5.

Table 5: Post Equipment

Equipment	HP	Control	Rated PSIG	Operating PSIG	Capacity (ACFM)
Existing compressor	100	IM w/ blowdown	100	95 – 100	490
Existing compressor	100	IM w/ blowdown	100	95 – 100	490
(new) Water-cooled, oil-injected rotary screw compressor	*150*	*Variable Speed*	*100*	*100 - 105*	*757*

The project proposed to also have a 2,000 gallon air receiver tank added to the existing tank capacity (to total 2,660 gallons) and an immersible mass flow meter installed downstream of the tanks in order to have better demand side feedback for the trim compressor and sequence logic. Both the air receiver and flow meter were not incentivized or claimed toward program savings – only the compressor replacement savings were considered in the tracking methodology.

Tracking Calculation Methodology

The project documentation did not clearly explain how the tracking savings were estimated, and a couple methodologies and savings estimates were included in the project documentation. These methods included (1) a vendor System Comparison Report using a proprietary savings approach; (2) a workbook summarizing pre- and post-installation metering results and savings estimates; and (3) a separate workbook summarizing savings results based off an "IR Report" (the "IR Report" – a post-installation report - was not included in the project documentation). The methodology and tracking savings values that were chosen for the final tracking savings claim are presented below.

Based on the savings calculation workbook (named “619361_186743_Other_619361 XXXXXXXX CUSTOM COMPRESSOR ENERGY SAVINGS CALCULATIONS-REV0.xls”) that was included in the project documentation compiled by NGRID, the following assumptions were made for savings input values:

- Average pre-existing (baseline) compressor load: 238.7 kW (“From IR Report pg. 4”)
- Operating hours: 8,700 hours (equivalent for the pre-existing and proposed periods). This estimate was based on the facility’s 3-shift schedule (they operate continuously)
- Average System Capacity: 947 CFM (“From IR Report pg. 1”)
- Proposed Specific Compressor Power: 18 kW/100 CFM

The pre-existing annual energy consumption of the compressed air system (2,076,690 kWh) was calculated by multiplying the average compressor load (238.7 kW) by the annual operating hours (8,700). The average compressor load of the proposed compressed air system (170.46 kW) was calculated by multiplying the average system capacity (947 CFM) by the proposed specific compressor power (18 kW/100 CFM). The annual energy consumption of the proposed compressed air system (1,483,002 kWh) was calculated by multiplying the average compressor load (170.46 kW) by the annual operating hours (8,700). The difference between the pre-existing and proposed annual energy consumptions was claimed as the annual energy savings. The difference between the pre-existing and proposed average compressor loads was claimed as the peak summer demand reduction.

Assessment of Tracking Methodology and Analysis

The assumed savings input values could not be sufficiently assessed by the evaluator because the IR Report was not available for review. Still, a discrepancy was discovered between the average pre-existing compressor load value (238.7 kW) used in the tracking savings calculation and the average pre-existing compressor load as observed in the pre-installation meter data (313.56 kW), which was included in the project documents. The final savings claim reflected in the tracking data did not use the pre- and post-M&V data to true up the estimated savings. The pre and post-installation metering periods each lasted approximately 7 days and measured either true power (kW) or current (amperage, A) of all the compressors to quantify the average compressor load for each scenario. Since these data were actual power/current measurements as opposed to assumed load values derived from the manufacturer specifications they should have been used to true up the assumed savings input values in the final claimed savings calculation; however, the lack utilizing these data could have been a decision made by the program implementer to remain conservative (the post-installation data and savings methodology using that M&D data showed higher savings than the pre-implementation claim) in their savings estimate. While using the post-installation M&V data would have increased the accuracy of the estimated compressor load profiles, the calculation methodology that utilized these M&V data only used single value average compressor loads (one for pre-existing, one for proposed) to estimate annual savings. Without a comprehensive methodology to incorporate varying air demand and corresponding compressor loads, the value of the M&V meter data decreases and may even increase perceived discrepancy between the tracking and evaluated savings estimates.

EVALUATION METHODOLOGY

The following sub-sections describe project scope and estimated savings based on observed site conditions. The sub-sections go over the pre-existing (baseline) and proposed operating conditions & equipment informed by the site visit and correspondence with the site contact. The sub-sections also discuss the data collection, analysis, and calculation methodology performed to estimate the evaluated savings.

Measure Verification

All of the proposed energy conservation measures listed in Table 6 were verified as having been installed and operating as intended. The project documentation, in particular the Minimum Requirements Document" and the post-installation site inspection form, incorrectly listed the air receiver tank capacity as 2,000 gallons. The installed tank capacity was observed to be 2,560 gallons. This is in agreement with the tank description in the project invoice documents.

Table 6 shows the ECMs and respective quantities installed.

Table 6: Proposed versus Implemented ECMs

Implemented ECMs	Proposed (tracking)	Implemented (evaluated)
150-HP VFD compressor	Installed	Installed
2,560 gallon vertical air receiver tank	Installed	Installed
Thermal Mass Submersible Flow Meter	Installed	Installed
(2) pre-existing 100-HP load/unload compressors	Retired & Removed	Retired & Removed

The specific compressor sequencing logic was indeterminable because the site contact did not have familiarity around that component. However, based on the proposed sequence operation and what was observed in the meter data (see the Evaluation Methodology section below for more detail), it appears that the proposed sequence logic was implemented successfully. Additionally, only two pre-existing 100-HP compressors were observed during the site visit. The remaining "backup" 100-HP compressor was not observed to be in the compressor room. The site contact was not aware of any other compressors besides the three that were observed (two pre-existing 100-HP compressors and the new 150-HP compressor) by the evaluator during the site visit.

The discharge (line) pressure for the 150-HP compressor was observed to be steady at 95 PSIG. The discharge (line) pressure for one of the base 100-HP compressors was observed to be steady at around 95 PSIG (the compressor uses an analog gauge).

When queried about possible production or compressed air demand seasonality, the site contact claimed that the facility experiences very consistent production which could be verified using a full (2013) year of flow trend data that was available from the facility. That data was collected by the evaluator but was ultimately used as a qualitative sanity check on flow estimations and as a means to support the air demand schedule developed from evaluation M&V data.

Data Collection

Two compressors were metered for the evaluation: (1) "compressor #1" – a pre-existing 100-HP compressor; and (2) "compressor #2" – the new 150-HP VFD compressor. The total package 3-phase true power of each compressor was metered using DENT Elite Pro SP loggers with split core CTs rated at 150A and 200A, respective to the compressors mentioned above. The metering period was approximately 4 weeks (November 21 to December 19, 2013) with a logging interval of 30 seconds. Spot power measurements were taken on each phase to verify that the Elite Pro loggers were recording power values with reasonable accuracy.

Other data collected during the on site visit included nameplate specifications for the metered compressors, line (discharge) pressures for the metered compressors, photographs of the installed ECMs (compressor, tank, and flow meter), and a spot flow measurement from the submersible flow meter. Additional 15-minute interval flow data covering the metering period and 30-minute flow data for the entire 2013 year were also collected from the site's energy management system. The flow data were generated from the submersible flow meter that was installed as part of the evaluated project. It is believed by the evaluator that the trended flow data was recording inaccurately high flow readings because most of the flow values exceeded the total rated system capacity. As an alternative utilization, the flow data was used as a sanity check against the calculated compressor flows and to estimate an annual air demand shape based on the 4 weeks of collected power data.

An internet search was conducted to obtain CAGI or product data specification sheets for the pre-existing and proposed compressors. The manufacturer specifications for the 100-HP compressor could not be obtained directly; referenced values (500 ACFM; 110 BHP) were taken from an internet source to estimate the pre-existing compressors' rated capacity and load. Default AirMaster+ motor efficiencies and performance curves were then used to supplement the referenced compressor specifications.

The site contact had very limited information regarding the compressed air project under evaluation, the pre-existing operating conditions, and the current operating sequence for the compressors. Table 7 summarizes the Evaluation team's measurement and verification details.

Table 7: Logger Information

Time-Series Data Information	
Measured Parameter	Total packaged True Power (kW) on pre-existing 100-HP Total packaged True Power (kW) on new 150-HP
Logger Make/Model	DENT Elite Pro SP on pre-existing 100-HP DENT Elite Pro SP on new 150-HP
Transducer/Equipment Type	(3x) 150A split-core CTs on pre-existing 100-HP (3x) 200A split-core CTs on new 150-HP
Installation Location	100-HP: Power compartment in packaged unit 150-HP: Upstream of VFD in power compartment in packaged
Observation Frequency	30 second interval
Metering Period	November 21 to December 19, 2013
Metered By	DNV GL and RISE electrician

Evaluation Savings Analysis

Approximately one month of time-series true power (kW) data was collected for one of the two 100-HP base compressors (labelled "Compressor #1" by the facility) and for the new 150-HP compressor (labelled "Compressor #2"). These data were used to directly characterize the air demand and performance of the pre-existing and installed compressed air system.

To begin the savings analysis, the metered data were re-sampled from 30-second to 5-minute intervals for ease of processing but also because of the observed consistent air demand and subsequent compressor load. Performance profiles were next generated for the compressor models that were logged:

- INSTALLED 150-HP water-cooled rotary screw compressor with VFD flow controls: kW vs. CFM – This performance curve was generated exclusively from the manufacturer's CAGI sheet for the respective model. Since the compressor is variable-speed, the CAGI sheet lists multiple capacities and their respective packaged input power values at the rated outlet pressure (100 psi in this case). A manufacturers cut sheet was also obtained (from the project documentation) to determine the installed compressor's capacity (CFM) at the observed discharge pressure of 95 psi. Based on the site contact interview, this operating pressure (of 95 psi) remains steady throughout facility operation. A linear power (kW) vs. capacity (CFM) trend was then formulated using these CAGI and cut sheet performance data.
- PRE-EXISTING 100-HP water-cooled rotary screw compressor with inlet modulation with blow down flow controls: kW vs. CFM – This performance curve was generated from two sources: (1) AirMaster+; and (2) an internet source (airbestpractices.com) referencing the manufacturer rated specifications (110 BHP and 500 ACFM). The lack of a CAGI sheet or other primary manufacturer cut sheets was primarily due to the age of this compressor model. This particular model was manufactured around 30 years ago; thus, technical sources were very limited and the site contact could not find any original cut sheet documentation for the pre-existing compressors. In order to develop a performance curve for the 100-HP compressor, a similarly sized (in rated HP, ACFM, and full load pressure) single stage rotary screw compressor with inlet modulation with blowdown flow controls was selected from the AirMaster+ compressor database. The default "Manufacturer Compressor Details" were then modified with the specifications found from the internet source (110 BHP and 500 ACFM). The AirMaster+ performance profile graph (% full load kW vs. % flow) was then tabulated in 10% flow increments and their corresponding % full load kW values. From this kW vs. flow table, cubic power vs. capacity trends (one equating % capacity as a function of % full load kW, and one equating kW as a function of ACFM) were formulated.

Installed Scenario

The performance profiles described above were then used to estimate the flow (CFM) corresponding to each time stamp in the metered (kW) data. Compressor #3, the 100-HP base compressor that was not metered, had its flow corresponding to each time stamp in the metered data estimated by comparing the measured power of the metered base and trim compressors to the trended flow data collected from the facility's EMS. If the trended flow and measured base compressor power were above a particular threshold (more than 1,000 SCFM and more than 80 kW, respectively), compressor #3 flow was set equal to the metered base compressor flow. If the trended flow and measured trim compressor power were below a particular threshold (less than 1,000 SCFM and less than 110 kW, respectively), compressor #3 was assumed to be unloaded and off with zero flow. The logic behind this flow assignment for compressor #3 is supported by the observations that: (1) the metered base compressor (compressor #1) operated at a near constant load during the entire metering period (varied between 84.9 - 86.5 kW); and (2) the trended flow data, although questionable in its accuracy, showed consistently high flow rates during the entire metering period (average varied between 1,303 – 1,705 SCFM), suggesting that both base compressors (base compressors #1 and #3 have 500 ACFM rated capacity) were operating at near constant load while the trim compressor (compressor #2, the VFD compressor) modulated load to match air demand observed by the flow meter. The assigned power (kW) corresponding to each time-stamped flow value assigned to compressor #3 was either: (1) equal to the power measured for compressor #1 for the respective time-stamp (compressor #3 equally loaded to compressor #1); or (2) equal to zero to model the compressor unloaded and off during the 5 minute interval. Unloading times were not considered because the expected frequency is negligibly low compared to the air demand and corresponding loaded runtimes at this facility.

Pre-existing Scenario

To estimate the corresponding performance of the pre-existing compressed air system, the calculated total flow in the installed case was used as input to a logic query to designate the appropriate load sharing sequence for the pre-existing scenario. The load sharing logic assumed that all four identical, pre-existing compressors equally share the total load down to 40% of their individual flow capacities. Once that threshold is reached, one compressor is unloaded while the loaded compressors take up the remaining load. This sequencing logic continues until air demand can be met by a single pre-existing compressor.

Using this load sharing sequence for the pre-existing controls, the calculated total flow in the installed case is equally spread among the pre-existing compressors that are loaded based on the sequencing logic. The power corresponding to the shared load is then calculated using the kW vs. CFM trend for the 100-HP compressor. The difference between the pre-existing compressor load and the installed case compressor load for each time stamp interval is the calculated demand reduction for that time interval. An hourly demand reduction profile for each weekday type (Monday through Sunday and observed NY ISO holidays) was then developed by averaging the demand reduction corresponding to their respective hour and weekday bins. The hourly demand reduction profile was then applied to the New York TM Reference Year (1995) 8,760 profile to calculate the annual electricity savings (kWh). The peak demand reduction was calculated by averaging the demand reduction estimate for every 4 P.M. – 5 P.M. hour on non-holiday week days (Monday through Friday) in the 8,760 profile. The full year extrapolation of the hourly demand reduction profile that was developed using the 4 weeks of compressor power data was considered to be reasonable because of the facility’s non-seasonal production rates. In 2013, the facility’s compressed air demand varied between 1,458 and 1,582 CFM (with a 24-hour production), based on trend data pulled from the facility’s flow meter.

EVALUATION RESULTS

The total evaluated electric savings was determined to be 551,590 kWh and 63.7 kW peak demand reduction. The tracking savings are 593,700 kWh and 68.2 kW peak summer demand reduction. The gross realization rates (GRR) comparing the evaluated savings to the tracking savings are 93% for kWh and 93% for kW *[0 – Savings Summary]*.

Primary Reasons for Savings Discrepancy

1. *Discrepancy #1 (Compressor Performance Profiles):* The evaluated compressor performance profiles were based on compressor model CAGI and cut sheets. By using the evaluated performance profiles in the tracking savings methodology (i.e., every variable in the tracking savings method stayed the same except the compressor performance was based on the evaluated findings) the average demand reduction increased from 68.2 kW to 134.2 kW between the pre-existing and proposed scenarios. This adjustment to the tracking savings method increases the peak demand reduction and annual energy savings by 573,833 kWh and 66.0 kW or 97% kWh and kW).
2. *Discrepancy #2 (Tracking Savings Method Using Evaluated Compressor Performance + Observed Average Capacity):* The evaluated average air demand was much higher (1,405 CFM) than the assumed tracking average air demand (947 CFM). The reason for the tracking calculation using a low air demand schedule could not be completely assessed. The site contact claimed that production air demand is relatively constant; this comment was supported with the full 2013 year of air flow trend data showing little fluctuation in demand (average of 1,527 CFM, with min/max of 1,458/1,582 CFM). The site contact was a relatively new employee and was not employed at this facility when the project was implemented so could not comment on the air demand of the plant in 2010. Using the higher average air demand increases the average compressor demand reduction from 134.2 kW to 160.4 kW. This discrepancy led to an increase to annual energy savings and peak demand reduction by 227,900 kWh and 26.2 kW or 38% kWh and kW.
3. *Discrepancy #3 (Evaluated Savings Method – Uses Observed Hourly Schedule & Optimal Load Sharing Sequence):* The evaluated savings method uses a more robust calculation method than the tracking estimate. The evaluated method uses a 24-hour load profile for each weekday, developed from approximately one month of power data for two compressors. The evaluated savings method also assumes an optimal load sharing sequence in the pre-existing scenario. The optimal load sharing sequence unloads top loaded compressors when they reach a minimum of 40% rated capacity. The tracking method assumes an air demand schedule and load sharing sequencing order such that all four compressors remain loaded at all times. The tracking method also uses single average compressor loads for the pre-existing and proposed cases and multiplies those loads by 8,700 operating hours to calculate the pre-existing and proposed energy usages. Comparing to the *Discrepancy #2* savings iteration, the energy savings and peak demand reduction decreased by -843,843 kWh and -96.7 kW or -142% kWh and -142% kW.

More Comments on Discrepancy #2

The tracking average pre-existing compressor load was estimated to be 238.7 kW while the evaluated average pre-existing compressor load was calculated to be 339.0 kW. The tracking average installed compressor load was estimated to be 170.46 kW while the evaluated average installed compressor load was calculated to be 275.9 kW. The difference between the tracking average pre-existing and installed compressor load is 68.24 kW while the difference between the evaluated average pre-existing and installed compressor load is 63.1 kW. These differences between the tracking and evaluated pre-existing and installed average compressor load appear to arise from the differences in estimated air demand schedules. While the actual tracking savings calculation does not have documentation that explains how the pre-existing average compressor demand was calculated, the compressor vendor estimates ("619361_180165_Vendor Energy Savings Analysis_XXXXXXXX Detail.pdf") three distinct "demand shifts" that are evenly distributed among the annual operating hours (2,912 hours each shift for an annual operating hours total of 8,736 hours). The calculation estimates that during a typical year, the facility experiences average capacity shifts of 1411 CFM, 1000 CFM, and 706 CFM. The evaluator believes that these vendor-estimated shifts underestimate the actual conditions of the facility which appears to have a relatively constant air demand that is higher than the average capacity of the three demand shifts (1039 CFM used in the vendor estimate; 947 CFM assumed for the tracking savings). This view is supported by the calculated flow rate using the power meter data; which show the average flow is approximately 1,405 CFM. This discrepancy between the tracking and evaluated average calculated flow could explain why the tracking pre-existing compressor load was significantly lower than the evaluated estimate. Similar conclusions can be drawn for the discrepancy between the tracking and evaluated installed average compressor load.

Peak Demand Discrepancy

The tracking peak summer demand reduction was calculated by dividing the annual energy savings by the assumed annual operating hours (i.e., average demand reduction). This estimate has no real association with the facility's compressor demand that is coincident with the NY ISO peak definition. The evaluated peak demand reduction estimate was calculated by averaging the demand reduction during the 4 – 5 P.M. hour on non-holidays weekdays. Whenever possible, program implementers should base peak summer demand reduction on actual regional "peak" definitions. When metering cannot coincide with peak periods, generalizations can be made to assume the coincidental weekdays and hour during the metering as the peak period[35]

[35] Under certain circumstances where the load would not be substantially affected by weather i.e., process and schedule dominant

SITE ID: DNVCA19

Project Type	Retrofit
Measure Category	Custom Compressed Air

PROJECT DESCRIPTION

This manufacturing facility has implemented multiple measures in Phase-1 and Phase-2 compressed air assessment projects. Phase-1 includes reduction of plant supply pressure and controlling it to an optimal pressure setting, and operating the air compressors at a lower discharge pressure. In addition to these measures, the plant compressed air distribution is planned to be divided into a 2-pressure system: low pressure (LP @ 50 PSI) and high pressure (HP @ 95 PSI), and provide trim capacity to the plant air system and waste heat recovery as well.

The site plans to operate the plant compressors efficiently and shut down few existing compressors. Phase-2 measures are implemented and incentivized through a different project application (#719621). Phase-2 measures include replacing (2) LP compressors and (1) HP compressor. Table 1 summarizes the initial savings estimates prior to the retrofit and the revised or evaluated savings values following project implementation. Table 2 outlines the reasons for discrepancy between the initial and evaluated project savings.

Table 1: Summary of Tracking Savings

Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
Tracking Annual Energy Savings (kWh)	471,584	450,230	95%
Tracking Peak Summer Demand Reduction (kW)	56.5	54.2	96%

Table 2: Discrepancy Analysis Summary

Discrepancy Factor	kWh	kW
Operating Conditions		
Equipment Specifications		
Calculation Method	Discrepancy #1 (Calculation method): -21,354 kWh, -5%	Discrepancy #1 (Calculation method): -2.30 kW, -4%
Inappropriate Baseline		

TRACKING SAVINGS

This section summarizes the methodology and assumptions used to estimate the Tracking savings claimed for the project.

Project Description

This project is implemented in an industrial manufacturing facility that has the compressed air system configured with interconnected compressed air distribution piping, which connects air compressors in four different locations. Two air compressors are in the Plant 2 compressor room, and one compressor each is located in the Boiler Room, Maintenance Shop, and Rod Room. Total installed compressor capacity is about 1,359 cfm.

All compressors are interconnected into a single common distribution system. System growth and changes over time have resulted in sections of piping that cause sustained pressure gradients, which affect compressor control and overall system efficiency. The plant experiences a constant production load that operates 24/7 throughout the year and low production load during holidays. The current configuration operates four compressor units of varying sizes at full load capacity and one unit operates as the trim unit and is operated in Load/Unload capacity control setting. The existing compressors are operated at high discharge pressure and all the compressed air generated at the plant is supplied to the plant shops at around 95 to 100 PSI.

The scope of this retrofit project is to reduce the plant air demand and system optimization. The Customer has reduced the supply pressure to the plant shops to the lowest optimal pressure and has programmed to operate the air compressor units at lower discharge pressure. The plant compressor air distribution system has been divided in to an LP and HP pressure system. This assessment even includes providing efficient trim capacity control and heat recovery of compressed air waste heat.

Table 3 provides a complete list of EEM's associated with this project.

Table 3: EEM List

EEM Type	Quantity	Size/Notes
Supply pressure reduction.	Multiple	95 PSI to 50 PSI
Lower Compressor discharge pressure.	Multiple	Operate compressors to produce air at 50 PSI
Implement (2) pressure system	N/A	Convert plant load to HP and LP.
Turn off/Retire compressor units as applicable	2	(2) 75 HP compressor units are retired.

Baseline

The plant compressed air equipment includes five compressors units. Based on the information available on the project submittals, the site is equipped with four oil-free two-stage air cooled compressors and one single-stage lubricant-injected rotary screw air compressor. The compressors are manually operated with other compressors in stand-by control mode. The plant has compressors as shown in Table 4.

Table 4: Pre-existing Equipment

Model	HP	Pressure (PSI)	Control	Phase 1 Status
Unit 1	75	125	ON/OFF	Retired
Unit 2	75	125	ON/OFF	Retired
Unit 3	75	125	ON/OFF	Retained in Load-unload mode
Unit 4	75	125	Load/Un-load	Retained.
Unit 5	50	125	ON/OFF	Retained in Load-unload mode

It was mentioned in the project submittal that during the pre-implementation measurement period five air compressors were operating in total; out of these, four units were operating at full load capacity and one unit in the plant was operating with Load / Unload capacity control as the trim compressor. The submitted project documentation states that the compressor units operate 24/7, 350 days/year, totalling 8,400 hours per year. The actual operating hours would be confirmed during the site visit. Figure 1 shows the site-monitored compressor operation on 7/30/2010.

Figure 1: Compressor Power Draw Data

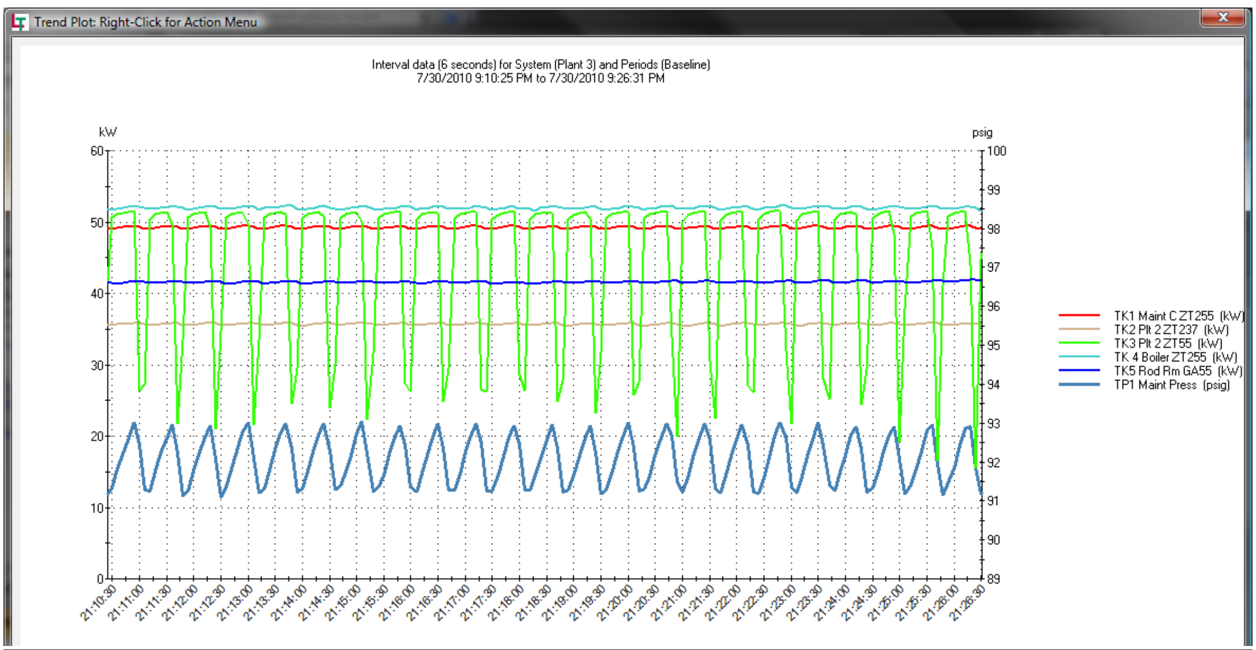


Table 5 shows the existing equipment power draw and measured CFM values.

Table 5: Pre-existing Equipment Operating Data

Size (HP)	Capacity (CFM)	SCFM	PSIG	Measured Power
75	320	280	125	41
75	282	220	125	52
75	282	206	125	49
75	290	235	125	15-51
50	185	179	125	35
	1359	**1120**		207

Proposed Condition

The customer has reduced the supply pressure on multiple plant shops and has identified the units which require HP compressed air and LP compressed air. This has led to the conversion of the plant air distribution system to LP and HP distribution system. Figure 2 shows the post plant configuration. The post equipment configurations and control scheme are summarized in Table 6.

Figure 2: Post Air Distribution System Data

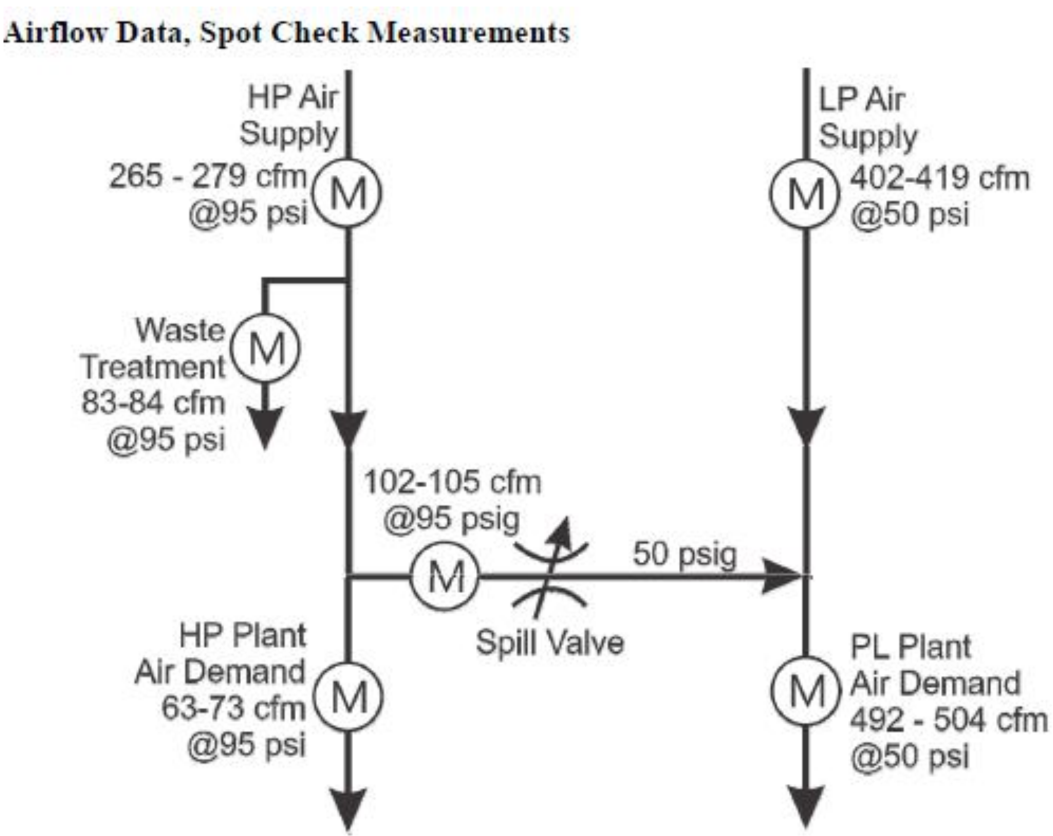


Table 6: Post Equipment

HP	Pressure (PSIG)	Control	Phase 1 Status
75	N/A	N/A	Retired
75	N/A	N/A	Retired
75	50	Load/Un-load	Retained on LP side
75	100	Load/Un-load	Retained on HP side
50	50	ON/OFF	Retained on LP side

Two of the existing compressors have been retired, and one 75 hp unit and 50 hp unit have been programmed to produce compressed air at 50 PSI. The other 75 hp unit has been programmed to produce compressed air at 100 PSI.

Air Compressor Sequencing and Control: The project submittal states that manual compressor controls as well as compressor sequencing has been implemented as follows:

- Normal plant operation: During the fully loaded operation, the two LP System (50 psig) air compressors will provide 404 cfm of delivered airflow. The HP System will require between 165 cfm and 225 cfm of air supply (80 -100 cfm HP to LP spill flow; 45 cfm HP Plant Air @ 85 psig, and 40 to 80 cfm of air demand in Waste Treatment).

Tracking Calculation Methodology

The site energy consultants conducted a comprehensive performance measurement during the normal plant operational period (July 29th – August 4th, 2010). The site measurements included all the operating compressor kW consumption, airflow measurements on all the compressors units. The tracking savings were estimated by utilizing the AirMaster+ software, and the measured plant parameters to establish the plant operational base-line. The measured data were not provided as part of the project submittals. The project report only included the screen shot of the savings estimate from the AirMaster+ software.

Base-line profile creation: The measured kW and CFM points were input in to the AiRMaster+ software to create an annual operational profile; this included 2 day types; regular and weekend profiles including 300 production days, 50 weekend days, and 15 holidays.

Measurements were taken by operating the existing compressors at various pressure points to record the compressor kW/CFM values at 100 PSI and 50 PSIG operating pressure.

Pressure reduction savings: The savings with respect to this measure are modelled by reducing air demand by an average of 270 cfm during all operating periods in AIRMaster+ software using the present single Plant air system.

Operating compressors at low pressure: This measure is modelled in the AiRMaster+ software using improved end use efficiency module. For this measure, the new compressor's performance data is added to the compressor inventory module with the compressor shut-off in the baseline profile module. Then in the EEM module, the existing air compressors are shut down and the low pressure compressor is marked as operating.

Assessment of Tracking Methodology and Analysis

- The site measured compressor flow and kW measurements were recorded for less than 2 weeks, and this trended data is considered inadequate to accurately capture the facility's entire load profile and seasonal/holiday load profiles. However, it was confirmed by the Customer that the plant load remains constant during the regular operating days; and the plant operates at a low load during holidays.
- The project documentation only included the screen shot of the savings estimate from the AirMaster+ software.

EVALUATION METHODOLOGY

The following sub-sections describe project scope and estimated savings based on observed site conditions. The sub-sections go over the pre-existing (baseline) and proposed operating conditions & equipment informed by the site visit and correspondence with the site contact. The sub-sections also discuss the data collection, analysis, and calculation methodology performed to estimate the evaluated savings.

Measure Verification

The Evaluation team conducted a comprehensive site visit to collect all the relevant name plate/equipment information and other controls information with respect to this project. The evaluator documented the base-line condition based on the information collected during the site visit. The EEMs with respect to this project were completed as proposed in the Tracking documentation. The evaluator collected installed equipment details from the equipment name plate, and other operational data were collected from the installed unit's display screen. The evaluator collected pressure and CFM readings from the site installed flow meters. The site has already implemented Phase-2 energy measures; this included removing all the existing compressors and replaced them with higher efficient compressors; Refer Application # 719621 for Phase 2 measures.

Data Collection

The new compressors that were installed as part of the Phase-2 retrofit project were installed with elite pro loggers to monitor system operation and true power consumption. The existing/back-up compressors were installed with a HOBO micro station logger. Spot power measurements were taken for all the existing and newly installed compressors to validate the baseline and proposed energy consumption profile. Additional air side data were collected from the site installed flow meters. Table 7 and Table 8 summarize the Evaluation team's measurement and verification details.

Table 7: Proposed Measurement and Verification Summary

Input	Tracking Analysis Variable	Verification Method
Annual Run Hours.	8,400	Elite Logger
HP Baseline (3 new units)	40,50,100 HP	On Site Verification
kW (3 new units)	22.3, 24, 75 kW	Elite Logger
Amperage (existing unit)	60 to 70 A	HOBO Logger
Air Pressure (2 lines)	95, 50 PSI	On Site Verification
Air Capacity (multiple units)	178, 228, 331 CFM	On Site Verification

Table 8: Logger Information

Time-series Data Information	
Measured Parameter	Total Package True Power (kW) and Amperage (A)
Logger Make/Model	New Units: DENT Elite Pro SP kW Logger (3 units), Back-up unit: Onset HOBO Logger (1 unit)
Transducer/Equipment Type	New Units: (3) 50 A, (3) 100 A , and (3) 150 A CTs (9 units in total) Back-up unit: (1) 100 A CT.
Installation Location	Outlet of VSD in Power Compartment
Observation Frequency	15 minute interval
Metering Period	5 weeks (12/11/13 – 1/16/14)
Metered By	DNV GL and RISE electrician

Evaluation Savings Analysis

The measured kW data and the air side cfm data were used to create custom kW/cfm curves, and these curves were used to create the proposed case energy consumption model. The user created proposed case energy consumption model were utilized to estimate the plant CFM profile. The evaluator created a spreadsheet based engineering calculation to evaluate savings with respect to this project.

The evaluation engineer utilized the trend data collected during the onsite evaluation to develop an 8,760 compressed air load profile. Using the load profile, the evaluator calculated the pre and post phase 2 retrofit kW demand using performance curves generated using baseline trend data for the pre-existing compressors and CAGI performance curves for the installed compressor.

The peak demand reduction was calculated in compliance with the NYISO, which states that system peaks generally occur during the hour ending at 5pm on the hottest non-holiday weekday. The New York Technical Manual (TM) states that this peak occurs on Friday, July 21, 1995 between 4 P.M. – 5 P.M. However, since compressed air load at this facility is not weather dependent, the peak demand reduction was calculated as the average demand reduction between 4 P.M and 5 P.M on all non-holiday weekdays. The customer provided the following holiday information. The customer mentioned that during holidays; the plant is still operating at a reduced load.

Holiday List	Start Date	Full List	Time	ON/OFF
New Year	1/1/1995	1/1/1995		OFF
		1/2/1995	7:00 AM	ON
Easter	4/15/1995	4/15/1995	11:00 PM	OFF
		4/16/1995		OFF
		4/17/1995	7:00 AM	ON
Memorial Day	5/29/1995	5/29/1995	7:00 AM	
		5/30/1995	7:00 AM	ON
Independence Day	7/3/1995	7/3/1995	7:00 AM	OFF
		7/4/1995		
		7/5/1995		
		7/6/1995		
		7/7/1995		
		7/8/1995		
		7/9/1995		
		7/10/1995	7:00 AM	ON
Labor Day	9/4/1995	9/4/1995	7:00 AM	OFF
		9/5/1995	7:00 AM	ON
Thanksgiving	11/23/1995	11/23/1995	7:00 AM	OFF
		11/24/1995		
		11/25/1995		
		11/26/1995	7:00 AM	ON
Christmas	12/24/1995	12/24/1995	7:00 AM	OFF
		12/25/1995		
		12/26/1995		
		12/27/1995		
		12/28/1995		
		12/29/1995		
		12/30/1995		
		12/31/1995		

The evaluator developed an hourly operating profile for the customer's compressed air system. The evaluator utilized the installed compressor time series kW data collected between 12/11/13 – 1/16/14 and compressor performance curves to generate the hourly CFM profiles. CAGI performance data and Generic Curves from the Best Practices for Compressed air Systems were used to create the CFM load profiles. The evaluator then created 2 separate hourly CFM profiles; Normal Day CFM profiles and Holiday CFM Profiles. Figure 3 and Figure 4 show the kW profiles for the 100 HP VSD compressors during regular working days and holidays respectively. The different color bands indicate the Day Types.:

Figure 3: 100 HP VSD Unit kW Profile; Normal Operation

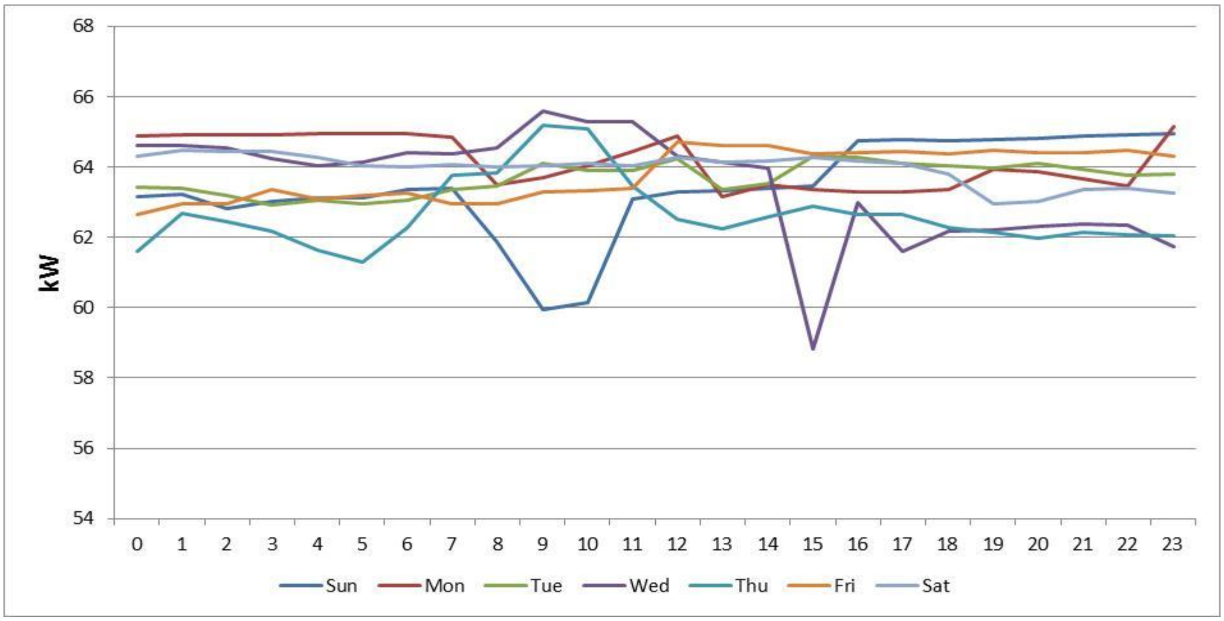
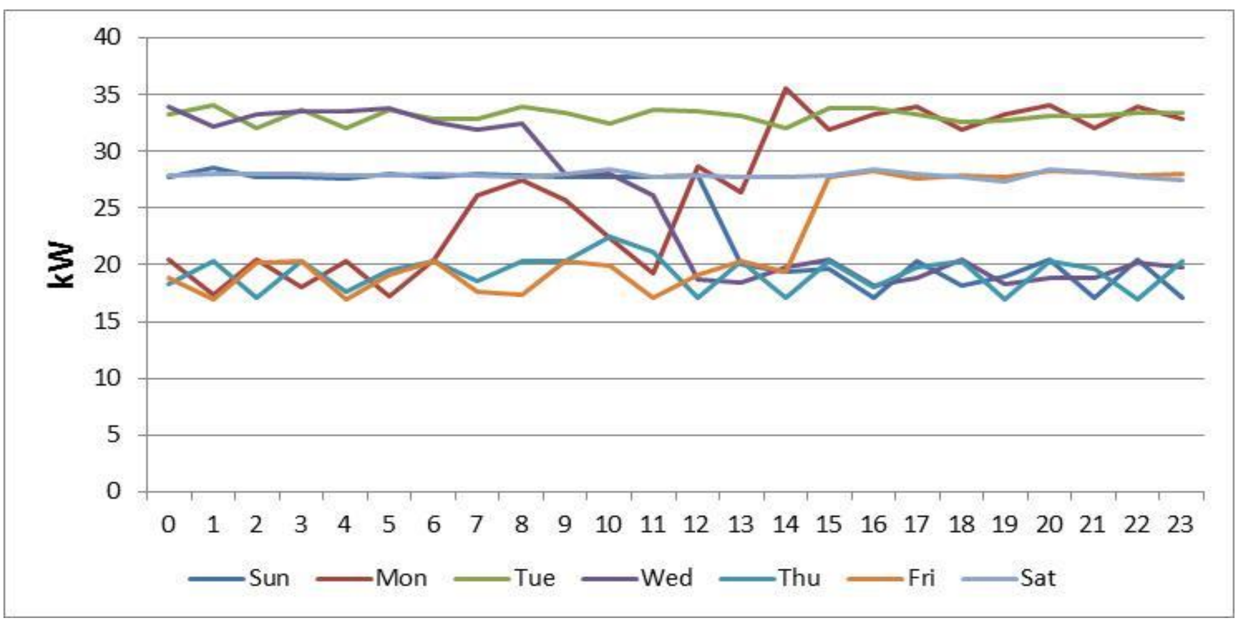


Figure 4: 100 HP VSD Unit kW Profile; Holiday Operation



The evaluator then created a lookup table which listed the average compressed air demand from the trending period based on hour and day type. This lookup table was used to generate an 8,760 load profile by matching each hour and day type throughout the year to the corresponding average compressed air demand in the lookup table. Table 10 summarizes all the compressor curve fit equations created for this project, where 'x' indicates CFM and 'y' indicates kW consumption.

Table 9: Compressor Performance Curve Fitting

Setup	Model	CFM	Type	Size	Equation
Phase -2 system	KNWAO-D/XL	331	HP	100 HP	y = 0.1828x + 6.0375
	KNWA0-A/L	225	LP	40 HP	y = 0.1389x + 8.2683
	KNWAO-B/L	178	LP	50 HP	y = 0.1632x + 12.326
Phase-1 system	ZT 237	226	LP	50 HP	$y = -0.0005x^2 + 0.2103x + 9.245$
	ZT 255	326	LP	75 HP	$y= -0.0004x^2 + 0.2173x + 15.573$
	ZT 55	326	HP	75 HP	$y = -8E\text{-}05x^2 + 0.1869x + 15.742$

The phase-1 compressed air system power consumption was determined based on the 8,760 compressed air load profile created by the evaluator. The kW consumption and the performance curves are used to estimate the CFM needed to meet the plant load in the phase-1 scenario.

For the LP system; ZT 255 unit is set to operate as the lead unit and ZT 237 acts as the lag unit. The ZT 55 unit provides all the required HP CFM.

Pre-existing Scenario

The evaluator utilized the compressor power draw and CFM measurements provided by the site compressed air assessment team, and used this data to develop an average kW/cfm inclusive for all the base-case compressor units. Refer to Table 10 for base-case compressor operation and average power draw.

Table 10: Base-case Compressor Performance Data

Model	Size (HP)	Capacity (CFM)	SCFM	PSIG	Measured Power	kW/SCFM	Operation
GA55	75	320	280	125	41	0.15	ON/OFF
ZT-255-100	75	282	220	125	52	0.24	ON/OFF
ZT-255-100	75	282	206	125	49	0.24	ON/OFF
ZT55	75	290	235	125	30	0.13	Load/Unload
ZT-237	50	185	179	125	35	0.20	ON/OFF
		1359	**1120**		**207**	**0.19**	

In the base-case scenario the ZT 55 unit operates in load/unload mode and it consumes 15 kW in un-load mode and 51 kW fully loaded. The evaluator modified the kW/CFM to 0.13 based on an average power draw of 30 kW throughout the year. The average plant kW/CFM value is 0.19; and total plant measured compressed air load is 1120 CFM.

Phase-2 to Phase-1 CFM profile modification

In phase-2 the max CFM load is 701 CFM, and the max CFM load in base-case is 1120. The evaluator utilized the phase-2 CFM profile and used a ratio to estimate the base-case CFM profile. The maximum CFM for base-case profile is 1120 and the minimum CFM is locked at 399 CFM; this is based on the assumption that at-least (2) compressor units will be operating during holidays. The user-estimated CFM profile and the plant measured average power draw are used to estimate the base-case energy consumption.

The peak demand reduction was calculated in accordance with the guidelines stipulated by the New York Technical Manual (TM), which states that system peaks generally occur between the hours of 4PM and 5PM on non-Holiday weekdays. Therefore, the average demand reduction during these hours served as the basis for the evaluated peak demand reduction.

EVALUATION RESULTS

The difference between the baseline and the installed kW served as the basis for the annual project savings. The total evaluated electric savings were determined to be 450,230 kWh and 54.2 kW peak demand reduction. The tracking savings are 471,584 kWh and 56.5 kW peak demand reduction. The gross realization rates (GRR) comparing the evaluated savings to the tracking savings are 95% for kWh savings and 96% for peak demand reduction.

Primary Reasons for Savings Discrepancy

The discrepancies between the tracking and evaluated savings can be attributed to the following source:

2. Discrepancy #1 (Calculation Method) – The primary source of discrepancy between the proposed and evaluated savings is due to the calculation method. However, the discrepancy between the tracking savings and the approved savings are very low. The project kWh savings was reduced by 21,354 kWh, -5% and 2.30 kW, -4%.

SITE ID: DNVCA20

Project Type	Normal Replacement and Add-On
Measure Category	Custom Compressed Air

PROJECT DESCRIPTION

This project involved the retirement of one (1) pre-existing air-cooled 200-hp oil-injected rotary screw compressor with inlet modulation controls and one (1) pre-existing air-cooled 150-hp oil-injected rotary screw compressor with load/unload controls. These retired compressors were replaced with one (1) air-cooled 335-hp oil-free rotary screw compressor with variable speed (VFD) flow controls. The project scope also installed a new flow controller, one (1) 1,550 gallon vertical air receiver tank, and one (1) 620 gallon vertical air receiver tank. The program claimed savings with a normal replacement baseline reference meaning that the pre-existing compressors were not used in the savings analysis. Rather, a comparable baseline compressor (a 300-hp oil-injected single-stage rotary screw compressor with inlet modulation controls) was chosen to estimate savings compared to the proposed compressor. Also, only the compressor replacement savings were claimed so this report evaluated the gross impact of the compressor replacement and only verified the installation and operation of the flow controller and additional air receiver tanks. Table 1 provides the gross impact results while Table 2 provides a summary of the discrepancy analyses.

Table 1: Summary of Evaluation Results

Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
Annual Energy Savings (kWh)	432,889	187,783	43%
Peak Demand Reduction (kW)	49.4	-5.2	-10%

Table 2: Discrepancy Analysis Summary

Discrepancy Factor	kWh	kW
Operating Conditions	Discrepancy #1 (Different average air demand): -238,092 (-55%) Discrepancy #2 (Different performance curves): 29,705 (7%)	Discrepancy #1 (Different average air demand): -27.2 (-55%) Discrepancy #2 (Different performance curves): 3.4 (7%)
Equipment Specifications	N/A	N/A
Calculation Method	Discrepancy #3 (Different calculation method and operating conditions): -36,719 (-8%)	Discrepancy #3 (Different calculation method and operating conditions): -30.8 (-62%)
Inappropriate Baseline	N/A	N/A

TRACKING SAVINGS

This section summarizes the methodology and assumptions used to estimate the Tracking savings claimed for the project.

Project Description

The customer had a compressed air system whose demand was met by one (1) air-cooled 200-hp oil-injected rotary screw compressor and one (1) air-cooled 150-hp oil-injected rotary screw compressor. A backup 100-hp air-cooled rotary screw compressor operated only during maintenance or emergency periods. The facility operates continuously and with relatively consistent demand profiles. It was decided that all of the pre-existing (primary) compressors would be replaced with one (1) new air-cooled, 335-hp oil-free rotary screw compressor with variable speed (VFD) flow controls. The pre-existing primary compressors would be retained for backup use while the pre-existing 100-hp backup compressor would be retired and decommissioned. The project scope also installed a new flow controller (rated to 3,000 SCFM), one (1) new 1,550 gallon vertical air receiver tank, and one (1) new 620 gallon vertical air receiver tank. These additional measures were installed to stabilize capacity, downstream air pressure, and moisture content.

The program implementer used a normal replacement reference baseline to estimate compressor energy savings. The rationale behind selecting a normal replacement baseline was not discussed in the project documentation; however, the *Assessment of Tracking Methodology and Analysis* section speculates why the program implementer chose a normal replacement baseline and assesses the reasonableness of the selection. A 300-hp air-cooled, oil-injected rotary screw compressor with inlet modulation flow controls was chosen as the baseline compressor; this is the reference compressor that is used to estimate savings compared to the proposed 335-hp VFD compressor.

Table 3 shows the ECMs and respective quantities installed.

Table 3: Tracking ECMs

Description of ECM	Quantity
335-hp air-cooled, oil-free rotary screw compressor with variable speed (VFD) flow control	1
1,560 gallon vertical air receiver tank	1*
620 gallon vertical air receiver tank	1*
Flow/Pressure Controller	1*

** These ECMs were mentioned in the Minimum Requirements Document (MRD) – a post-installation project completion form – but their incremental savings were not claimed in the tracking savings.*

Baseline

Based on the pre-implementation site inspection form and savings calculations, the discharge pressure of the pre-existing compressors was 110 psig and the system pressure (downstream of supply-side equipment) was 100 psig. The baseline operating condition was described using only one demand schedule, based on the average flow rate measured during the pre-installation M&V period which took place in February 2011. The selected 300-hp baseline compressor was calculated to have an average power demand of 211 kW (based on an average flow rate of 825 cfm); the demand schedule was assumed to be constant, 168 hours per week, 52 weeks per year (8,736 hours per year). The annual hours of operation were estimated by the program implementer and were based on the typical facility operating hours (operates continuously). The tables below summarize the in situ equipment, reference baseline compressor, and the average demand schedule.

Table 4: Pre-Existing Equipment[36]

Equipment Description	hp	Control	Rated psig	Operating psig	Capacity (acfm)
(Pre-existing) One (1) air-cooled, oil-injected, single stage, rotary screw compressor	200	Inlet modulation	Not provided	110	Not provided
(Pre-existing) One (1) air-cooled, oil-injected, single stage rotary screw compressor	150	Load/unload	Not provided	110	Not provided
(Pre-existing & backup) One air-cooled, oil-injected single stage rotary screw compressor	100	Load/unload	Not provided	Not provided	Not provided
One (1) 1,000 gallon vertical air receiver tank	N/A	N/A	N/A	100	N/A
(BASELINE) One (1) air-cooled, oil-injected rotary screw compressor	*300*	*Inlet modulation with unload*	*125*	*110*	*1314*

[36] The information in this table is based on what information could be collected from the utility project documentation. "Not provided" means that this information was not available in the utility documents or the energy savings assumptions

Table 5: Baseline Compressed Air Demand Schedule

Demand Schedule	CFM	Hours per Week	Hours per year	Baseline Average Power (kW)
Average	825	168	8,736	211

Proposed Condition

The proposed operating conditions used to model the compressor replacement savings uses the same air demand schedule as the baseline scenario, using the new variable speed compressor.

Table 6: Proposed Equipment

Equipment Description	hp	Control	Rated psig	Operating psig	Rated Capacity (acfm)
One (1) air-cooled, oil-free rotary screw compressor	335	Variable Speed (VFD)	125	110	1,341
One (1) 1,560 gallon vertical air receiver tank	N/A	N/A	N/A	N/A	N/A
One (1) 620 gallon vertical air receiver tank	N/A	N/A	N/A	N/A	N/A
Flow Controller	N/A	N/A	Not provided	N/A	3,000 SCFM max

Tracking Calculation Methodology

The tracking calculation methodology used seven (7) days of one-minute interval air flow measurements and the baseline and proposed manufacturer CAGI performance specifications to generate one-minute interval power measurements corresponding to the one-minute average flow values. The average power demand over the 1-week metering period was calculated for both the baseline and proposed compressors and then applied to the estimated operating hours (8,736 hours) to calculate the baseline and proposed annual energy consumption. The difference in annual energy consumption between the baseline and proposed scenario is the project's energy savings. Peak demand reduction appears to have been calculated by the program implementer or technical reviewer because the actual peak demand reduction calculation was not included in the project documentation. The peak demand reduction was calculated by dividing the annual energy savings by 8,760 hours (different from the annual operating hours estimate of 8,736). The incremental savings of the additional air storage tanks and the flow controller were not assessed or claimed by the program nor were savings estimated by the vendor.

The installed compressor system was not monitored for post-implementation M&V; however, it appears based on the Utility documentation that an inspection occurred to confirm that the proposed compressor, receiver tanks, and flow controller were installed.

Assessment of Tracking Methodology and Analysis

The evaluator considered the selected 300-hp baseline compressor to be a reasonable reference compressor to estimate energy savings. The facility requires compressed air during all production periods and needs backup compressors to operate during any downtime (e.g., maintenance) the primary compressors experience. The pre-existing primary compressors (the 200-hp IM compressor and the 150-hp LNL compressor) were still functional but were getting old and were experiencing an increased frequency in downtime. The pre-existing backup compressor (the 100-hp LNL) was also smaller than desired and required modification in production demand while it was operating. Finally, policy changes at the facility required the use of food-grade lubricant for the lubricant-injected compressors or optionally, oil-free compressors. To reduce operating and downtime risk and costs, it was decided by the customer that the pre-existing backup compressor would be scrapped, the pre-existing primary compressors would be retained for backup and a single primary compressor appropriately sized for their typical air demand would be purchased. The customer believed that purchasing an oil-free primary compressor would ultimately save on long term maintenance costs versus a food-grade lubricant-injected primary compressor. Additionally, the customer decided to retain the pre-existing 200-hp and 150-hp primary compressors and have them converted over to food-grade lubricant so that they could be used as backup compressors. This decision was made because the cost estimated for (1) converting these compressors to use food-grade lubricant; (2) the increased maintenance costs due to using food-grade lubricant (i.e., higher PM frequency); and (3) the fact that these compressors would have a much smaller annual run time (i.e., smaller PM costs than previously) operating as backup compressors would be cheaper than the initial cost of purchasing a new backup compressor. Under this context, a normal replacement baseline is a reasonable savings approach because converting the pre-existing compressors to food-grade lubricant and operating them as primary compressors was not an option for the customer, regardless of program influence. Additionally, the baseline compressor was appropriately sized to accommodate the observed pre-existing air demand and has a capacity similar to the installed compressor. While the installed compressor is oil-free, the evaluation determined that the oil-flooded baseline is an acceptable reference because the facility's policy does not require oil-free but rather requires that at least food-grade oil is used.

The claimed tracking savings appears to have collected a reasonable period of flow data to establish an average air demand profile. The instrumentation used to collect the flow data was not documented; this information could be useful during the evaluation period for quality & accuracy assessment. The tracking savings methodology uses single average compressor loads for the baseline and proposed scenarios and extrapolates these values to an entire year to estimate energy savings. Based on the reasonably periodic weekly air profile observed in the pre-implementation flow data, this simplified calculation was an appropriate method but could have been expanded to account for non-periodic variations in the measured air demand. The peak demand reduction calculation should be estimated using the NY ISO definition (non-holiday summer weekdays, 4 – 5 P.M.) whenever possible, rather than averaging the demand reduction over the entire annual operating period as was done for this project. In this project's case, the data format and resolution was available to perform the suggested peak demand reduction calculation.

While this particular project did not have critical issues around project documentation, it is also recommended that future custom compressed air projects retain all data and sources used to arrive to the final claimed tracking savings. This includes e-mail correspondence that may have attached documents or sources, or pre-existing and proposed operating conditions and assumptions.

EVALUATION METHODOLOGY

The following sub-sections describe project scope and estimated savings based on observed site conditions. The sub-sections go over the pre-existing (baseline) and proposed operating conditions & equipment informed by the site visit and correspondence with the site contact. The sub-sections also discuss the data collection, analysis, and calculation methodology performed to estimate the evaluated savings.

Measure Verification

The pre-existing conditions, including actual compressor equipment and specifications, were largely determined from the site contact. The facility site contact (the plant engineer) verified the actual nameplate information of the pre-existing compressors and operating discharge pressures the compressors were operating at (115 psig). The pre-implementation site inspection form had a discrepancy for the pre-existing primary compressor proposed to be replaced. The inspection form had noted that the pre-existing compressor being replaced was 300-hp with inlet modulation control. It was discovered during the site visit that the 300-hp compressor was actually the *normal replacement* baseline compressor and was never actually installed at the facility. The actual pre-existing primary compressors were noted on the site inspection form, but the discrepancy led the evaluator to interpret the pre-existing condition differently than what was discovered during the site visit. When queried on whether production levels had recently changed the site contact could not specifically comment on the pre-existing production levels but thought that production probably increased since the tracking pre-implementation monitoring period in late 2011 because of continual efficiency improvements made to the production line (*not an increase in orders but in an increase in production rate/efficiency)*. This comment was supported by a week-long sample of flow data collected in October 2013 for the installed compressor[37]. The 2013 flow data shows that average and peak air demand increased since the pre-implementation flow data was collected back in February 2011.Figure 1, below, shows a chart of the pre-implementation flow data while Figure 2 shows the post-implementation flow data. The charts demonstrate that the facility's air demand increased since the pre-implementation flow measurement period, with peak air demand increasing from around 1,200 CFM to around 1,300 CFM.

[37] The customer hired a consultant to conduct a compressed air survey on the installed system. During the site visit, the customer informed the evaluator about the air survey and after the site visit, the customer e-mailed the survey summary to the evaluator

Figure 1: Pre-implementation Air Demand Profile

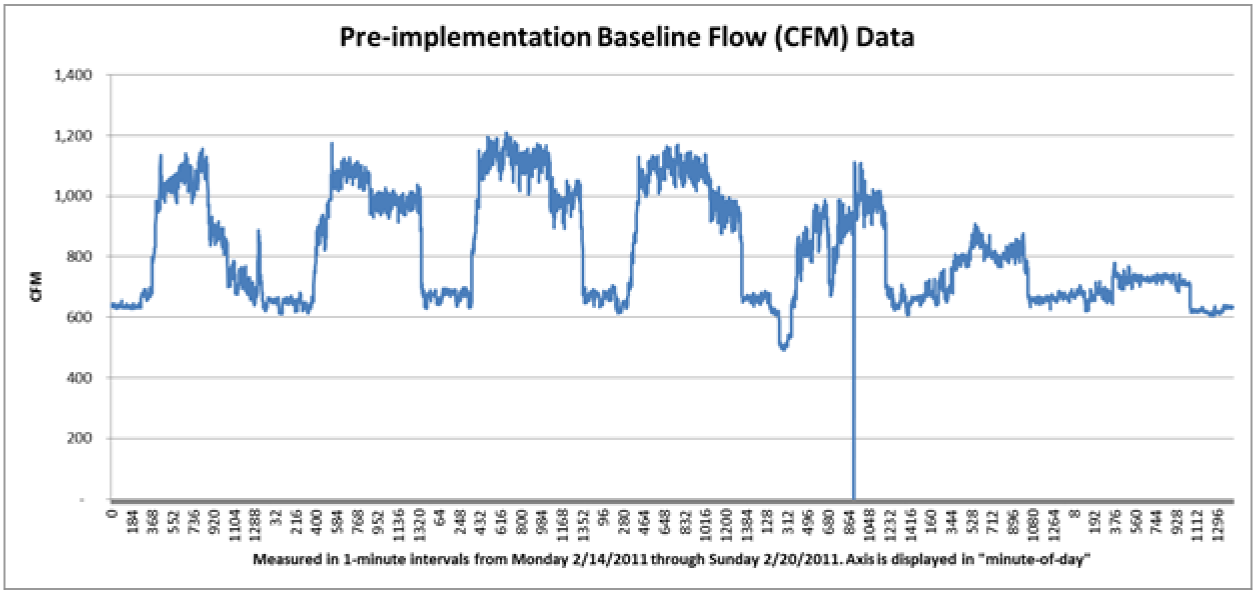
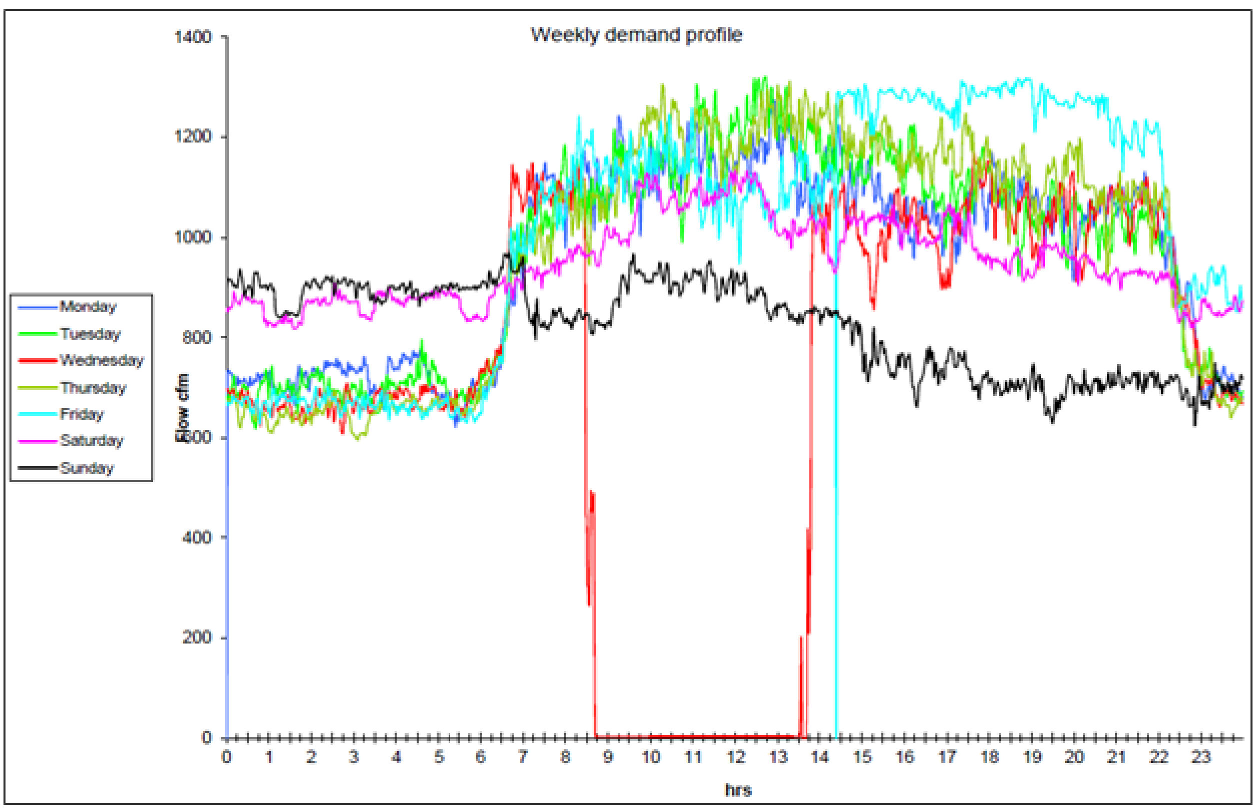


Figure 2: Post-implementation Air Demand Profile



The site contact did not believe that the facility has seasonal variation in air demand and commented that production intervals are periodic when production is running smoothly, a comment confirmed with the air flow data presented above.

All of the proposed energy conservation measures listed in Table were verified to be installed and operating as generally proposed. The discharge (line) pressure of the compressors was observed to be steady at 115 psig, with a system pressure around 100 psig. Two wet air tanks (one was 400 gallons, one was around 150 gallons) were observed to be in the compressor room. Two pre-existing air dryers (one 600 CFM and one 800 CFM) operated in parallel and supplied dry air downstream to the pre-existing 1,000 gallon air receiver tank and the new 620 gallon and 1,560 gallon air receiver tanks.

Table 7 shows the ECMs and respective quantities installed.

Table 7: Proposed versus Implemented ECMs

Implemented ECMs	Proposed (tracking)	Implemented (evaluated)
One (1) 335-hp air-cooled, oil-free rotary screw compressor with variable speed (VFD) flow control	Installed	Installed
One (1) 1,560 gallon vertical air receiver tank	Installed	Installed
One (1) 620 gallon vertical air receiver tank	Installed	Installed
Flow/Pressure Controller	Installed	Installed
One (1) 200-hp air-cooled, oil-injected rotary screw compressor with inlet modulation and unload flow controls	Retired & Retained as backup	Retired & retained as backup
One (1) 150-hp air-cooled, oil-injected rotary screw compressor with load/unload flow controls	Retired & Retained as backup	Retired & retained as backup
One (1) 100-hp air-cooled, oil-injected rotary screw compressor with load/unload controls	Not documented	Retired & removed from backup duty

Data Collection

The total packaged 3-phase true power of the installed 335-hp VFD compressor unit was metered using a DENT Elite Pro SP logger with split core CTs rated at 1000A. The metering period was approximately 4 weeks (November 22 to December 20, 2013) with a logging interval of 30 seconds. Spot power measurements were taken on each phase to verify that the Elite Pro loggers were recording power values with reasonable accuracy.

Other data collected during the on site visit included nameplates for the compressed air equipment (installed compressor, air dryers), line (discharge) pressure, and photographs of the installed ECMs (tanks and flow controller). Flow (trend) data was requested during the site visit based on the site contact’s comment that these data would be available (through the installed flow controller or some other metering device); however, after follow-up e-mail requests to the site contact, it was determined that flow trend data is not available (or the customer was not forthcoming with producing that data). The site contact instead provided a compressed air survey summary report (conducted during the post-implementation period) whose average air demand profile is provided in Figure 2, above. The table below documents the evaluator instrumentation used to measure the installed compressor's 3-phase true power.

Table 8: Evaluation Measurement Summary

Time-Series Data Information	
Measured Parameter	Total packaged True Power (kW) on installed 335-hp VFD compressor
Logger Make/Model	DENT Elite Pro SP on installed 335-hp VFD compressor
Transducer/Equipment Type	(3x) 1,000A split-core CTs on installed 335-hp two-stage VFD compressor
Installation Location	Meters was installed at the local disconnect of the packaged compressor unit capturing complete packaged load (including VFD losses)
Observation Frequency	30 second interval
Metering Period	4 weeks (November 22 to December 20, 2013)
Metered By	DNV GL and RISE electrician

Evaluation Savings Analysis

Approximately one month of time-series true power (kW) data were collected for the installed compressor. These data were used to directly characterize the air demand and performance of the baseline and installed compressed air system.

To begin the savings analysis, the metered data had the time stamps formatted for ease of processing; performance profiles were next generated for the installed and baseline compressors. The performance of the *pre-existing* compressors was not estimated because this project was considered a normal replacement and as such it used an appropriately sized baseline compressor that could have been selected to replace the pre-existing compressors:

- *INSTALLED 335-hp air-cooled, oil-free, single-stage rotary screw compressor with variable speed flow control kW vs. cfm* – This performance curve was generated from the manufacturer's CAGI sheet and the manufacturer's detailed specifications sheet for the respective model. The specifications sheet listed the compressor performance (packaged kW and air delivery) at various discharge pressures and shaft speeds so it allowed the evaluator to use the manufacturer's measured estimates for compressor performance at discharge pressures other than the model's rated pressure (125 psig in this case). Based on the site contact interview, the programmed discharge pressure (of 115 psig) does not change throughout facility operation. A quadratic power (kW) vs. capacity (cfm) trend was then formulated using these CAGI and specification sheet performance data so that time-series volumetric flow rates (acfm) corresponding to the time-series power data (kW) collected for this compressor could be calculated.

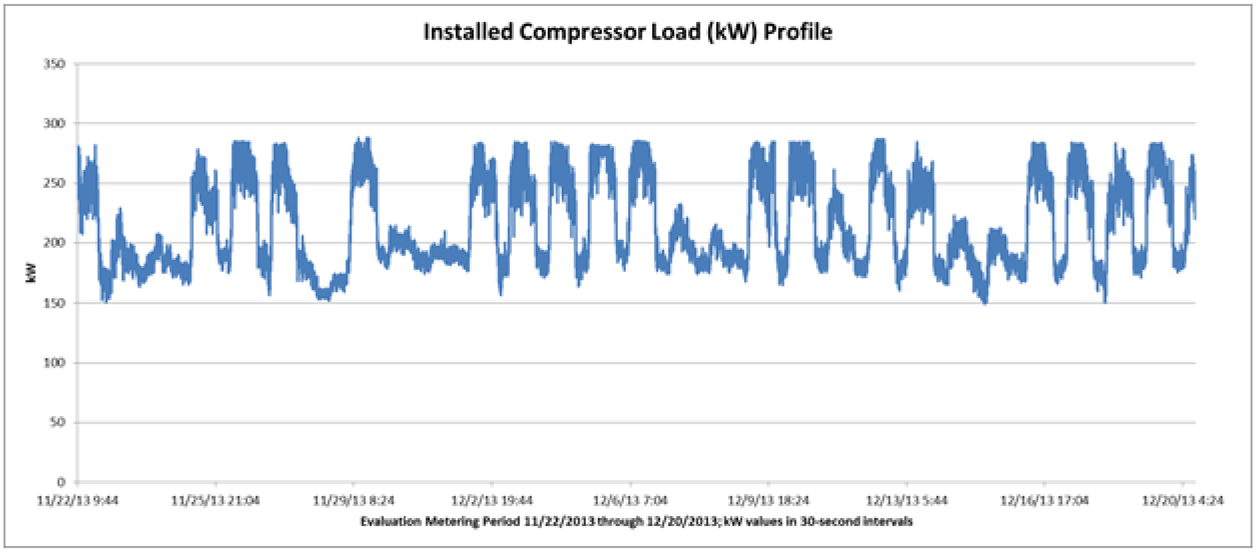
- *BASELINE 300-hp air-cooled, oil-injected, single stage rotary screw compressor with inlet modulation and unload flow controls: kW vs. cfm* – This performance curve was generated from two sources: (1) AirMaster+; and (2) manufacturer CAGI sheets for the respective model rated at different operating pressures. The CAGI sheets only provide the total packaged full load input power at the rated operating pressure (100 psig, 125 psig, and 150 psig) and the total packaged input power at zero flow (i.e., unloaded). The full load capacity of the baseline compressor corresponding to the observed discharge pressure of 115 psig was calculated by applying a psig vs. cfm linear slope relationship developed from year 2013 CAGI sheets to the 2011 CAGI specifications listed for the baseline compressor. In order to develop a performance curve equation for this baseline compressor, a similarly sized (in rated hp, acfm, and full load pressure) single-stage rotary screw compressor with inlet modulation and unloading flow controls was selected from the AirMaster+ compressor database. The default "Manufacturer Compressor Details" were then modified with the specifications found from the manufacturer's CAGI sheet. The full load ("cut-in") pressure was adjusted from the rated pressure of 100 psig to the pre-existing discharge pressure of 115 psig. The corresponding rated capacity was also adjusted from 1,314 acfm (at the rated operating pressure of 125 psig) to 1,371 acfm (at the discharge pressure of 115 psig). The AirMaster+ performance profile graph (packaged compressor kW vs. acfm) was then tabulated in 10% flow increments with their corresponding kW values. From this power vs. flow table, a fourth order power vs. capacity trend was formulated.

Installed Scenario

The performance (kW vs. cfm) profile for the installed compressor described above was used to estimate the flow (cfm) corresponding to each time stamp in the metered (kW) data. The installed compressor was observed to operate fully- or partially-loaded during the entire metering period. There were power data which showed that the compressor operated beyond its rated full load power (of 276.3 kW) approximately 6% of the metering period (around 39 hours in the 674 hour metering period). During these periods the calculated air flow was capped at the estimated full load capacity (1,371 acfm) because there was no indication that the VFD was exceeding the rated maximum shaft speed[38]. Figure 3 below shows the installed compressor load (kW) profile observed during the evaluation's metering period. Note that the load profile generally matches the air demand (cfm) profile shapes in Figure 1 and Figure 2.

[38] Generally speaking for variable speed rotary screw compressors, air flow rate is linearly proportional to shaft speed (RPM).

Figure 3: Installed Compressor Load Profile over Evaluation Metering Period



Pre-existing Scenario

The pre-existing scenario was constructed such that the selected baseline compressor would handle the entire air demand. The calculated total system flow in the installed case was used to estimate the baseline compressor's corresponding load. Using the baseline compressor kW vs. cfm performance profile the baseline compressor load corresponding to the (installed) air demand was calculated for each time stamp interval.

The difference between the baseline compressor load and the installed case compressor load using the installed air demand for each time stamp interval is the calculated compressor demand reduction for that time stamp interval. An hourly demand reduction profile for each weekday type (Monday through Sunday and holidays) was then developed by averaging the demand reduction corresponding to their respective hour and weekday bins, for a total of 192 bins. Only one profile needed to be developed because the facility does not have notable seasonal fluctuations in operation and production. The hourly demand reduction profile was then applied to the New York TM Reference Year (1995) 8,760 profile to calculate the annual electricity savings (kWh).[39] Peak demand reduction was calculated by averaging the hourly compressor demand reduction for all peak hours (4 P.M. – 5 P.M. on non-holiday week days) as defined by the NY ISO.

EVALUATION RESULTS

The total evaluated electric savings was determined to be 187,783 kWh and -5.2 kW peak demand reduction. The tracking savings are 432,889 kWh and 49.4 kW peak demand reduction. The gross realization rates (GRR %) comparing the evaluated savings to the tracking savings are 43% for kWh and -10% for kW.

Primary Reasons for Savings Discrepancy

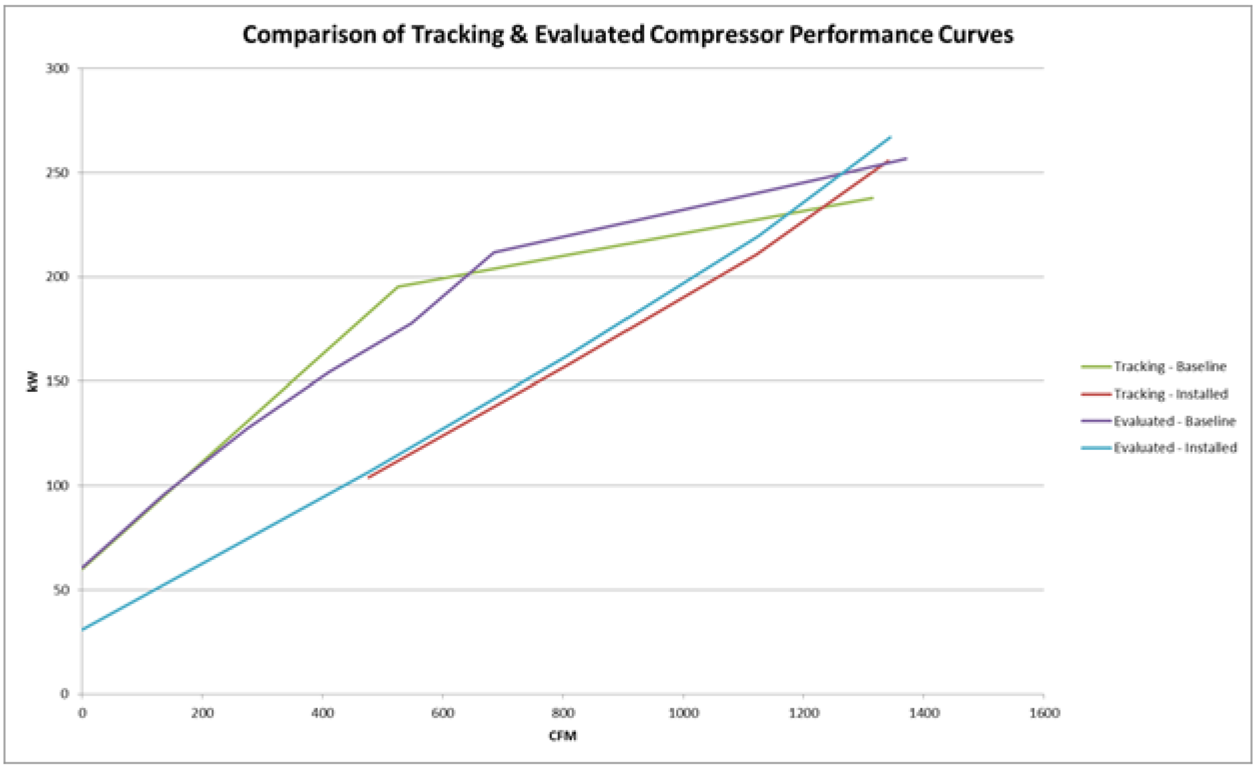
1. *Discrepancy #1 – Tracking Air Demand Different from Evaluated Air Demand:* The air demand profile calculated for the evaluated savings is critically higher than what was measured during the tracking

[39] 1995 was chosen as the reference year to standardize the weekday and holiday dates to the New York TM

metering period. The tracking air demand profile had an average flow rate of 825 cfm compared to the evaluated average flow rate of 1,067 cfm (not including the holiday air demand profile). Calculating the average baseline and installed compressor load (kW) at the evaluated average flow rate provides a smaller average demand difference (than the tracking case) between the baseline and installed compressor[40]. Since these average loads are used to calculate annual energy consumption, the evaluated energy savings decreased proportionally to the decrease in average demand difference between the installed and baseline compressor.

2. *Discrepancy #2 – Different Performance Curves:* There were minor differences between the compressor performance curves used in the tracking savings and evaluated savings. The figure below illustrates that the installed compressor performance in the evaluated savings is slightly less efficient than the performance estimated in the tracking savings. Additionally, the baseline compressor performance in the evaluated savings is slightly more efficient than the performance estimated in the tracking savings. The effect of these differences is a smaller potential for demand differences between the baseline and installed compressor loads.

Figure 4: Comparison of Tracking and Evaluated Compressor Performance Curves



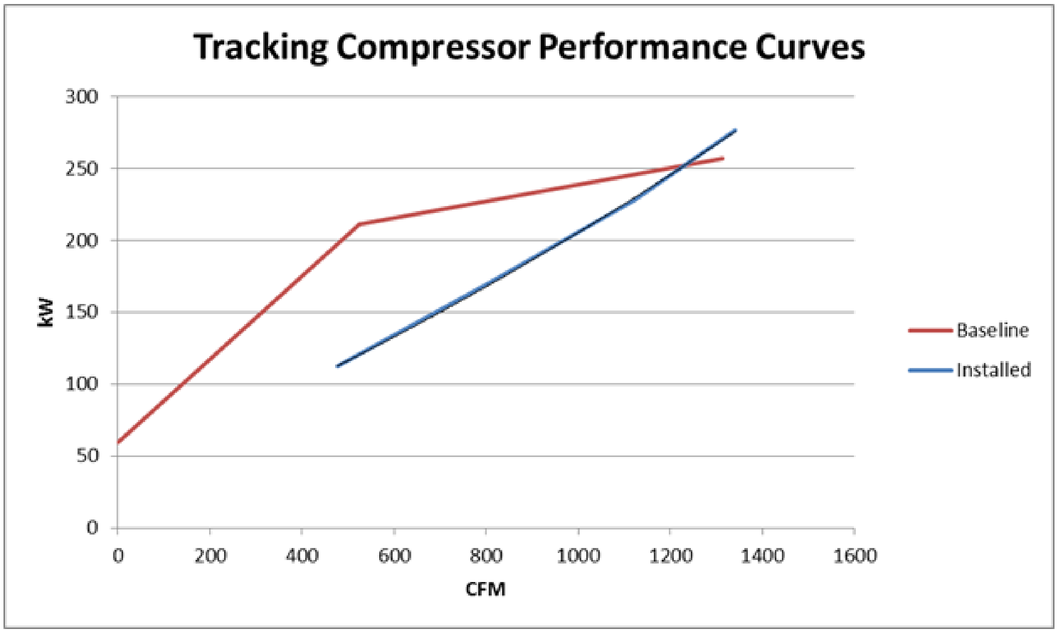
40 The average demand difference between the baseline and installed compressor was 49.6 kW using the average tracking flow rate. The average demand difference between the baseline and installed compressor was only 22.2 kW using the evaluated average flow rate.

3. *Discrepancy #3 – Different Calculation Method and Operating Conditions:* The tracking savings method uses seven days of flow data and CAGI performance curves to estimate the baseline and installed compressor annual energy consumptions. The tracking savings also uses a typical rule of thumb (0.5% power decrease for every 1 psig drop in discharge pressure) to adjust the estimated compressor loads. The tracking savings also assumes that the baseline and installed operating discharge pressure was 110 psig leading to a 7.5% full load power reduction, based on a rated operating pressure of 125 psig for both the baseline and installed compressors. The evaluated savings method relies on four weeks of power data and CAGI performance curves to estimate the installed air demand and the corresponding baseline compressor loads. The collected power data is used directly to characterize the installed compressor load profile and subsequent annual energy consumption. The evaluated savings method also uses a higher discharge pressure of 115 psig; this value was chosen based on the observed discharge pressure set point programmed in to the installed compressor.

More Comments on Discrepancy #1 and the Effects of Higher Air Demand on Savings Potential

Continuing the discussion for Discrepancy #1, the peak flow rates during the tracking measurement period were around 1,200 CFM while the peak flow rates during the evaluation measurement period were around 1,300 CFM. The compressor performance curves (CFM vs. kW) used in the tracking savings calculations intersect at around 1,231 CFM (as shown in Figure 5). At flow rates greater than this intercept point, the installed compressor operates less efficiently than the baseline compressor, leading to energy penalties during peak demand periods. Using the tracking air demand profile, all flow rate measurements fell below this savings penalty threshold. The evaluation's calculated air demand profile had hours where the peak demand was above the savings penalty threshold so those profile hours have negative demand reduction. The NY ISO defined peak hours (4 – 5 P.M. on non-holiday weekdays) happened to coincide with the facility's higher air demand period where the savings penalty threshold was passed, resulting in a negative peak demand reduction estimate.

Figure 5: Tracking Compressor Performance Curve Comparison



Peak Demand Discrepancy

The tracking peak demand reduction was calculated by averaging the annual energy savings over 8,760 hours. The evaluated peak demand reduction estimate was based on averaging the hourly demand reduction values for the 4 P.M. – 5 P.M. hour for all non-holiday weekdays. Performing this calculation method on the tracking flow data and corresponding baseline and proposed compressor loads, the tracking peak demand reduction would have been calculated to be 27.2 kW (a discrepancy of 22 kW or 45%).

SITE ID: DNVCA21

Project Type	Retrofit
Measure Category	Custom Compressed Air

PROJECT DESCRIPTION

The customer replaced the pre-existing 75 hp and 100 hp start/stop compressors with a two-stage 125 hp variable speed air compressor. A 500 gallon air receiver was installed in addition to the two pre-existing 1000 gallon receivers. Table 1 summarizes the initial savings estimates prior to the retrofit and the revised or evaluated savings values following project implementation. Table 2 outlines the reasons for discrepancy between the initial and evaluated project savings.

Table 1: Summary of Evaluation Results

Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
Annual Energy Savings (kWh)	487,200	504,372	104%
Peak Summer Demand Reduction (kW)	46.0	60.7	132%

Table 2: Discrepancy Analysis Summary

Discrepancy Factor	kWh	kW
Operating Conditions	Discrepancy #1 (Annual Operating Hours): -7,290 kWh; -1.5% Discrepancy #2 (Load Discrepancy): 24,462 kWh; 5.0%	
Equipment Specifications		
Calculation Method		Discrepancy #3 (Calculation Method): 15 kW; 32%
Inappropriate Baseline		

TRACKING SAVINGS

This section summarizes the methodology and assumptions used to estimate the Tracking savings claimed for the project.

Project Description

The customer operates a manufacturing facility 24 hours a day, 7 days a week. As a result of the retrofit, the customer replaced two pre-existing start/stop compressors with one variable speed compressor. By installing a variable speed compressor, the customer will be able to operate more efficiently at part load and reduce compressor run time. Table outlines the measures listed in the tracking data.

Table 3: Tracking ECMs

Description of ECM	Quantity
Installation of 125 hp Variable Speed Compressor	1

Baseline

Prior to the retrofit, the customer operated two compressors to meet the facility's compressed air load. The specifications of the two pre-existing compressors are outlined in Table 4.

Table 4: Pre-Existing Equipment

Description	Stages	hp	Control Method	Rated PSIG	Operating PSIG	Rated ACFM	Fan hp	Date of Installation
Rotary Screw	1	100	Start/Stop	125	110	420	3	2000
Rotary Screw	1	75	Start/Stop	125	110	320	3	1990

The pre-retrofit power, pressure, and flow trend data collected during the initial site visit showed that compressor #1 (100 hp) acted as the lead compressor and was able to meet the facility load roughly 95% of the time, while compressor #2 (75 hp) primarily ran unloaded, but acted as a trim compressor when facility compressed air load exceeded the capacity of compressor #1.

Proposed Condition

As part of the retrofit, the customer installed one 125 hp, 2 stage rotary screw, variable speed air compressor with compressed air pressure and flow controls to meet the facility's compressed air load. The pre-existing 75 hp compressor was decommissioned and removed from the facility, while the 100 hp compressor remains onsite as a backup in case of emergency. Furthermore, a 500 gallon air receiver was installed in addition to the two pre-existing 1000 gallon air receivers, totalling 2500 gallons of compressed air storage. Table 5 summarizes the equipment installed as a result of the retrofit.

Table 5: Proposed Equipment

Description	hp	Stages	Control	Rated PSIG	Operating PSIG	Capacity (ACFM)	Fan hp
Rotary Screw	125	2	VSD	100	100	677	5

Tracking Calculation Methodology

In order to calculate the initial project savings, the compressed air system was fitted with pressure, flow, and power data loggers from May 9, 2011 to May 23, 2011. This data was used to develop a time weighted demand profile of flow for the two compressors during the baseline period. This data was used in conjunction with the manufacturer provided kW vs. flow data to estimate the annual power consumption of the new compressor.

Table 6: Proposed Compressor Performance Data

ACFM	Input Power (kW)	Specific Power (kW/100 acfm)
0	0	0
115.0	24.8	21.6
203.0	37.9	18.7
339.0	57.0	16.8
474.0	78.0	16.5
609.0	102.1	16.8
677.0	116.9	17.3

The compressor load profile was split into 16 separate bins based on the ACFM demand. The ACFM supplied by each compressor during the baseline period was determined based on the compressor sequence of operations. The kW demand for each compressor was then determined using the data collected during the two week trending period. The kW demand and annual operating hours for each load profile bin were multiplied in order to calculate annual kWh for each bin. The annual kWh for all 16 bins were summed to calculate the baseline case annual kWh.

The installed compressor annual power consumption was calculated in a similar manner. The % load of the compressor was determined using the compressed air demand data collected during the initial site audit. The kW demand for each bin was subsequently determined using kW vs. flow performance curves generated using AirMaster+. The kW demand and annual operating hours for each load profile bin were multiplied in order to calculate the annual kWh for each bin. The annual kWh for all 16 bins was summed to calculate the installed case annual kWh.

Equations:

4. Individual Load kWh = (kW at Specific Load) x (Number of Hours at Load)
5. Total System kWh = Load 1 kWh + Load 2 kWh +…+ Load 16 kWh
6. kWh Savings = Total System kWh_{Base} – Total System $kWh_{Proposed}$

Assessment of Tracking Methodology and Analysis

1. The project documentation does not detail how peak demand reduction was calculated. By not documenting how peak reduction was calculated, the calculation cannot be replicated and the sources of discrepancy between the tracking and evaluated peak demand reduction cannot be isolated.
2. The facility compressor flow was metered for a period of 2 weeks. This trending period provides the flow profiles for a short period of time which may not be adequate to fully capture the facility's entire load range or any seasonality in load.

EVALUATION METHODOLOGY

The following sub-sections describe project scope and estimated savings based on observed site conditions. The sub-sections go over the pre-existing (baseline) and proposed operating conditions & equipment informed by the site visit and correspondence with the site contact. The sub-sections also discuss the data collection, analysis, and calculation methodology performed to estimate the evaluated savings.

Measure Verification

The conditions found on site were similar to those outlined in the tracking analysis. The customer's compressed air system powers pneumatic machinery in the manufacturing facility. Furthermore, the evaluator was able to visually verify nameplate information of the pre-existing and installed compressors, as all three compressors were onsite at the time of the evaluation. During the onsite interview, the customer indicated that both air compressors operated 24 hours a day during the pre-existing period, but noted that the 100 hp compressor was likely capable of handling the facility load. Both compressors were used due to the presence of an air threading machine. The facility's air threading process is air intensive, so both compressors remained on during the baseline period in case the threading machine needed to operate.

Since no time series trend data characterizing the post-installation operating pressure was available onsite, the evaluator utilized spot verification to substantiate the system operating pressure claimed in the tracking calculations. The evaluation engineer utilized the digital display located on the variable speed compressor, which displayed real time compressor outlet pressure, to verify the operating pressure used in the tracking analysis. The digital display verified that the compressor outlet pressure was held at 100 PSIG.

Table 7 shows the ECMs and respective quantities installed.

Table 7: Proposed versus Implemented ECMs

Implemented ECMs	Proposed (tracking)	Implemented (evaluated)
100 hp Start/Stop Air Compressor	Retired & Removed	Retained as backup
75 hp Start/Stop Air Compressor	Retired & Removed	Retired & Removed
125 hp VSD Air Compressor	Installed	Installed
500 Gallon Compressed Air Storage Tank	Installed	Installed

Data Collection

An ElitePro SP kW logger was installed on the 125 hp variable speed compressor for a period of 4 weeks. The evaluation engineer used this time series kW data to create an hourly compressed air system operating profile.

Table 8 outlines the specifications of the kW data logger installed during the evaluation.

Table 8: Evaluation Measurement Summary

Time-Series Data Information	
Measured Parameter	Total Package True Power (kW)
Logger Make/Model	DENT Elite Pro SP kW Logger
Transducer/Equipment Type	(3x) 150A split-core CTs
Installation Location	Outlet of VSD in Power Compartment
Observation Frequency	1 minute interval
Metering Period	4 weeks (11/8/13 – 12/4/13)
Metered By	DNV GL and RISE electrician

The customer was asked to provide production data in order to allow the evaluator to verify the tracking hours of operation. The customer was able to provide daily production data (lbs.) for the 4 week trending period, as well as monthly production data from January 2010 – October 2013. Lastly, during the onsite interview the customer informed the evaluation engineer that production occurs 24 hours a day, 7 days a week but the facility observes 14 days of holidays and plant shutdowns.

Evaluation Savings Analysis

The evaluation engineer utilized the trend data collected during the onsite evaluation to develop an 8,760 compressed air load profile. Using the load profile, the evaluator calculated the pre and post retrofit kW demand using performance curves generated using baseline trend data for the pre-existing compressors and CAGI performance curves for the installed compressor.

The peak demand reduction was calculated in compliance with the NYISO, which states that system peaks generally occur during the hour ending at 5pm on the hottest non-holiday weekday. The New York Technical Manual (TM) states that this peak occurs on Friday, July 21, 1995 between 4 P.M. – 5 P.M. However, since compressed air load at this facility is not weather dependent, the peak demand reduction was calculated as the average demand reduction between 4 P.M and 5 P.M on all non-holiday weekdays.

Installed Scenario

In order to calculate project savings, the evaluator developed an hourly operating profile for the customer's compressed air system. To accomplish this, the evaluator utilized the installed compressor time series kW data collected between 11/8/13 – 12/4/13 and compressor performance curves which outline the relationship between compressed air demand and power consumption and are generated using CAGI performance data. Using this relationship, the evaluator was able to generate a lookup table which listed the average compressed air demand from the trending period based on hour and day type. This lookup table was used to generate an 8,760 load profile by matching each hour and day type throughout the year to the corresponding average compressed air demand in the lookup table. However, merely annualizing the average compressed air load assumes 8,760 hours of operation.

Customer-provided production data was used to verify the annual production hour estimate used in the tracking analysis. The tracking analysis assumed 8,760 annual operating hours for savings estimation. The production data provided showed lbs. of production during the evaluation trending period, as well as total production dating back to January 2010. The trend data showing production hours was used in conjunction with the production data to determine a lbs/hr estimate for the trending period. This figure was applied to the average annual production dating back to January 2010 in order to calculate the average production hours per year. This method calculated 8,296 hours per year rather than the 8,760 hours used in the tracking calculations.

In order to obtain 8,296 annual hours of operation, the evaluator first assumed no production during 14 major Federal Holidays, as indicated by the site contact during an onsite interview. Additionally, the evaluation engineer assumed no production during 6 days and 8 hours throughout the year in order to obtain the correct number of operating hours resulting from the calculation mentioned above. The result of the previous steps is an 8,760 compressed air load profile which correctly reflects 8,296 annual hours of operation.

Once the correct compressed air load profile was generated, the corresponding kW demand for each load was calculated based on a performance curve taken from the CAGI data sheet. The 8,760 kW were summed in order to calculate the annual compressor energy consumption for the post-installation period.

Pre-existing Scenario

The pre-existing compressed air system power consumption was determined based on the corrected 8,760 compressed air load profile which reflects 8,296 annual hours of operation and performance curves generated using trend data collected during the baseline period. The trend data collected between 5/9/2011-5/23/2011 showed the power consumption vs. flow relationship for each pre-existing compressor. The load met by each individual compressor was determined using the sequence of operations verified during the onsite evaluation, which dictated that pre-existing compressor #1 would act as the lead compressor and pre-existing compressor #2 would act as the trim compressor. Using the performance relationship between the pre-existing CFM and the compressor kW and the compressor sequencing strategy, the evaluator was able to calculate the 8,760 hourly kW demand as a function of the 8,760 compressed air demand from the pre-installation period. The 8,760 kW were then summed in order to calculate the annual compressor power consumption for the pre-installation period.

The peak demand reduction was calculated in accordance with the guidelines stipulated by the New York Technical Manual (TM), which states that system peaks generally occur between the hours of 4PM and 5PM on non-Holiday weekdays. Therefore, the average demand reduction during these hours served as the basis for the evaluated peak demand reduction.

EVALUATION RESULTS

The difference between the baseline and installed 8,760 kW served as the basis for the annual project savings. The total evaluated electric savings were determined to be 504,372 kWh and 60.7 kW peak demand reduction. The tracking savings are 487,200 kWh and 46.0 kW peak demand reduction. The gross realization rates (GRR) comparing the evaluated savings to the tracking savings are 104% for kWh savings and 132% for peak demand reduction.

Primary Reasons for Savings Discrepancy

The discrepancies between the tracking and evaluated savings can be attributed to the following sources:

1. *Discrepancy #1 (Annual Operating Hours)* – Production data collected during the onsite evaluation was used to calculate the facility's annual operating hours. The tracking analysis had assumed 8,400 hours. However, the evaluation yielded a slightly lower annual hour count at 8,291 hours. The reduction in annual operating hours accounted for an impact of -7,290 kWh savings, approximately -1.5%.
2. Discrepancy #2 (Operating Conditions) – The primary source of discrepancy between the proposed and evaluated savings comes in the operating conditions. The initial tracking calculations calculated that the pre-existing compressed air system operated at 400-450 ACFM load for approximately 90% of the year. However, power trend data collected during the onsite evaluation showed that the compressed air load never exceeded 315 ACFM. Since the variable speed compressor is much more efficient than the pre-existing compressors at part load conditions, the project kWh savings increased by 5.0% (24,462 kWh).
3. Discrepancy #3 (Calculation Method) – The method by which the reported peak demand reduction was calculated cannot be verified using the tracking analysis. The revised tracking estimate claimed a peak demand reduction of 58 kW. However, tracking data shows a reported demand reduction of 46 kW. The evaluated peak demand was calculated following the guidelines set forth by the NY Technical Manual (TM), which states that system peaks generally occur between 4 P.M and 5 P.M on the hottest non-holiday weekday. However, since compressed air load at this facility is not weather dependent, the peak demand reduction was calculated as the average demand reduction between 4 P.M and 5 P.M on all non-holiday weekdays. The difference in calculation method resulted in a discrepancy of 15 kW, leading to a 32% increase in kW gross realization rate.

SITE ID: DNVCA22

Project Type	Retrofit
Measure Category	Custom Compressed Air

PROJECT DESCRIPTION

This manufacturing facility has implemented multiple measures and eliminated the plant leaks to reduce the plant supply pressure and controlling it to an optimal pressure setting, and operating the existing air compressors in ON/OFF control setting. The customer has installed a new 125 HP VFD compressor to replace an existing 100 HP modulating compressor, a new mist eliminator and a flow controller to reduce the plant supply pressure from 100 psi to 70 psi. Table 1 summarizes the initial savings estimates prior to the retrofit and the revised or evaluated savings values following project implementation. Table 2 outlines the reasons for discrepancy between the initial and evaluated project savings.

Table 1: Summary of Tracking Savings

Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
Annual Energy Savings (kWh)	646,760	490,970	76%
Peak Summer Demand Reduction (kW)	74	55.5	75%

Table 2: Discrepancy Analysis Summary

Discrepancy Factor	kWh	kW
Operating Conditions		
Equipment Specifications		
Calculation Method	Discrepancy #1 (Calculation method): - 155,790 kWh, -24%	Discrepancy #1 (Calculation method): -18.5 kW, -25%
Inappropriate Baseline		

TRACKING SAVINGS

This section summarizes the methodology and assumptions used to estimate the Tracking savings claimed for the project.

Project Description

This project is implemented in an industrial manufacturing facility which has the compressed air system configured with interconnected compressed air distribution piping which consists of 3 air compressor. The existing compressors include (2) 150 HP rotary screw compressors operating in modulating mode, and (1) 100 HP rotary screw compressor operating in standby-mode. Total installed compressor capacity is about

1,940 cfm. All compressors are interconnected into a single common distribution system. System growth and changes over time have resulted in sections of piping that cause sustained pressure gradients which affect compressor control and overall system efficiency. The plant experiences a constant production load which operates 24/7 throughout the year and low production load during holidays. The current configuration operates 2 compressor units operating close to full load capacity in modulating mode and one unit operates as the trim unit. The existing compressors are operated at high discharge pressure and all the compressed air generated at the plant is supplied to the plant shops at around 95 to 100 PSI.

The scope of this retrofit project is to reduce the plant air demand and system optimization. The Customer has fixed the plant compressor air leaks and has reduced the supply pressure to the plant shops to the lowest optimal pressure (70 PSI) and has programmed to operate the existing air compressors in ON/OFF mode. The new 125 HP VSD compressor is currently installed as the lead compressor, and one of the existing 150 HP compressors have been programmed to operate as the lag compressor in redundancy. The existing 100 HP compressor has been retired and decommissioned. This assessment even includes providing efficient trim capacity control to operate the existing compressor in ON/OFF mode.

Refer Table 3 below for the complete list of EEM's associated with this project.

Table 3: EEM List

EEM Type	Quantity	Size/Notes
Supply pressure reduction	N/A	95 PSI to 70 PSI
Fix Air Leaks	146	Implemented
Install new VSD compressor	1	125 HP VSD unit is installed
Turn off/Retire compressor units as applicable	1	100 HP compressor unit is retired
Install new Mist Eliminator	1	Installed

Baseline

The plant compressed air equipment includes three compressors units. Based on the information available on the project submittals; the site is equipped with 3 rotary screw compressors. The compressors are manually operated with one compressor in stand-by control mode. The plant has the following compressors:

Table 4: Pre-Existing Equipment

Unit	HP	Pressure (PSI)	Control	Phase 1 Status
Unit 1	150	100	Modulating	Retained in ON/OFF mode
Unit 2	150	100	Modulating	Retained in ON/OFF mode
Unit 3	100	100	Modulating	Retired

It was mentioned in the project submittal that during the pre-implementation measurement period two 150 HP air compressors were operating, and the one 100 HP unit in the plant was OFF. The submitted project documentation states that the compressor units operate 24/7, 350 days/year totalling 8,400 hours per year.

The actual operating hours would be confirmed during the site visit. Table 5 shows the existing equipment power draw and CFM values.

Table 5: Pre-Existing Equipment Operating Data

Unit	Size (HP)	Capacity (CFM)	SCFM	PSIG	Measured Power
AC-19	150	726	722	125	129.7
AC-20	150	726	722	125	129.7
AC-21	100	490	488	125	81.8
		1942	**1932**		341.2

Proposed Condition

The customers have reduced the supply pressure on multiple plant shops and have rectified the plant air leaks. A new 125 HP VFD compressor along with a new mist eliminator have been installed.   The 100 HP compressor have been retired and the (2) existing 150 HP compressors have been programmed to operate as the lag compressor in redundancy mode. The post equipment's configurations and control scheme are summarized in Table 6 below.

Table 6: Post Equipment

Unit	HP	Pressure (PSIG)	Control	Status
New unit	125	100	VFD	Lead Unit
AC-19	150	100	Modulating	Retained as Lag unit.
AC-20	150	100	Modulating	Retained as Lag unit.
AC-21	100	100	N/A	Retired

The project submittal states that the VFD unit would operate all the time to meet the plant load, and either AC-19 or AC-20 unit would operate in lag mode to provide additional CFM as per the plant load requirement.

Tracking Calculation Methodology

The site energy consultants conducted a comprehensive performance measurement during the normal plant operational period in May 2011. The site measurements included all the operating compressor kW consumption, airflow measurements on all the compressors units. The tracking savings were estimated by the consultants by utilizing the measured plant parameters to establish the plant operational base-line and the savings were calculated based on vendor software and estimations. The measured data or any other information regarding the energy savings were not provided as part of the project submittals.

<u>Base-line profile creation:</u> The measured kW and CFM points were utilized to create an annual operational profile.

Energy Savings: The Consultant has utilized a vendor calculator to estimate the savings with respect to fixing the air leaks. The VFD savings and programming the existing compressor to operate as lag unit has been calculated based on an estimated reduction in compressor kW consumption.

Assessment of Tracking Methodology and Analysis

1. The project documentation only included savings estimates and not much detail regarding the calculation methodology.

EVALUATION METHODOLOGY

The following sub-sections describe project scope and estimated savings based on observed site conditions. The sub-sections go over the pre-existing (baseline) and proposed operating conditions & equipment informed by the site visit and correspondence with the site contact. The sub-sections also discuss the data collection, analysis, and calculation methodology performed to estimate the evaluated savings.

Measure Verification

The Evaluation team conducted a comprehensive site visit to collect all the relevant name plate/equipment information and other controls information with respect to this project. The evaluator documented the base-line condition based on the information collected during the site visit. The EEM's with respect to this project were completed as proposed in the Tracking documentation. The evaluator collected installed equipment details from the equipment name plate, and other operational data were collected from the installed unit's display screen. The evaluator collected pressure and CFM readings from the site installed flow meters. Table 7 shows the ECMs and respective quantities installed.

Table 7: Proposed versus Implemented ECMs

Implemented ECMs	Proposed (tracking)	Implemented (evaluated)
100 HP unit	Retired & Removed	Retired & Removed
150 HP (2) units	Retained	Retained
New VFD unit	Installed	Installed
New mist eliminator	Installed	Installed

Data Collection

The new and existing compressors were installed with elite pro loggers to monitor system operation and true power consumption. Spot power measurements were taken for all the existing and newly installed compressors to validate the baseline and proposed energy consumption profile. Additional air side data were collected from the site installed flow meters. Table 8 and 9 summarizes the Evaluation team's measurement and verification details.

Table 8: Proposed Measurement and Verification Summary

Input	Tracking Analysis Variable	Verification Method
Annual Run Hours.	8,400	Elite Logger
HP Baseline (3 units)	125,150,150 HP	On Site Verification
kW (3 units)	116.9, 129.7, 129.7 kW	Elite Logger
Air Capacity (3 units)	677, 726, 726 CFM	On Site Verification

Table 9: Logger Information

Time-Series Data Information	
Measured Parameter	Total Package True Power (kW) and Amperage (A)
Logger Make/Model	DENT Elite Pro SP kW Logger (3 units),
Transducer/Equipment Type	200 A CT's (9 units in total)
Installation Location	Outlet of VSD in Power Compartment
Observation Frequency	15 minute interval
Metering Period	5 weeks (12/11/13 – 1/16/14)
Metered By	DNV GL and RISE electrician

Evaluation Savings Analysis

The measured kW data and the air side cfm data were used to create custom kW/cfm curves, and these curves were used to create the proposed case energy consumption model. The user created proposed case energy consumption model were utilized to estimate the plant CFM profile. The evaluator created a spreadsheet based engineering calculation to evaluate savings with respect to this project.

The evaluation engineer utilized the trend data collected during the onsite evaluation to develop an 8,760 compressed air load profile. Using the load profile, the evaluator calculated the pre and post retrofit kW demand using CAGI performance curves.

The peak demand reduction was calculated in compliance with the NYISO, which states that system peaks generally occur during the hour ending at 5pm on the hottest non-holiday weekday. The New York Technical Manual (TM) states that this peak occurs on Friday, July 21, 1995 between 4 P.M. – 5 P.M. However, since compressed air load at this facility is not weather dependent, the peak demand reduction was calculated as the average demand reduction between 4 P.M and 5 P.M on all non-holiday weekdays. The customer provided the following holiday information. The customer mentioned that during holidays; the plant is still operating at a reduced load.

Holiday List	Start Date	Full List	Time	ON/OFF
New Year	1/1/1995	1/1/1995		OFF
		1/2/1995	7:00 AM	ON
Easter	4/15/1995	4/15/1995	11:00 PM	OFF
		4/16/1995		OFF
		4/17/1995	7:00 AM	ON
Memorial Day	5/29/1995	5/29/1995	7:00 AM	
		5/30/1995	7:00 AM	ON
Independence Day	7/3/1995	7/3/1995	7:00 AM	OFF
		7/4/1995		
		7/5/1995		
		7/6/1995		
		7/7/1995		
		7/8/1995		
		7/9/1995		
		7/10/1995	7:00 AM	ON
Labor Day	9/4/1995	9/4/1995	7:00 AM	OFF
		9/5/1995	7:00 AM	ON
Thanksgiving	11/23/1995	11/23/1995	7:00 AM	OFF
		11/24/1995		
		11/25/1995		
		11/26/1995	7:00 AM	ON
Christmas	12/24/1995	12/24/1995	7:00 AM	OFF
		12/25/1995		
		12/26/1995		
		12/27/1995		
		12/28/1995		
		12/29/1995		
		12/30/1995		

12/31/1995

Installed Scenario

The evaluator developed an hourly operating profile for the customer's compressed air system. The evaluator utilized the installed compressor time series kW data collected between 12/11/13 – 1/16/14 and compressor performance curves to generate the hourly CFM profiles. CAGI performance data and Generic Curves from the Best Practices for Compressed air Systems were used to create the CFM load profiles. The evaluator then created 2 separate hourly CFM profiles; Normal Day CFM profiles and Holiday CFM Profiles. Figure 1 and 2 shows the kW profiles for the 125 HP VSD compressors during regular working days and holidays respectively. The different color bands indicate the Day Types.

Figure 1: 125 HP VSD unit kW profile; normal operation

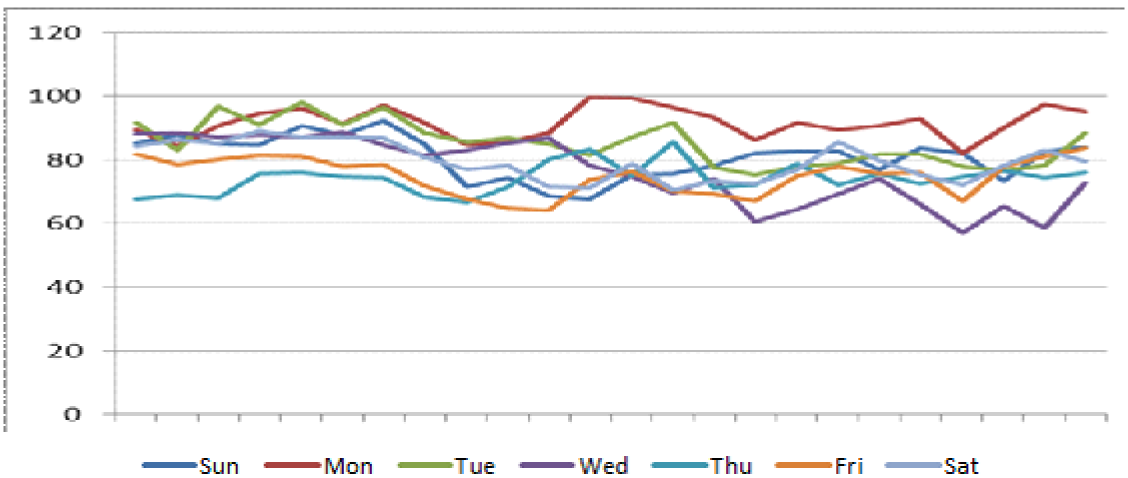
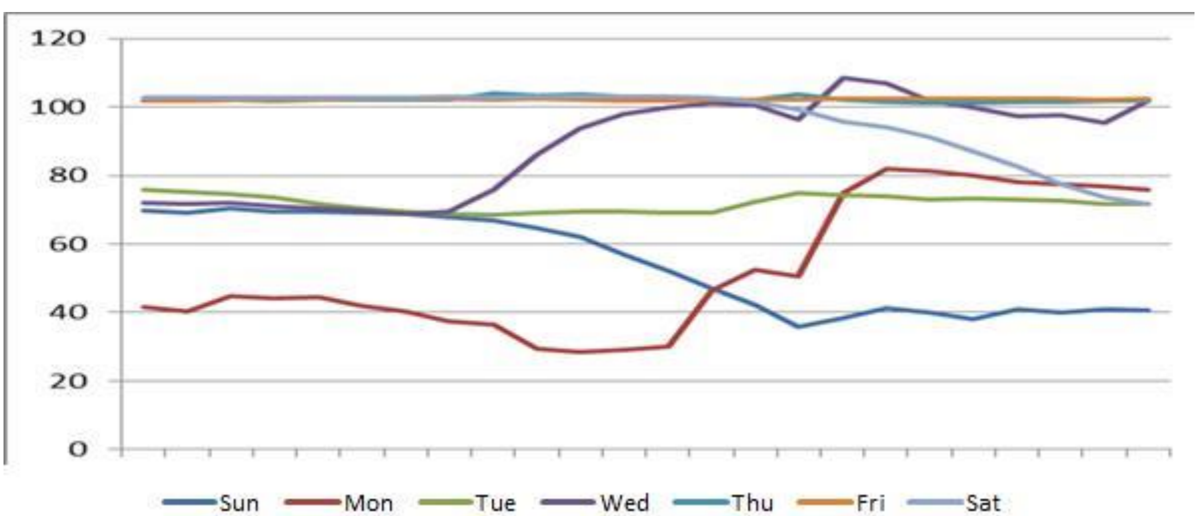


Figure 2: 125 HP VSD unit kW profile; holiday operation



The evaluator then created a lookup table which listed the average compressed air demand from the trending period based on hour and day type. This lookup table was used to generate an 8,760 load profile by matching each hour and day type throughout the year to the corresponding average compressed air demand in the lookup table. Table 10 summarizes all the compressor curve fit equations created for this project, where 'x' indicates CFM and 'y' indicates kW consumption.

Table 10: Compressor Performance Curve fitting

		CFM	Type	Size	Equation
Proposed System	VSD	677	VSD	125 HP	$y = 7E\text{-}05x^2 + 0.1087x + 12.157$
	AC-19	726	ON/OFF	150 HP	$y = 0.1787x - 0.0237$
	AC-20	726	ON/OFF	150 HP	$y = 0.1787x - 0.0237$
		2129			
Base System	AC-19	726	Modulation	150 HP	$y = -9E\text{-}06x^2 + 0.0611x + 91.515$
	AC-20	726	Modulation	150 HP	$y = -9E\text{-}06x^2 + 0.0611x + 91.515$
	100 HP	470	Modulation	100 HP	$y = -1E\text{-}05x^2 + 0.0595x + 57.72$
		1922			

The post compressed air system power consumption was determined based on the 8,760 compressed air load profile created by the evaluator. The kW consumption and the performance curves are used to estimate the CFM needed to meet the plant load in the base-case scenario.

Pre-existing Scenario

The evaluator utilized the kW consumption and the performance curves to estimate the CFM needed to meet the plant load.

In the base-case scenario the AC-19 and AC-20 unit operates continuously in modulating mode to meet the plant load. Based on the project submittal it is estimated that the (100) HP compressor will turn ON only during maintenance periods and hence, this compressor is not programmed to operate in the Analysis.

Post to base CFM profile modification

To attribute the savings with respect to fixing the air leaks; the base-case CFM has been increased by 10% CFM. This increase was an assumption used by the evaluator to account for the air leaks that were repaired, which helped the customer to operate with less overall air compressor HP than prior. This increase in CFM has increased the operating load on the existing compressors.

The peak demand reduction was calculated in accordance with the guidelines stipulated by the New York Technical Manual (TM), which states that system peaks generally occur between the hours of 4PM and 5PM on non-Holiday weekdays. Therefore, the average demand reduction during these hours served as the basis for the evaluated peak demand reduction.

EVALUATION RESULTS

The difference between the baseline and the installed kW served as the basis for the annual project savings. The total evaluated electric savings were determined to be 490,970 kWh and 55.5 kW peak demand reduction. The tracking savings are 646,760 kWh and 74 kW peak demand reduction. The gross realization rates (GRR) comparing the evaluated savings to the tracking savings are 74% for kWh savings and 75% for peak demand reduction.

Primary Reasons for Savings Discrepancy

The discrepancies between the tracking and evaluated savings can be attributed to the following source:

1. Discrepancy #1 (Calculation Method) – The primary source of discrepancy between the proposed and evaluated savings is due to the calculation method. The project submittal didn't include much detail regarding the evaluation calculation methodology. The project kWh savings was reduced by -155,790 kWh, -24% and 18 kW, -25%.

SITE ID: DNVCA24

Project Type	Retrofit
Measure Category	Custom Compressed Air

PROJECT DESCRIPTION

This manufacturing facility has completed a compressor retrofit project, and this project includes adding a VFD compressor to the existing (3) fixed speed rotary screw compressors. The three existing compressor were operating in load/un-load mode to satisfy the plant load. The new VFD compressor will act as the lead compressor and the existing compressors will act as lag compressors to satisfy the plant load. Table 1 summarizes the initial savings estimates prior to the retrofit and the revised or evaluated savings values following project implementation. Table 2 outlines the reasons for discrepancy between the initial and evaluated project savings.

Table 1: Summary of Tracking Savings

Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
Annual Energy Savings (kWh)	758,234	599,562	79%
Peak Summer Demand Reduction (kW)	96.0	60.4	63%

Table 2: Discrepancy Analysis Summary

Discrepancy Factor	kWh	kW
Operating Conditions		
Equipment Specifications		
Calculation Method	Discrepancy #1 (Calculation method): - 158,672.4 kWh, - 21%	Discrepancy #1 (Calculation method): - 35.6 kW, - 37%
Inappropriate Baseline		

TRACKING SAVINGS

This section summarizes the methodology and assumptions used to estimate the Tracking savings claimed for the project.

Project Description

This project is implemented in an industrial manufacturing facility which has the compressed air system comprising of (3) air compressors. The existing compressors include (2) 300 HP rotary screw compressors and (1) 200 HP rotary screw compressor operating in load/unload mode. Total installed compressor capacity is about 419 cfm. The plant operates 24 hours, seven days per week. The current configuration operates all (3) units in load/unload mode. The existing compressors are operated at high discharge pressure and all the compressed air generated at the plant is supplied to the plant shops at125 PSI.

The scope of this retrofit project is to increase the plant compressed air capacity, and to operate the existing compressors more efficiently by adding a VSD compressor. The new VSD compressor is currently installed as the lead unit, and the plant load can be satisfied by operating the VFD unit and two out of the three existing compressors. The (3) existing compressors are currently programmed to act as lag compressors and will operate to satisfy the plant load. Refer Table 3 below for the complete list of EEM's associated with this project.

Table 3: EEM List

EEM Type	Quantity	Size/Notes
Install new VSD compressor	1	390 HP VSD unit is installed

Baseline

The plant compressed air equipment includes three compressor units. Based on the information available on the project submittals; the site is equipped with 3 rotary screw compressors. The plant has the following compressors:

Table 4: Pre-Existing Equipment

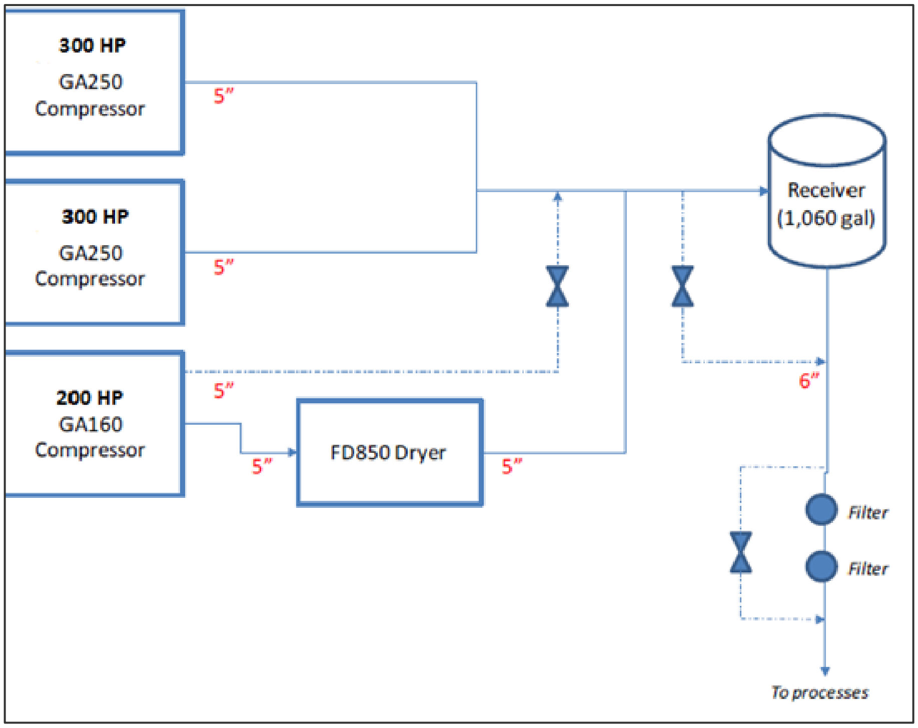
Unit	HP	Pressure (PSI)	Control	Phase 1 Status
Unit 1	200	125	Load/Unload	Retained as lag unit.
Unit 2 & 3	300	150	Load/Unload	Retained as lag unit.

It was mentioned in the project submittal that during the pre-implementation measurement period all the three compressors were operating continuously during the normal production period, Monday through Sunday, 24 hours a day. The actual operating hours would be confirmed during the site visit. Table 5 shows the existing equipment power draw and CFM values. Please refer Figure 1 for plant equipment setup.

Table 5: Pre-Existing Equipment Operating Data

Unit	Size (HP)	Capacity (CFM)	PSIG	Measured Power
Unit-1	300	1325	150	299 kW (Max)
Unit-2	300	1325	150	299 kW (Max)
Unit-3	200	926	125	150 kW (Avg)

Figure 1: Plant Equipment Setup



Proposed Condition

The new 390-HP VFD compressor have been installed, and the (3) existing compressors have been programmed to operate as lag compressors. The post equipment's configurations and control scheme are summarized in Table 6 below.

Table 6: Post Equipment

Unit	HP	Pressure (PSIG)	Control	Status
New Unit 1	67	138	VFD	Lead Unit
Old Unit 1	300	150	Load/Unload	Lag Unit
Old Unit 1	300	150	Load/Unload	Lag Unit
Old Unit 2	200	125	Load/Unload	Lag Unit

The project submittal states that the VFD units would operate all the time to meet the varying plant load, and the lag units will be operated by the Controller to meet the additional plant load.

Tracking Calculation Methodology

The site energy consultants recorded the plant compressors operational data for one week, 11/28/11 to 12/4/11. The site measurements included the operating compressor power reading, airflow, and pressure measurements on all the compressors units. The tracking savings were estimated by the consultants by utilizing the measured plant parameters to establish the plant base-line energy consumption.

Base-line profile creation: Based on the plant sub-metered demand data, the power consumption of the base-line compressors was estimated. The base-line energy consumption is estimated based on the measured demand and AIRMaster + generated air flow profiles. The vendor monitored both electrical demand and air flow data. Only the electrical data was used as an input to AirMaster+; the model was allowed to calculate the air flow profile as a function of the published compressor characteristics in the software's database. The calculated flow was then compared to the metered flow data and was deemed consistent. The specific power shown by the vendor's model (19.5 kW per 100 cfm) is within 10% of the rated full load specific power (20.8 kW per 100 cfm) of the compressors. For the entire modelled week, the modelled specific power is 22.0 kW per 100 cfm, which is within 6% of the rated value (20.8 kW per 100 cfm). This modelled value is less efficient than the full load ratings, which is to be expected given the amount of idle and part-load operation shown by the Unit 3. Table 7 shows the base-line energy profiles created by AirMaster+.

Table 7: AirMaster+ baseline profiles

Day	Annual Operating Hours	Average Air Flow (acfm)	Maximum Demand (kW)	Annual Energy (kWh)
Mon	988	1,969	558	436,446
Tue	1,248	2,392	551	651,134
Wed	1,248	2,473	625	671,611
Thu	1,248	2,522	589	690,232
Fri	1,248	2,371	550	622,170
Sat	1,248	2,402	552	647,681
Sun	636	1,006	539	153,244
System Total	7,864	2,258	625	3,872,518

Energy Savings:

The VFD savings has been calculated based on an estimated reduction in the compressor kW consumption. The post-case average specific power is estimated at 17.5 kW per 100 cfm. Based on the power reduction; the energy savings are estimated by utilizing the yearly profiles created by AirMaster+ and user estimated power reduction. There were not much information provided regarding how they calculated the power reduction, and the AirMaster+ models were not provided. Table 8 shows the estimated savings and demand reduction values as per the project submittal.

Table 8: Tracking Energy Savings

	Usage (kWh)	Maximum Demand (kW)
Existing	3,872,518	625
Future	3,114,284	526
Savings	758,234	99

Assessment of Tracking Methodology and Analysis

1. The savings for this project are calculated based on the plant data, which was collected for a week's period of time. It is deemed that it is difficult to capture the dynamic nature of the plant load in one week's monitoring period.
2. The operating hours used for the calculation was 7,864, and the correct operating hours for the site considering 10 holidays/per year is 8,520.
3. The demand savings were calculated based on the maximum demand experienced by the plant.
4. The post-case average specific power is estimated at 17.5 kW per 100 cfm. This value is low compared to the VSD compressor's estimated full load specific power at 138 psig is 19.98 kW per 100 cfm.
5. AirMaster+ models were not provided with the project submittal.

EVALUATION METHODOLOGY

The following sub-sections describe project scope and estimated savings based on observed site conditions. The sub-sections go over the pre-existing (baseline) and proposed operating conditions & equipment informed by the site visit and correspondence with the site contact. The sub-sections also discuss the data collection, analysis, and calculation methodology performed to estimate the evaluated savings.

Measure Verification

The Evaluation team conducted a comprehensive site visit to collect all the relevant name plate/equipment information and other controls information with respect to this project. The evaluator documented the base-line condition based on the information collected during the site visit. The EEM's with respect to this project were completed as proposed in the Tracking documentation. The evaluator collected installed equipment details from the equipment name plate, and other operational data were collected from the installed unit's display screen. The evaluator collected pressure and CFM readings from the site installed flow meters. Table 9 shows the ECMs and respective quantities installed.

Table 9: Proposed versus Implemented ECMs

Implemented ECMs	Proposed (tracking)	Implemented (evaluated)
(2) 300 HP units	Retained as lag unit	Retained as lag unit
(1) 200 HP unit	Retained as lag unit	Retained as lag unit
(1) New 390 HP VFD unit	Installed	Installed

Data Collection

The newly installed compressor as well as the existing units was either installed with elite pro loggers or HOBO loggers to monitor system operation, Amperage and true power consumption. Spot power measurements were taken for the newly installed compressor as well as the existing compressors to validate the proposed energy consumption profile. During the site inspection it was recorded that the new VFD unit and 2 out of the 3 existing compressors were operating. Additional air side data were collected from the site installed flow meters. Table 10 and 11 summarizes the Evaluation team's measurement and verification details.

Table 10: Proposed Measurement and Verification Summary

Input	Tracking Analysis Variable	Verification Method
Annual Run Hours.	8,520	Elite Logger, HOBO Logger.
Unit HP (4 units)	(1) 390 HP, (2) 300 HP and (1) 200 HP	On Site Verification
kW (2 units)	265.7 kW, 171 kW	Elite Logger
Amperage (2 units)	200 A, 416 A	HOBO Logger
Air Capacity (4 units)	926 CFM, 1,325 CFM , 1,576 CFM	On Site Verification

Table 11: Logger Information

Time-Series Data Information	
Measured Parameter	Total Package True Power (kW) and Amperage (A)
Logger Make/Model	DENT Elite Pro SP kW Logger, and HOBO Microstation
Transducer/Equipment Type	400 A CT's (12 units in total), 600 A CT's (6 units in total)
Installation Location	Outlet of VSD in Power Compartment
Observation Frequency	15 minute interval on Elite and 1 minute interval on HOBO
Metering Period	5 weeks (12/12/13 – 1/15/14)
Metered By	DNV GL and RISE electrician

Evaluation Savings Analysis

The measured kW data and the air side cfm data were used to create custom kW/cfm curves, and these curves were used to create the proposed case energy consumption model. The user created proposed case energy consumption model were utilized to estimate the plant CFM profile. The evaluator created a spreadsheet based engineering calculation to evaluate savings with respect to this project.

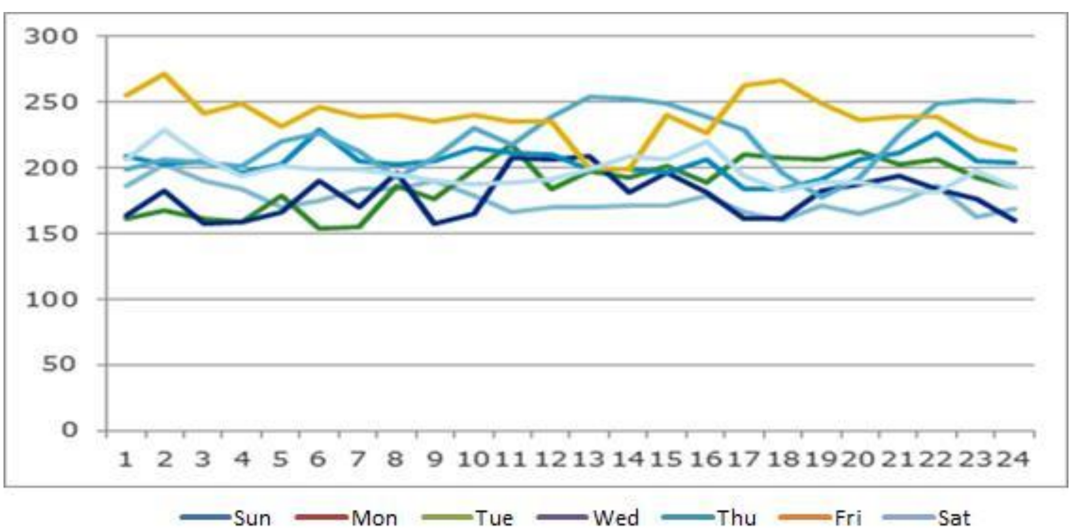
The evaluation engineer utilized the trend data collected during the onsite evaluation to develop an 8,760 compressed air load profile. Using the load profile, the evaluator calculated the pre and post retrofit kW demand using CAGI performance curves.

The peak demand reduction was calculated in compliance with the NYISO, which states that system peaks generally occur during the hour ending at 5pm on the hottest non-holiday weekday. The New York Technical Manual (TM) states that this peak occurs on Friday, July 21, 1995 between 4 P.M. – 5 P.M. However, since compressed air load at this facility is not weather dependent, the peak demand reduction was calculated as the average demand reduction between 4 P.M and 5 P.M on all non-holiday weekdays. The customer mentioned the compressors operate 24/7 throughout the year to meet the plant load and the compressors are shut down only during holidays. Based on the monitored data it is determined that the new VSD unit and the 200 HP existing unit operates continuously and (1) 300 HP unit operated few hours to satisfy the higher plant loads. The other 300 HP compressor was OFF for most period of time, and it turned ON very rarely.

Installed Scenario

The evaluator developed an hourly operating profile for the customer's compressed air system. The evaluator utilized the installed and the existing compressor time series kW data collected between 12/12/13 – 1/15/14 and compressor performance curves to generate the hourly CFM profiles. CAGI performance data and Generic Curves from the Best Practices for Compressed air Systems were used to create the CFM load profiles. The evaluator then created hourly CFM profile for Normal Day operation. Figure 2 shows the kW profiles for the VSD compressor. The different color bands indicate the Day Types.

Figure 2: (390) HP VSD unit kW profile.



The evaluator then created a lookup table which listed the average compressed air demand from the trending period based on hour and day type. This lookup table was used to generate an 8,760 load profile by matching each hour and day type throughout the year to the corresponding average compressed air demand in the lookup table. Table 12 summarizes all the compressor curve fit equations created for this project, where 'x' indicates kW and 'y' indicates CFM consumption.

Table 12: Compressor Performance Curve fitting

		CFM	Type	Size	Equation
Proposed System	VFD Unit	1,576	VFD	390 HP	CFM = 5.349 x kW - 74.118
	GA 250	1,325	Load/Unload	300 HP	$y = 0.0048x^2 + 4.7713x - 306.06$
	GA 160	926	Load/Unload	200 HP	$y = 0.0082x^2 + 5.1812x - 213.9$
Base System	GA 250	1,325	Load/Unload	300 HP	$y = 0.0048x^2 + 4.7713x - 306.06$
	GA 250	1,325	Load/Unload	300 HP	$y = 0.0048x^2 + 4.7713x - 306.06$
	GA 160	926	Load/Unload	200 HP	$y = 0.0082x^2 + 5.1812x - 213.9$

The post compressed air system power consumption was determined based on the 8,760 compressed air load profile created by the evaluator. The kW consumption and the performance curves are used to estimate the CFM needed to meet the plant load in the base-case scenario.

Pre-existing Scenario

The evaluator utilized the kW consumption and the performance curves to estimate the CFM needed to meet the plant load.

In the base-case scenario the 200-HP and the (2) 300 HP units operates continuously in load/unload mode respectively to meet the plant load.

The peak demand reduction was calculated in accordance with the guidelines stipulated by the New York Technical Manual (TM), which states that system peaks generally occur between the hours of 4PM and 5PM on non-Holiday weekdays. Therefore, the average demand reduction during these hours served as the basis for the evaluated peak demand reduction.

EVALUATION RESULTS

The difference between the baseline and the installed kW served as the basis for the annual project savings. The total evaluated electric savings were determined to be 591,081 kWh and 60.4 kW peak demand reduction. The tracking savings are 758,234 kWh and 96 kW peak demand reduction. The gross realization rates (GRR) comparing the evaluated savings to the tracking savings are 78% for kWh savings and 63% for peak demand reduction.

Primary Reasons for Savings Discrepancy

The discrepancies between the tracking and evaluated savings can be attributed to the following source:

1. Discrepancy #1 (Calculation Method) – The primary source of discrepancy is the calculation method. The tracking savings are estimated based on plant consumption data collected for a week's period.

It is deemed that it is difficult to capture the dynamic nature of the plant load in one week's monitoring period. The demand savings were calculated based on the maximum demand experienced by the plant. The post-case average specific power is estimated at 17.5 kW per 100 cfm. This value is low compared to the VSD compressor's estimated full load specific power at 138 psig is 19.98 kW per 100 cfm. The project kWh savings was reduced by 158,672.4 kWh, - 21% and the kW savings was reduced by 35.6 kW, - 37%.

SITE ID: DNVCA25

Project Type	Early Replacement and Add-On
Measure Category	Custom Compressed Air

PROJECT DESCRIPTION

The project involved the retirement of two (2) pre-existing 400-HP water-cooled, oil-injected, single-stage rotary screw compressors and one (1) pre-existing 200-HP water-cooled, oil-injected, single-stage rotary screw compressor. The retired compressors were replaced with two (2) 300-HP water-cooled, oil-injected, tandem two-stage rotary screw compressors and one (1) 350-HP water-cooled, oil-injected, tandem two-stage compressor. The project scope also involved the retrofit of the pre-existing air dryer with a 5,000 cfm cycling refrigerant air dryer, installation of a pressure flow controller, and the addition of two 3,600 gallon vertical air receiver tanks; however, only compressor and dryer replacement measures were claimed in the tracking savings. Table 1 provides the gross impact results while Table 2 provides a summary of the discrepancy analyses.

Table 1: Summary of Evaluation Results

Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
Annual Energy Savings (kWh)	1,972,489	1,216,445	62%
Peak Demand Reduction (kW)	199.28	132.0	66%

Table 2: Discrepancy Analysis Summary

Discrepancy Factor	kWh	kW
Operating Conditions	N/A (could not be assessed)	N/A (could not be assessed)
Equipment Specifications	N/A (could not be assessed)	N/A (could not be assessed)
Calculation Method	Evaluation Results - Different Calculation Method: -756,044 (-38%)	Evaluation Results - Different Calculation Method: -67.0 (-34%)
Inappropriate Baseline	N/A	N/A

TRACKING SAVINGS

The following sub-sections describe the project scope and estimated savings based on tracking data and project documentation. The sub-sections go over the pre-existing (baseline) and proposed operating conditions & equipment, the tracking data collection and analysis, and the tracking calculation methodology as interpreted from the tracking documentation. An assessment of the tracking calculation methodology is also described, with recommendations for improvement where feasible.

Project Description

The customer had a compressed air system whose demand was met by two (2) water-cooled 400-HP rotary screw compressors and one (1) water-cooled 200-HP rotary screw compressor. The facility's relatively wide range of demand expectations would benefit from a more efficient compressor staging and control strategy. It was decided that all of the pre-existing compressors would be replaced with two (2) new two-stage tandem, water-cooled, 300-HP rotary screw compressors (variable displacement) and one (1) two-stage tandem, water-cooled 350-HP variable speed (VFD) rotary screw compressor. The new compressors would be staged such that the 350-HP VFD compressor would handle trim load for the different air demand schedules, while one of the 300-HP compressors would be turned off during the lower demand periods and both 300-HP compressors would run during the peak periods. The project scope also installed a new 5,000 cfm water-cooled refrigerated cycling air dryer, two (2) new 3,800 gallon vertical air receiver tanks, and a pressure controller. These additional measures were installed to stabilize capacity, downstream air pressure, and moisture content. The air dryer was considered a "retrofit" but information on the pre-existing air dryer was not provided.

Table 3 shows the ECMs and respective quantities installed.

Table 3: Tracking ECMs

Description of ECM	Quantity
300-HP water-cooled, tandem two-stage, oil-injected rotary screw compressor with variable displacement flow control	2
350-HP water-cooled, tandem two-stage, oil-injected rotary screw compressor with variable speed (VFD) flow control	1
5,000 scfm refrigerated cycling air dryer	1
3,800 gallon vertical air receiver tank	2
Flow/Pressure Controller	1

Baseline

The pre-existing compressed air system produced air at a nominal pressure of 100 PSIG and whose demand was described using three "bucket" air demand schedules: High, Medium, and Low. The two 400-HP compressors handled the low and medium demands while the 200-HP compressor cycled on to handle the high demand periods. The pre-implementation TA report mentions that the 200-HP compressor would frequently cycle on but immediately unload and turn off because the peak periods would be just above the capacity of the two 400-HP compressors. The pre-existing equipment and air demand profile are listed below. There is no description or mention of the pre-existing air dryer other than a comment that "when the dryer retrofit is complete, this compressor [the 200-HP compressor] will not run at all". This suggests that the pre-existing dryer was a regenerative desiccant dryer that requires compressed air to purge condensate.

Table 4: Pre-Existing Equipment

Equipment Description	HP	Control	Rated PSIG	Operating PSIG	Capacity (SCFM)
Two (2) water-cooled, oil injected, single stage, rotary screw compressor	400 each	(1) Inlet modulation (1) Load/unload	100	100	1850
One (1) water-cooled, oil injected, single stage, rotary screw compressor	200	Load/unload	100	100	N/A, not reported
One (1) air dryer (presumed to be regenerative desiccant type)	N/A	Unknown	Unknown	100	Unknown, presumed to be 5,000 SCFM

Table 5: Pre-existing Compressed Air Demand Schedule

Demand Schedule	SCFM	Hours per Week	Hours per year	Reported Average Power (kW)
High	3206	65	3,380	690
Medium	2459	57	2,964	630
Low	1797	46	2,416	596

Proposed Condition

The proposed operating conditions used to model the incremental compressor replacement savings require the same air demand schedule as the pre-existing scenario, using the new compressors, compressor sequencing, and additional air storage tanks. During the low and medium demand periods, one 300-HP compressor will be sequenced to operate at full load while the VFD compressor handles trim loads. During high demand periods, both 300-HP compressors will be sequenced to operate full load while the VFD compressor handles the trim.

For the incremental air dryer replacement savings, the proposed operating conditions would require less air demand (216 SCFM as assumed in the tracking calculations) than the pre-existing scenario because the pre-existing desiccant dryer (that requires compressed air to purge condensate) will be replaced with a refrigerant air dryer. The penalty of adding additional compressor motor load (from the dryer's refrigerant compressor) is offset by the reduced air compressor load due to the removed desiccant dryer purge air demand.

Table 6: Proposed Equipment

Equipment Description	HP	Control	Rated PSIG	Operating PSIG	Rated Capacity (ACFM)
Two (2) water-cooled, oil injected, tandem two-stage rotary screw compressor	300 each	Variable Displacement	125	100	1,440 each
One (1) water-cooled, oil-injected, tandem two-stage rotary screw compressor	350	Variable Speed	125	100	1,645
Water-cooled refrigerated air dryer	N/A	Cycling/non-cycling with auto control	100	100	5,000 SCFM
Two (2) 3,800 gallon vertical air receiver tanks	N/A	N/A	N/A	N/A	N/A
Flow Pressure Controller	N/A	N/A	150 max	N/A	5,500 SCFM max

Tracking Methodology and Analysis

It appears, based on a memo (post-implementation "TA report") in the project documents dated December 27, 2011, that the final tracking savings are based on seven days of power (kW) metering for both the pre-existing and installed compressed air systems. Seven charts are provided in the memo showing the daily pre- and post-implementation loads for the seven day metering period. The charts presumably show the total pre-existing compressed air system load and total installed compressed air system load (i.e., includes the three packaged compressors and dryer load); however, no raw or tabulated summaries for important parameters like average system loads or air demand profiles were included in the memo. Furthermore, the final tracking savings does not disaggregate dryer and compressor savings. The memo whose savings (kWh) estimate is used for the final tracking savings claim is completely void of documentation or workbooks showing how the estimate was calculated[41]. The technical consultant advises that the 7-day metering periods of the pre-existing and installed compressed air systems were conducted over different time periods so the results assume that production during both metering periods were reasonably similar. The consultant also mentions that the "manufacturer's specifications were used to predict the new system performance", but the evaluator could not determine how those specifications may have been used to inform the collected post-implementation meter data. For some unknown reason, the peak demand reduction reported in the

[41] The consultant notes that "the secondary spreadsheets used for this revision is larger than e-mail limits will allow…"

final savings memo (159 kW) was not used as the final claimed tracking peak summer demand reduction. Instead, a value of 199.28 kW was used, the origin of which is unknown by the evaluator.

The pre-implementation TA report describes in greater detail how the pre-existing (and installed) compressed air system performance was measured. It appears that all of the pre-existing compressors were fitted with amp loggers to collect current data from the compressors over a seven day period. These data, along with compressor manufacturer specifications (both electric and air delivery) and typical annual operating hours of the facility, were used to develop the compressed air demand profile, operational efficiency (SCFM/kW), and annual energy consumption of the existing compressed air system over an annual period. The estimated air demand profile, as presented in Table , was then used to analyze the compressor replacement savings. Based on manufacturer data sheets and CAGI sheets, the proposed compressed air system's performance and annual energy consumption were calculated to estimate the annual energy savings (for the compressor replacements). The air dryer retrofit savings are estimated separately and incrementally, after the compressor replacements. The savings calculation assumes that the dryer retrofit will reduce the required volumetric air flow for each air demand bucket (by 216 SCFM) presumably due to the replacement of a pre-existing regenerative desiccant dryer (that requires compressed air during purging cycles) with the proposed refrigerant air dryer. The following table shows the change in assumed air demand conditions after the dryer retrofit and the refrigerated dryer load (kW) penalty:

Table 7: Air Dryer Retrofit Impact on Estimated Air Demand Profile

Demand Schedule	SCFM – Pre-implementation	SCFM – Post-implementation	New Dryer Load (kW)	Reduction in Compressor Load (kW)
High	3,206	2,990	12	31
Medium	2,459	2,243	9	42
Low	1,797	1,581	6	32

The savings penalty from the added dryer load is offset by the savings due to the reduced air compressor load.

Assessment of Tracking Methodology and Analysis

The claimed tracking savings could not be sufficiently assessed by the evaluator because the claimed savings come from a memo source with no supporting documentation on how average compressor loads (or dryer loads) were calculated for the pre-existing and installed scenarios. They appear to be based on amperage (current) data, assumed power factor (0.88) and voltages (475 or 2,300 volts), and manufacturer compressor performance data sheets. Additionally, the claimed tracking peak summer demand reduction is not documented anywhere in the project files. This information would have been helpful for the discrepancy analysis because it would have allowed the evaluator to isolate specific calculation assumptions and attribute discrepancy values in kWh and kW to those specific differences between the tracking estimates and evaluation estimates. Still, it appears that pre- and post-implementation metering was performed and summary reports were provided as requested in the Minimum Requirements Document (MRD). However, the MRD also requests that "raw data in CSV format" be retained and provided in the project documentation, but these data were not provided to the evaluator. It is recommended that future custom compressed air projects retain all data and sources used to arrive to the final claimed tracking savings so that future evaluation of those projects can assess the quality of the tracking savings more completely.

EVALUATION METHODOLOGY

The following sub-sections describe project scope and estimated savings based on observed site conditions. The sub-sections go over the pre-existing (baseline) and proposed operating conditions & equipment informed by the site visit and correspondence with the site contact. The sub-sections also discuss the data collection, analysis, and calculation methodology performed to estimate the evaluated savings.

Site Findings

The pre-existing conditions, including equipment sequencing and specifications, were largely determined from the tracking documentation. The facility site contact (a plant technician) was only able to verify the pre-existing compressor specifications, compressor sequence logic, compressor flow controls, and operating pressure given on the pre- and post-installation inspection forms. No performance or operating conditions for the pre-existing air dryer were known by the site-contact. The site contact could not specifically comment on pre-existing production levels but thought that production probably increased since the tracking monitoring period in late 2011. When queried on whether production data could be requested for the evaluation monitoring period and for the entire 2013 year, the site contact did not think that data could be made available to the evaluator[42]. The site contact did not have any specific estimates for seasonal variation in air demand but did not think it varied “widely” and that the proposed evaluation metering period (late November through mid-December) will “probably see our [the facility’s] normal production levels”.

All of the proposed energy conservation measures listed in Table 3 were verified to be installed and operating as generally proposed. The discharge (line) pressure of the compressors was observed to be steady at 102 psig. One of the 3,800 gallon air storage tank’s pressure gauge (downstream of the supply-side equipment i.e., system pressure) read 98 psig.

Table 8 shows the ECMs and respective quantities installed.

Table 8: Proposed versus Implemented ECMs

Implemented ECMs	Proposed (tracking)	Implemented (evaluated)
Two (2) 300-HP water-cooled, tandem two-stage, oil-injected rotary screw compressors with variable displacement flow control	Installed	Installed
One (1) 350-HP water-cooled, tandem two-stage, oil-injected rotary screw compressor with variable speed (VFD) flow control	Installed	Installed
5,000 scfm refrigerated cycling air dryer	Installed	Installed

[42] Additional data requests after the site visit were not successful

Two (2) 3,800 gallon vertical air receiver tanks	Installed	Installed
Flow/Pressure Controller	Installed	Installed
Two (2) 400-HP water-cooled, single-stage, oil-injected rotary screw compressors with inlet modulation and unload flow controls	Retired & Removed	Retired & Removed
One (1) 200-HP water-cooled, single-stage, oil-injected rotary screw compressors with load/unload flow controls	Retired & Removed	Retired & Removed

Evaluation Data Collection

Due to metering equipment constraints, it was decided by the evaluator to monitor the full three-phase true power (kW) of the three installed compressors and to not monitor the installed air dryer. Based on the pre-implementation TA report savings estimates, the dryer retrofit accounted for only 17% of the total project savings, with the remaining 83% attributed to the compressor replacements[43]. The evaluator reasoned that collecting accurate three-phase power data for the installed compressors would have more benefit to the overall accuracy of the evaluated savings than monitoring only two of the three installed compressors and the installed air dryer. This decision was based on the potential range in operating load of the dryer versus the compressors. The dryer represents a relatively small load (25-HP refrigerant compressor) compared to the compressor loads (totaling 950-HP in rated motor capacity with the smallest single motor capacity of 300-HP).

The installed compressors (two 300-HP two-stage compressors and one 350-HP two-stage compressor) were metered for the evaluation. The total packaged 3-phase true power of the compressor units were metered using DENT Elite Pro SP loggers with split core CTs rated at either 400A or 600A[44]. The metering period was approximately 4 weeks (November 20 to December 18, 2013) with a logging interval of 30 seconds. Spot power measurements were taken on each phase to verify that the Elite Pro loggers were recording power values with reasonable accuracy.

Other data collected during the on site visit included nameplates for the metered equipment, line (discharge) pressures for the metered compressors, and photographs of the installed ECMs (compressors, tanks, and dryer). Production data was not available (or the customer was not forthcoming with production data) for collection

The site contact had very limited information regarding the compressed air project under evaluation and the pre-existing operating conditions of both the dryer and compressors. The table below documents the instrumentation used.

[43] The final claimed tracking savings do not disaggregate air dryer replacement and compressor replacement savings so the pre-implementation savings estimate (different from the tracking savings) was the only source where the evaluator could disaggregate the project savings.

[44] Some of the compressor units had 2-wire parallel feeds for each voltage phase. The diameter of the 2 wires restricted the evaluator in some cases to meter only one of the two wire's current flow; however, since the two parallel wires were of the same gauge and length, the current flows of the two wires are very likely to be identical.

Table 9: Evaluation Measurement Summary

Time-Series Data Information	
Measured Parameter	Total packaged True Power (kW) on installed 300-HP two-stage VD compressor Total packaged True Power (kW) on installed 300-HP two-stage VD compressor Total packaged True Power (kW) on installed 350-HP two-
Logger Make/Model	DENT Elite Pro SP on installed 300-HP two-stage VD compressor DENT Elite Pro SP on installed 300-HP two-stage VD compressor
Transducer/Equipment Type	(3x) 600A split-core CTs on installed 300-HP two-stage VD compressor (3x) 400A split-core CTs on installed 300-HP two-stage VD compressor
Installation Location	All meters were installed in the power compartment of the packaged compressor units, capturing complete packaged load (including VFD losses for the variable
Observation Frequency	30 second interval
Metering Period	4 weeks (November 20 to December 18, 2013)
Metered By	DNV GL and RISE electrician

Evaluation Savings Analysis

Approximately one month of time-series true power (kW) data were collected for the three installed compressors. These data were used to directly characterize the air demand and performance of the pre-existing and installed compressed air system.

To begin the savings analysis, the metered data had the time stamps formatted for ease of processing; performance profiles were next generated for the installed and pre-existing compressors, and the installed dryer:

- *INSTALLED 350-HP water-cooled, oil-injected, two-stage tandem rotary screw compressor with variable speed flow control kW vs. CFM* – This performance curve was generated exclusively from the manufacturer’s CAGI sheet for the respective model. Since the compressor is variable-speed, the CAGI sheet lists multiple capacities and their respective packaged input power values along the performance curve at the rated outlet pressure (125 psi in this case). CAGI sheets for the respective model at rated discharge pressures of 100 and 150 psig were also collected so that a correlation between power, capacity, and discharge pressure could be determined. This correlation was used to estimate the performance curve of the compressor based on the observed discharge pressure of 102 psig. Based on the site contact interview, this discharge pressure (of 102 psig) remains relatively steady and deviates no more than “around +/- 5 psi” throughout facility operation. A quadratic power (kW) vs. capacity (CFM) trend was then formulated using these CAGI and cut sheet performance data so that time-series volumetric flow rates (ACFM) corresponding to the time-series power data (kW) collected for this compressor could be calculated.

- *INSTALLED 300-HP water-cooled, oil-injected, two-stage tandem rotary screw compressor with variable displacement flow control kW vs. CFM* – This performance curve was generated from three sources: (1) AirMaster+; and (2) manufacturer's CAGI sheet for the respective model; and (3) the manufacturer's specification sheet for the respective model. In order to develop a performance curve for this compressor model, a similarly sized (in rated HP, ACFM, and full load pressure) two-stage oil-injected rotary screw compressor with variable displacement and unloading flow controls was selected from the AirMaster+ compressor database. The default "Manufacturer Compressor Details" were then modified with the specifications found from CAGI sheet or the specifications sheet. The full load ("cut-in") pressure was adjusted from the rated pressure of 125 psi to the observed discharge pressure of 102 psi. The corresponding full load capacity at the observed discharge/operating pressure was also adjusted according to the manufacturer's cut sheet which showed the compressor model's full load capacity corresponding to various operating pressures (e.g., 100 psig, 125 psig, 150 psig). The AirMaster+ performance profile (package kW vs. acfm) was then tabulated in 10% flow increments with their corresponding packaged kW values. From this kW vs. flow table, a cubic power vs. capacity trend was formulated and used to calculate the time-series volumetric air flow rate corresponding to the metered time-series power data.
- *INSTALLED 5,000 SCFM refrigerant cycling air dryer: kW vs. CFM* – Since the installed air dryer was not metered for the evaluation, the evaluator used the manufacturer's data sheet for the respective air dryer model to retrieve the full load operating power (18 kW) and correction factors to adjust the actual air dryer capacity based on observed air temperature and pressure conditions. A linear part-load performance was assumed with the dryer shutting off completely (0 kW) during no load periods.
- *PRE-EXISTING 400-HP water-cooled, oil-injected, single-stage rotary screw compressor with inlet modulation and unload flow controls: kW vs. CFM* – This performance curve was generated from two sources: (1) AirMaster+; and (2) manufacturer's brochure specification sheet for the respective model. Pre-implementation meter data could not be used because the raw data was not available in the project documentation; however, the summarized pre-implementation compressor loads were compared on a high-level with the evaluated findings for discrepancy analysis. In order to develop a performance curve for this pre-existing compressor, a similarly sized (in rated HP, ACFM, and full load pressure) single-stage rotary screw compressor with inlet modulation and unloading flow controls was selected from the AirMaster+ compressor database. The default "Manufacturer Compressor Details" were then modified with the specifications found from the manufacturer's brochure sheet. The full load ("cut-in") pressure was adjusted from the rated pressure of 100 psig to the pre-existing discharge pressure of 102 psig. The AirMaster+ performance profile graph (packaged compressor kW vs. acfm) was then tabulated in 10% flow increments with their corresponding kW values. From this power vs. flow table, a fourth order power vs. capacity trend was formulated.
- *PRE-EXISTING 400-HP water-cooled, oil-injected, single-stage rotary screw compressor with load/unload flow controls: kW vs. CFM* – This performance curve was generated similar to the preceding 400-HP compressor but without inlet modulation flow controls. These two 400-HP compressors were of the same manufacturer and model except that this compressor did not have inlet valve modulation controls. From the generated AirMaster+ performance profile, a quadratic power vs. capacity trend was formulated.

- *PRE-EXISTING 200-HP water-cooled, oil-injected, single-stage rotary screw compressor with load/unload flow controls: kW vs. CFM* – This performance curves was generated similar to the preceding 400-HP load/unload compressor but with a different rated motor size and capacity. From the generated AirMaster+ performance profile, a quadratic power vs. capacity trend was formulated.
- *PRE-EXISTING Regenerative Desiccant Air Dryer* – Without any details on the pre-existing operating conditions of the air dryer besides the tracking purge rate assumption of 216 SCFM, the evaluator chose to use the tracking assumption to model the pre-existing air demand profile. The tracking assumption for the average purge rate of the pre-existing air dryer appears to be a reasonable estimate. The actual purge rate (CFM) of a 5,000 SCFM (heatless) desiccant air dryer would typically be higher than 216 SCFM (typical purge rates for heatless air dryers are 15% of the nominal dryer capacity or 750 SCFM in this case). The average purge rate of 216 SCFM suggests that the pre-existing air dryer might have purged in 20 minute cycles (i.e., purge on for 20 minutes, purge off for 20 minutes).

Installed Scenario

The performance (kW vs. cfm) profiles for the installed compressors described above were used to estimate the flow (CFM) corresponding to each time stamp in the metered (kW) data. One of the 300-HP compressors and the 350-HP VFD compressor were observed to operate continuously during the entire 4-week metering period while one 300-HP compressor was observed to cycle frequently between unloaded/off and partially-loaded. It appears, based on the meter data for this particular compressor that the air demand is frequently just below what is necessary for this compressor to stage on and operate at partial-load. If the time-series power of this 300-HP compressor fell below 101 kW the compressor was assumed to be unloaded and not producing compressed air (0 acfm). This threshold was determined by observing what appears to be unloading periods in the meter data. Based on the frequency of the unloading/loading periods, this 300-HP compressor appears to have been programmed to have a short unloading period (~30 seconds) and to have a short shutdown timer (around 3 minutes).

The installed dryer load was calculated for each time-stamp by applying the dryer's performance curve to the calculated installed system capacity (the sum of the three compressors).

Pre-existing Scenario

Compressor Replacement Savings:

The pre-existing scenario was broken down in to two parts to address the incremental savings from the air dryer replacement. For the compressor savings, the calculated total system flow in the installed case was used to estimate each of the three pre-existing compressors' corresponding loads. Using the pre-existing compressor sequencing logic and the kW vs. CFM performance profiles developed for the pre-existing compressors, pre-existing compressor loads corresponding to the calculated air demand were calculated for each time stamp interval.

Air Dryer Replacement Savings:

For the air dryer incremental savings, the assumed average purge rate of 216 CFM was added to the total system flow calculated for the installed case in order to model the pre-existing scenario where the heatless desiccant dryer required dry compressed air. Each of the pre-existing compressors' loads was then calculated based on this added air demand for each time stamp interval.

The difference between the pre-existing compressor loads using the installed air demands (i.e., without the pre-existing desiccant dryer purge air demand) and the installed case compressor loads for each time stamp interval is the calculated compressor demand reduction for that time interval. An hourly demand reduction profile for each weekday type (Monday through Sunday and holidays) was then developed by averaging the demand reduction corresponding to their respective hour and weekday bins. Only one profile needed to be developed because the facility does not have notable seasonal fluctuations in operation and production. The hourly demand reduction profiles were then applied to the New York TM Reference Year (1995) 8,760 profile to calculate the annual electricity savings (kWh) and the peak demand reduction. Peak demand reduction was calculated by averaging the hourly compressor demand reduction for all peak hours (4 P.M. – 5 P.M. on non-holiday week days) as defined by the NY ISO.

An air dryer hourly demand reduction profile was also developed by calculating the difference in pre-existing compressor loads between the observed (installed) air demand and the observed air demand with the additional pre-existing dryer purge air demand. That compressor load increase is then offset by the additional load from the installed air dryer. Annual energy savings and peak demand reduction for the air dryer replacement were calculated using the same method as the compressor replacement savings, described in the preceding paragraph.

EVALUATION RESULTS

The total evaluated electric savings was determined to be 1,216,445 kWh and 132.0 kW peak demand reduction. The tracking savings are 1,972,489 kWh and 199.28 kW peak demand reduction. The gross realization rates (GRR %) comparing the evaluated savings to the tracking savings are 62% for kWh and 66% for kW.

Primary Reasons for Savings Discrepancy

Isolated discrepancy analyses could not be performed because the final claimed savings do not have any supporting documentation to assess the difference between the tracking savings and the evaluated savings. Furthermore, the final claimed savings did not disaggregate compressor savings from air dryer savings; and did not provide supporting (raw) data to allow the evaluator to disaggregate the compressor and dryer savings. Any discrepancy analyses would need to leverage pre-implementation TA report values; however, the pre-implementation savings are different from the claimed tracking savings so assessment would be qualitative and speculative at best.

Peak Demand Discrepancy

1. The tracking peak demand reduction was calculated using an unknown method and could not be assessed. The evaluated peak demand reduction estimate was based on averaging the hourly demand reduction for the hour 4 P.M. – 5 P.M. for all non-holiday weekdays.