1997 INDUSTRIAL ENERGY EFFICIENCY INCENTIVES PROGRAM

FIRST YEAR LOAD IMPACT EVALUATION

FINAL REPORT

Study ID No. 1019

Prepared for

San Diego Gas & Electric
San Diego, California

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1 INTRODUCTION

1.1 INTRODUCTION

This is an evaluation of the 1997 Program Year (PY97) first year load impacts for SDG&E's industrial customers. The Industrial EEI Program help customers reduce energy costs and increase energy efficiency at their facilities. There are three major end uses covered by this report: (1) industrial process, (2) motors, and (3) lighting.

The industrial process, interior lighting and motors end use evaluations completed by XENERGY entail on-site verifications of the installation of the measures and the gathering of ex post site data that was used in the ex post evaluation,

The IEEI Program study results shown in the designated unit of measurement for each end use are as shown in Table 1-1.

Table 1-1
Study Results for the PY96 IEEI Program
First Year Load Impact Evaluation

End Use	Industrial Projects	Ex Post kWh Savings	Realization Rate	Ex Post kW Reduction	Realization Rate	Ex Post Therm Savings	Realization Rate
Indoor Lighting	101	3,846,053	97.0%	818.47	93.1%	0	0
Motors	213	430,181	107.9%	107.57	79.1%	0	0
Process	32	15,169,305	79%	1,936.91	67%	1,987,273	115%

1.2 REPORT ORGANIZATION

The report is organized into several sections.

Section 2: Study Summary: This section presents summary tables with the results of the ex post first year load impact evaluation for process, motor and lighting measures.

Section 3: Indoor Lighting Evaluation: This section discusses the evaluation approach used for this study for process and motor measures. The methodology for lighting is described in Section 6.

Section 4: Process Measures: This section contains the first year load impact study for industrial process measures.

Section 5: Motors Measure: This section contains the first year load impact study for industrial motor measures.

Section 6: Lighting Measures: This section contains the first year load impact study for industrial lighting measures.

Appendix A: Revised Table E-3 for the PY97 Industrial EEI Program.

Appendix B: Table 6 for process measures.

Appendix C: Table 6 for motor measures.

Appendix D: Table 6 for lighting measures.

Appendix E: Table 7.

Other data and information: Hard copy files of the projects evaluated and electronic files are being submitted with this report.

2 SUMMARY

This section presents a set of summary tables for the First Year Load Impact Evaluation of SDG&E's PY97 Industrial Energy Efficiency Incentives Program.

Table 2-1
Process Measures
Ex Post Load Impact Evaluation Summary
PY97 IEEI Program Process Measures

	kWh Savings	kW Reduced	Therm Savings	Total
Ex Post Gross	**15,169,305**	**1,936.91**	**1,987,273**	
Ex Ante Gross	19,248,113	2,912.42	1,726,364	
Gross Realization Rate	0.79	0.67	1.15	
Ex Post Net	**14,677,074**	**1,915.83**	**1,644,923**	
Ex Ante Net	19,000,797	2,882.83	1,553,728	
Net Realization Rate	0.7724	0.6642	1.0587	
Program Net-To-Gross Ratio	0.9676	0.9886	0.8277	
Total Participants (N)	29		3	32
Survey Participants (n)	18		3	21
Total Measures	79		5	84
Measures - Survey Participants	60		5	65

2.1 MOTOR MEASURES

Table 2-2
Summary of Ex Post Load Impacts
Motor Measures
PY97 Industrial EEI Program

	kWh Savings	kW Reduced
Ex Ante Gross	430,181	107.57
Ex Ante Net	322,636	80.68
Ex Post Gross Load Impacts	463,977	85.07
Ex Post Net Load Impacts	218,042	54.68
Gross Realization Rate	107.86%	79.09%
Net Realization Rate	67.58%	67.77%
Ex Post NTGR	0.47	0.64

2.2 LIGHTING MEASURES

Table 2-3
Summary of Ex Post Load Impacts
Lighting Measures
PY97 Industrial EEI Program

		kWh Savings	kW Reduced
Ex Ante	Total Gross	3,846,053	818.47
	Total Net	3,382,703	713.89
Ex Post	Total Gross	3,729,651	761.92
	Total Net	3,647,831	745.21
	Net-To-Gross Ratio	0.98	0.98
	Gross Realization Rate	97.0%	93.1%
	Net Realization Rate	107.8%	104.4%

3 METHODOLOGY

This section describes the methodology used to conduct SDG&E's *1997 Industrial Energy Efficiency Incentives Program First Year Load Impact Evaluation.*

3.1 OVERVIEW

The approach used to conduct the *Evaluation* utilized end-use **engineering models** with verified input assumptions. Measurements of equipment performance and monitoring of equipment operations were performed to refine the inputs into the engineering models developed for each measure. The methodology used for this study is consistent with Table C-5 of *the M&E Protocols*. The approach used for estimating *ex post* load impacts for industrial process measures is described in Section 3.2, while the approach used for estimating the *ex post* load impacts for motor measures is described in Section 3.3.

3.2 *EX POST* LOAD IMPACT ESTIMATION APPROACH FOR INDUSTRIAL PROCESS MEASURES

This section describes the approach and tasks used to conduct the site-specific impact studies for the 1997 IEEI Program.

3.2.1 Task 1: Gather Available Site Data

Site data were gathered and compiled from available sources. Typically, these sources included hard copies of customer applications, SDG&E work papers, design reports, invoices, billing information and pre-retrofit and post- retrofit field surveys. A site profile was developed from which an evaluation plan was designed.

3.2.2 Task 2: Develop Sample

A stratified sample was developed using the Dalenius-Hodges stratification approach with a Neyman allocation. The sample for process measures was selected at the project level, as identified by the Project ID No. (known as the *site_nbr* on the tracking system datasets). The total kWh savings impact for each project was used as the sampling variable. A sample design with three strata was used. Projects surveyed from Strata 1 and 2 were randomly selected. Stratum 3 was a certainty group.

3.2.3 Task 3: Develop Site Evaluation Plan

The initial evaluation plan for each site was developed by XENERGY and submitted to SDG&E for review. An example of the *general* work flow is displayed as Figure 3-1. Process sites totaling percent of savings were targeted for on-site visits. The remaining projects were subjected to a detailed file review with telephone verification of key operating factors where appropriate to the evaluation methodology.

Evaluation Approach and Methodologies

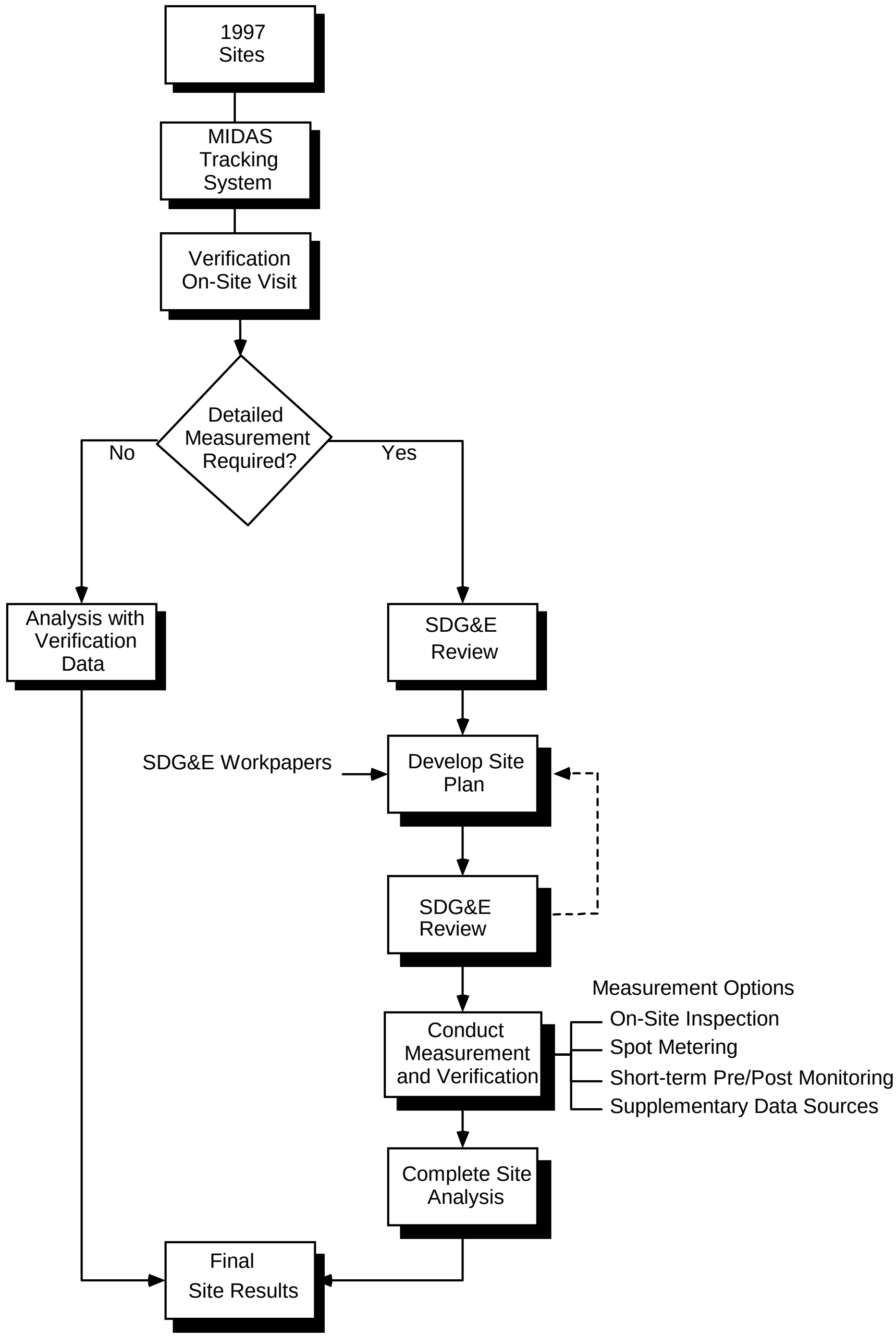
The measurement approach must take into account the various types of technologies, processes, and operations schedules found in the industrial sector.

To meet the impact measurement needs of this project, appropriate combinations of the following tools were used:

- engineering models and analysis;
- equipment data collection tools and methods;
- on-site surveys; and
- short-term metering and spot measurements.

On-site surveys were conducted to verify the installation of the measures, and to verify or improve the engineering assumptions that were used to estimate *ex ante* load impacts. Previously collected data were used to help reduce the scope of the on-site data collection effort where feasible. In most cases, project documentation provided by SDG&E was the primary source for engineering calculations of *ex ante* energy impact estimates.

Figure 3-1
General Study Work Flow



3.2.4 Task 4: Conduct Site-Specific Analysis of IEEI Program Projects

Site-specific analyses were completed for all participants of *SDG&E's 1997 Industrial Energy Efficiency Incentives Program* that installed measures classified as industrial process.

Sub-Task 4a: Develop Project-Specific Evaluation Plan

Individual evaluation plans were developed for each IEEI Program participant and summarized in spreadsheet form. Each site plan was developed individually using the appropriate methodology as discussed in Section 3.2.3.

Sub-Task 4b: Determine Gross Site-Specific Impacts

The next subtask was to estimate the gross impacts for each site.

Data Collection

On-site data collection activities were conducted from November 1998 through December 1998 for those sites evaluated using the on-site approach. Measure installations were verified, measurements were taken to support load impact estimation, and other on-site data were collected via interview with site personnel and inspection of operating records.

Gross impacts were calculated on an individual project basis.

Load Impacts For Process Measures

The gross load impacts of industrial process measures were estimated *ex post* using engineering based models. A detailed analysis based on on-site measurements and observations was carried out. The power of major electrical measures was monitored for at least one week in order to verify operating schedule and loading patterns. When monitoring was not feasible or inappropriate, the systems were observed in operation. The operating staff was interviewed and logs were reviewed to verify schedule and other key engineering assumptions used in the *ex ante* analysis.

In general, the engineering approach used to estimate the *ex ante* impacts was the basis for the *ex post* analysis. In several cases where savings were a significant proportion of total use at the site, a billing analysis, or "unit energy consumption" method was used.

3.2.5 Task 5: Estimate Total Gross Impacts

Gross impacts were estimated for the PY97 industrial energy efficiency measures. This includes total gross kW, kWh and therm impacts, as appropriate. Realization rates were calculated for each type of measure as defined in Table 6 of the *M&E Protocols*, where it is defined as "the load impacts estimated by the Evaluation, divided by the load impacts filed in a utility's first year earnings claim."

Integrate Site-Specific Gross Impacts

After the individual impacts from each project were estimated, the results were aggregated to estimate total program gross impacts.

3.2.6 Task 6: Determine Total Net Impacts

Net impacts were addressed through an assessment of the net-to-gross ratio. An interview was conducted with each site contact as part of the on-site post-installation field visit. Assessment of net-to-gross was done through self-reported responses to questions about the factors that affected the customer's decision to implement the measure recommendation, as well as supporting documentation found in project files.

A net-to-gross ratio was estimated for each measure installed based on information gathered during the site visit and from the project files. The decision rules for estimating the net-to-gross are shown in Table 3-1. Among the underlying principles upon which these rules were based is a basic consumer behavior model comprised of four steps:

1. awareness of a problem or need;
2. information gathering for solutions;
3. evaluation and (more information gathering if necessary); and
4. the purchase.

Through the IEEI Program, SDG&E has several opportunities to intervene and facilitate this consumer process. SDG&E can proactively identify energy efficiency opportunities and quantify their potential impacts and costs. The customer can be made aware of energy efficiency measures and provided information on associated costs and benefits. Incentives may be provided to reduce the cost barriers to implementation. The customer will go through an evaluation phase, where additional information may be gathered, perhaps a different equipment configuration. Finally, a decision will be made whether to implement the measure or not.

Figure 3-2 shows a decision tree that reflects the rules described in Table 3-1 for assigning the net-to-gross ratio on a site-specific basis.

Table 3-1
Decision Rules For Estimating Net-To-Gross Ratio

Level of SDG&E Involvement	Description	Net-To-Gross Ratio
High: Clear evidence that: (1) SDG&E performed or commissioned a site-specific engineering study in advance of the conceptual development of the project; or (2) the unincentivized paybacks were outside the firm's payback investment threshold and the incentive allowed the firm to invest in the measure.	The IEEI Program was primarily responsible for the development of the energy efficiency concept and/or ultimate development of the measure through a combination of technical and financial assistance.	1.00
Medium: SDG&E prepared analysis that provided cost-justification through engineering analysis and the incentives in advance of the installation of the measure. The originator of the project concept was not clear. SDG&E did however, provide clear assistance in the evaluation and implementation phases of the process.	The IEEI Program was instrumental in providing information to the customer. The project concept, however, may have been originated by a non-program source, e.g., a vendor. In these cases, project cost barriers may have been reduced through incentives offered through the program.	**If incentive influenced the decision:** If payback w/o incentive >2.0 years: 1.00 If payback w/o incentive is 0.5-2.0 years: 0.75 If payback w/o incentive <0.5 years: 0.40 **If incentive did not influence the decision:** If payback w/o incentive >0.5 years: 0.50 If payback w/o incentive <0.5 years: 0.40
Low: Little evidence of technical support and/or engineering analysis that affected the final decision making, e.g., the origination of the measure concept.	The IEEI Program appeared to have little involvement and little influence on the decision to implement. Unincentivized paybacks were not sufficiently long enough to affect the purchase decision.	**If incentive influenced the decision**: 0.40 **If incentive did not influence the decision**: 0.00

Process Measures. By evaluating information gathered from customer personnel and the project files, the net-to-gross ratios were assigned for each site. The site specific net-to-gross ratios were combined with the gross savings estimate per site to estimate the net impacts on a site-specific basis. The net impacts were then estimated to the program level. The program net-to-gross ration was calculated by dividing the ex post net load impacts by the ex post gross load impacts.

Lighting Measures. The net-to-gross ratio for lighting measures was estimated in the same manner as process measures.

Motor Measures. For motor measures, a net-to-gross ratio was estimated for each participant. Motor measures were evaluated based on: (1) the reason (as described by the customer or as indicated in the file) for the purchase of a motor; and (2) the reason for the purchase of an energy efficient motor.

3.3 *EX POST* LOAD IMPACT ESTIMATION APPROACH FOR INDUSTRIAL MOTOR MEASURES

This section provides an overview of the *ex ante* and *ex post* methodologies and general equations used for estimating the load impacts of the industrial motor measures.
For PY97, all motor measures were classified as high efficiency (HE) motors.

3.3.1 Sampling

A stratified sample was developed using the Dalenius-Hodges stratification approach with a Neyman allocation. The sample for process measures was selected at the project level, as identified by the Project ID No. (known as the *site_nbr* on the tracking system datasets). The total kWh savings impact for each project was used as the sampling variable. A sample design with three strata was used.

3.3.2 Ex Ante Load Impact Estimation Methodology - High Efficiency Motors

Each of the motor measures was installed as part of SDG&E's Energy Efficient Motor Rebate Program. Under this program, the nonresidential market in San Diego was targeted. Open Drip-Proof (ODP) and Totally Enclosed Fan-Cooled (TEFC) motors from 1 to 200 HP were included in the program. These motors were single-speed energy efficient motors. A method documented by EPRI[1] was used to estimate *ex ante* impacts for single-speed motors. Equations 3-1 and 3-2 were used to estimate *ex ante* load impacts, using standard assumptions regarding the operations of the motors. Among these assumptions were 3,000 hours of annual operation and a rated load factor for base and energy efficient motors of 0.75.

[1] Electric Power Research Institute, Engineering Methods for Estimating the Impacts of Demand-Side Management Programs, Volume 2: Fundamental Equations for Residential and Commercial End Uses, pp. 3-84 to 3-85.

$$(\text{Eq.}3-1) \qquad \Delta kWh = (units)(0.746)\left[\frac{(hp_{base})(RLF_{base})}{\eta_{base}} - \frac{(hp_{ee})(RLF_{ee})}{\eta_{ee}}\right](FLH),$$

where:

ΔkWh = gross annual energy savings,
$units$ = number of motors installed under the program,
η_{base} = efficiency of base motor,
η_{ee} = efficiency of high-efficiency motor,
hp_{base} = horsepower of base motor (hp),
hp_{ee} = horsepower of high-efficiency motor (hp),
RLF_{base} = rated load factor for the base motor,
RLF_{ee} = rated load factor for the high-efficiency motor,
FLH = full-load hours, and
0.746 = conversion factor (kW / hp).

Ex ante demand impacts were estimated using Equation 3-2.

$$(\text{Eq. } 3\text{-}2) \qquad \Delta \text{kW} = (\text{units})(0.746)\left[\frac{(\text{hp}_{\text{base}})(\text{RLF}_{\text{base}})}{\text{h}_{\text{base}}} - \frac{(\text{hp}_{\text{ee}})(\text{RLF}_{\text{ee}})}{\text{h}_{\text{ee}}}\right](\text{DF})(\text{CF}),$$

where:

ΔkW = gross coincident demand savings,
units = number of motors installed under the program,
h_{base} = efficiency of base motor,
h_{ee} = efficiency of high-efficiency motor,
hp_{base} = horsepower of base motor (hp),
hp_{ee} = horsepower of high-efficiency motor (hp),
RLF_{base} = rated load factor for the base motor,
RLF_{ee} = rated load factor for the high-efficiency motor,
FLH = full-load hours,
DF = demand diversity factor,
CF = coincidence factor, and
0.746 = conversion factor (kW / hp).

3.3.3 Ex Post Gross Load Impact Estimation Methodology

Engineering analysis with verified data on operating characteristics was the basis for *ex post* load impact estimates for motor measures. The following describes the approach used for the HE motors.

Verification of the operating conditions of the motors was performed through on-site inspections and/or telephone interviews.. Interviews with site personnel were conducted in order to confirm motor operating hours and to estimate the loading pattern.

The *ex post* estimation methodology used Equations 3-3 and 3-4 to estimate the load impacts of each of the motor measures.

$$\text{(Eq.3-3)} \qquad \Delta kWh = (units)(0.746)\left[\frac{(hp_{base})(RLF_{base})}{h_{base}} - \frac{(hp_{ee})(RLF_{ee})}{h_{ee}}\right](H),$$

where:

ΔkWh = gross annual energy savings,

$units$ = number of identical motors installed under the program,

h_{base} = efficiency of base motor at operating load factor (Motormaster),

h_{ee} = efficiency of high-efficiency motor at operating load factor (Motormaster),

hp_{base} = horsepower of base motor (hp),

hp_{ee} = horsepower of high-efficiency motor (hp),

RLF_{base} = observed operating load factor for the base motor (0.75 default),

RLF_{ee} = observed operating load factor for the high-efficiency motor (0.75 default),

H = annual operating hours (customer estimate), and

0.746 = conversion factor (kW / hp).

Ex post demand impacts were estimated using Equations 3-4 and 3-5. For most industrial systems the operation was consistent during the on-peak period. Where loads or cycle duration varied, the variation was reported to be random.

$$\text{(Eq. 3-4)} \qquad \Delta kWh_{on\text{-}peak} = (\Delta kWh_{annual}) \text{ x } \left(\frac{\text{Equipment Operating Hours}_{on\text{-}peak}}{\text{Equipment Operating Hours}_{annual}}\right),$$

where,

$\Delta kWh_{on\text{-}peak}$ = kWh savings during on-peak period,

ΔkWh_{annual} = annual kWh savings,

Equipment Operating $\text{Hours}_{on\text{-}peak}$ = total hours equipment operated during on-peak period,

Equipment Operating Hours_{annual} = total hours equipment operated per year.

$$\text{(Eq. 3-5)} \qquad \Delta kW_{on\text{-}peak} = \frac{\Delta kWh_{on\text{-}peak}}{\text{Hours}_{on\text{-}peak}},$$

where,

$\Delta kWh_{on\text{-}peak}$ = kWh savings during on-peak period,

$\text{Hours}_{on\text{-}peak}$ = Total hours during on-peak period.

Estimating Base Case For HE Motor Measures

For those sites where the new motor was a *retrofit of a working motor*, the description of the old motor from the Energy Efficient Motor Program Customer Enrollment Form (“Enrollment

Form") was used to define the base case. However, (1) for those motors where the new motor was *replacing a burned out unit,* (2) for those sites where a *new facility or application* was indicated on the "Enrollment Form," or (3) for those measures where the old motor information was not provided on the "Enrollment Form," a base case motor representing an "average" motor that would typically be purchased over the counter was developed using the following procedures.

Baseline (standard) motor efficiency data was obtained from the MotorMaster+ database (Washington State Energy Office, 1996). This database contains cost and efficiency data on more than 10,000 NEMA Design B motors. Baseline motor data was chosen by searching the database for motors with efficiencies less than the NEMA 12-6B standard and selecting the motor with the median efficiency at 100 percent load. Efficiency and Power Factor curve data were available for load conditions from 25 percent to 100 percent in quartile increments.

Load Impact Estimation of HE Motor Measures

The gross load impacts for the motors were estimated by taking the difference of energy use for the baseline and energy efficient motors.

Realization rates were calculated for the Program as defined in Table 6 of the *M&E Protocols*, where it is defined as "the load impacts estimated by the Evaluation, divided by the load impacts filed in a utility's first year earnings claim."

The realization rate was applied to the *ex ante* total kWh saved and kW reduced to estimate the Program gross load impacts.

3.3.4 Net-To-Gross Ratio

The net-to-gross ratio was estimated for motors based on customer reported responses during the survey. The information given by the customer was in response to two questions: (1) Why was the motor purchased?; and (2) Why was an energy efficient motor chosen? A net-to-gross ratio was assigned to each surveyed motor. The net-to-gross ratio was determined based on the response given by the customer for each of the two questions, as shown in Table 3-2.

Table 3-2
Net-To-Gross
Industrial Motor Measures

		Q2				
		A	**B**	**C**	**D**	**E**
Q1	1. Replace a burned out/inoperable motor	0.40	0.4	0.00	0.00	0.00
	2. To save electricity (replaced operating motor)	1.00	1.00	1.00	1.00	1.00
	3. Needed a larger motor (more HP)	0.75	0.75	0.00	0.00	0.00
	4. New application/end use/equipment	0.75	0.75	0.00	0.00	0.00
	5. Inventory/Spare	0.00	0.00	0.00	0.00	0.00
	6. Other	0.00	0.00	0.00	0.00	0.00

Q1 - Why was the motor purchased?

Q2 - Why was an energy efficient motor chosen?

- **A** - SDGE rep told me about the E.E. program
- **B** - Retail salesman told me about the E.E. program
- **C** - I heard about the incentives from a friend
- **D** - I don't remember where I heard about the incentives
- **E** - Other

The assigned net-to-gross ratios were applied to the gross *ex post* energy and demand impacts to estimate the net impacts for the motors studied. The Program net-to-gross ratio for industrial motors was estimated by dividing total net impacts by total gross impacts for the studied motors. The Program net load impacts were estimated by applying the Program net-to-gross to the total Program *ex post* gross load impacts.

4 PROCESS MEASURES

4.1 INTRODUCTION

This section presents the results of the first year load impact evaluation of process measures installed under SDG&E's PY97 Industrial Energy Efficiency Incentives Program. Simplified engineering analyses with verified inputs, as discussed in Section 3, were used to estimate the load impacts.

The remainder of this report organized as follows:

Section 4.2	describes the sampling approach
Section 4.3	presents the results of the evaluation
Sections 4-4	through 4-24 presents reports of the individual projects surveyed and evaluated in this study.

4.2 SAMPLING

The sample for process measures was selected at the project level, as identified by the Project ID No. (known as the *site_nbr* on the tracking system datasets). The total kWh savings impact for each project was used as the sampling variable. A stratified sample was developed using the Dalenius-Hodges approach. A sample design with three strata was used. Projects surveyed from Strata 1 and 2 were randomly selected. Stratum 3 was a certainty group. Table 4-1 provides an overview of the sample design.

Table 4-1
Ex Ante Load Impacts by Stratum
PY97 Industrial EEI Program
Process Measures

Stratum	Ex Ante kWh Savings	N	n	Min. kWh Savings	Max kWh Savings
1	602,561	13	5	0	146,832
2	3,775,494	10	6	146,833	823,435
3	14,870,058	8	8	823,436	3,444,389
Total	**19,248,113**	**31**	**19**		

4.3 RESULTS

This section presents the results of the ex post fist year load impact evaluation. These results used data from the individual project reports presented in Sections 4-3 through 4-24. A summary of the program and survey participants is shown in Table 4-2.

Table 4-2
Program Summary
PY97 IEEI Program Process Measures

Stratum	Survey	Project ID No.	Measure Description	Meas. Qty	Ex Ante Gross kWh Savings	Ex Ante Gross kW Reduced	Ex Ante Gross Therm Savings	Ex Ante NTGR	Meas. Qty Survey	kWh Savings Survey	kW Reduced Survey	Therm Savings Survey
1	yes	14201	Duct Burners & HRSG Rerating	3			452,760	0.90	3			452,760
1	yes	47489	Temperature Control Modulating Systems	3	17,340	0.00		0.90	3	17,340	0.00	
1	yes	51143	Combined Compressed Air Systems	1	47,391	31.47		1.00	1	47,391	31.47	
1	yes	48467	Catalytic Thermal Oxidizer w/Heat Exchanger	1			501,757	0.90	1	,,		501,757
1	yes	49180	IPA Column #3 w/Heat Recovery	1			695,647	0.90	1			695,647
1		19413	Screw Compressor w/capacity Control System	1	109,000	4.50		0.90				
1		45649	Air Compressor Replacement	1	89,122	9.35		1.00				
1		46517	Efficient all electric injection molding machine	2	94,800	15.80		0.90				
1		47422	Efficient Heat Treat Furnace	1			76,200	0.90				
1		47599	Control Valves	1	17,812	2.03		0.90				
1		47599	Control Valves	1	99,896	11.40		0.90				
1		49376	Injection molding machine w/VFD	1	55,200	9.20		0.90				
1		49572	Electra Injection Molding Machine	1	72,000	12.00		0.90				
Stratum 1 Subtotal				**18**	**602,561**	**95.75**	**1,726,364**		**9**	**64,731**	**31.47**	**1,650,164**
2	yes	46113	5 hp pony recip air compressor	1	146,833	0.00		0.90	1	146,833	0.00	
2	yes	49944	VFD	1	161,302	22.00		0.90	1	161,302	22.00	
2	yes	44734	Efficiency Compress Air Sys 1x100hp & 3x20hp	1	219,876	25.10		1.00	1	219,876	25.10	
2	yes	50154	Injection mold machines drum w/insulation blanke	29	391,119	62.68		0.90	29	391,119	62.68	
2	yes	50009	Plastic injection machines with VFDs	7	426,139	56.90		0.90	7	426,139	56.90	
2	yes	47988	Compressed Air System w/Controls	1	555,388	48.66		1.00	1	555,388	48.66	
2		46575	Injection Molding Machines w/ VSDs	4	220,800	36.80		0.90				
2		48124	Modified Compress Air System	1	823,435	214.30		1.00				
2		48989	VFDs 2 x 100 HP	2	660,918	62.60		0.90				
2		50702	Modified Compressed Air Systems	3	169,684	17.38		1.00				
Stratum 2 Subtotal				**50**	**3,775,494**	**546.42**	**0**		**40**	**1,900,657**	**215.34**	**0**

(continued)

Table 4-2 (continued)- Program Summary PY97 IEEI Program Process Measures

Stratum	Survey	Project ID No.	Measure Description	Meas. Qty	Ex Ante Gross kWh Savings	Ex Ante Gross kW Reduced	Ex Ante Gross Therm Savings	Ex Ante NTGR	Meas. Qty Survey	kWh Savings Survey	kW Reduced Survey	Therm Savings Survey
3	yes	48562	Compressed Air System w/Storage & Controls	1	855,249	150.30		1.00	1	855,249	150.30	
3	yes	46628	Modifications to Supply Side & Demand Side	1	861,326	356.00		1.00	1	861,326	356.00	
3	yes	46697	Compressed Air Sys w/ controls & storage	1	934,800	117.00		1.00	1	934,800	117.00	
3	yes	48698	Vacuum Pump Generation System	1	935,480	106.79		1.00	1	935,480	106.79	
3	yes	47445	Optimized Comp Air Sys w/ 3 Compressors	1	986,911	93.67		1.00	1	986,911	93.67	
3	yes	48652	Compressed Air System w/Controls & Storage	1	988,222	238.15		1.00	1	988,222	238.15	
3	yes	46572	Plant Compressed Air Sys w/Automation & Storage	1	1,338,949	280.00		1.00	1	1,338,949	280.00	
3	yes	48378	Compressed Air System w/Automation & Controls	1	1,777,020	182.38		1.00	1	1,777,020	182.38	
3	yes	46324	Air Compressors System Controls & Storage	7	2,747,712	205.00		1.00	7	2,747,712	205.00	
3	yes	48605	Compressed Air System w/Controls & Storage	1	3,444,389	540.96		1.00	1	3,444,389	540.96	
Stratum 3 Subtotal				**16**	**14,870,058**	**2,270.25**	**0**		**16**	**14,870,058**	**2,270.25**	**0**
Total				**84**	**19,248,113**	**2,912.42**	**1,726,364**					
Percent of Total												
Stratum 1				**50%**	**3.1%**	**3.3%**	**100.0%**					
Stratum 2				**25%**	**19.6%**	**18.8%**	**0.0%**					
Stratum 3				**25%**	**77.3%**	**78.0%**	**0.0%**					

Table 4-3 shows a summary of the first year load impact evaluation.

Table 4-3 Ex Post Load Impact Evaluation Summary PY97 IEEI Program Process Measures

	kWh Savings	kW Reduced	Therm Savings	Total
Ex Post Gross	**15,169,305**	**1,936.91**	**1,987,273**	
Ex Ante Gross	19,248,113	2,912.42	1,726,364	
Gross Realization Rate	0.79	0.67	1.15	
Ex Post Net	**14,677,074**	**1,915.83**	**1,644,923**	
Ex Ante Net	19,000,797	2,882.83	1,553,728	
Net Realization Rate	0.7724	0.6642	1.0587	
Program Net-To-Gross Ratio	0.9676	0.9886	0.8277	
Total Participants (N)	28		4	32
Survey Participants (n)	18		3	21
Total Measures	78		6	84
Measures - Survey Participants	60		5	65

4.3.1 Gross Load Impacts

To estimate the program load impacts the load impacts from each of the individual project analyses was used. The average gross realization rate was calculated for Strata 1 and 2. The ex post gross load impacts for Strata 1 and 2 were calculated by applying the average realization rates to the ex ante gross load impacts for the strata. Stratum 3 was a certainty group, thus the ex post load impacts for Stratum 3 were estimated by summing the load impacts from the individual project analyses. Table 4-4 shows the gross realization rates. Table 4-5 shows the ex post load impact estimates for the strata and program.

Table 4-4
Gross Realization Rates
PY97 IEEI Program Process Measures

				Ex Ante Gross			Ex Post Gross			Gross Realization Rate		
Strat-um	**Survey**	**Project ID**	**Measure Description**	**kWh Savings**	**kW Reduced**	**Therm Savings**	**kWh Savings**	**kW Reduced**	**Therm Savings**	**kWh Savings**	**kW Reduced**	**Therm Savings**
1	yes	14201	Duct Burners & HRSG Rerating	0	0.00	452,760			621,909			1.3736
	yes	48467	Catalytic Thermal Oxidizer w/Heat Exchanger	0	0.00	501,757			497,510			0.9915
	yes	49180	IPA Column #3 w/Heat Recovery	0	0.00	695,647			757,049			1.0883
	yes	47489	Temperature Control Modulating Systems	17,340	0.00		17,667	2.00		1.0189		
	yes	51143	Combined Compressed Air Systems	47,391	31.47		57,317	14.30		1.2094	0.4544	
2	yes	46113	5 hp pony recip air compressor	146,833	0.00		128,587	0.00		0.8757		
	yes	49944	VFD	161,302	22.00		139,836	15.90		0.8669	0.7227	
	yes	44734	Efficiency Compress Air Sys 1x100hp & 3x20hp	219,876	25.10		192,287	20.40		0.8745	0.8127	
	yes	50154	Injection mold machines drum w/insulation blanke	391,119	62.68		485,782	60.11		1.2420	0.9590	
	yes	50009	Plastic injection machines with VFDs	426,139	56.90		408,378	55.60		0.9583	0.9772	
	yes	47988	Compressed Air System w/Controls	555,388	48.66		561,212	67.34		1.0105	1.3839	
3	yes	48562	Compressed Air System w/Storage & Controls	855,249	150.30		1,254,460	253.30		1.4668	1.6853	
	yes	46628	Modifications to Supply Side & Demand Side	861,326	356.00		431,006	77.40		0.5004	0.2174	
	yes	46697	Compressed Air Sys w/ controls & storage	934,800	117.00		906,184	107.57		0.9694	0.9194	
	yes	48698	Vacuum Pump Generation System	935,480	106.79		707,527	83.99		0.7563	0.7865	
	yes	47445	Optimized Comp Air Sys w/ 3 Compressors	986,911	93.67		145,936	28.86		0.1479	0.3081	
	yes	48652	Compressed Air System w/Controls & Storage	988,222	238.15		673,165	111.20		0.6812	0.4669	
	yes	46572	Plant Compressed Air Sys w/Automation & Storage	1,338,949	280.00		694,740	79.31		0.5189	0.2833	
	yes	48378	Compressed Air System w/Automation & Controls	1,777,020	182.38		1,743,798	199.83		0.9813	1.0957	
	yes	46324	Air Compressors System Controls & Storage	2,747,712	205.00		2,777,300	266.37		1.0108	1.2994	
	yes	48605	Compressed Air System w/Controls & Storage	3,444,389	540.96		1,496,568	176.70		0.4345	0.3266	
Total Surveyed				**16,835,446**	**2,517.06**	**1,650,164**	**12,821,750**	**1,620.18**	**1,876,468**			

Table 4-5
Ex Post Gross Load Impacts
PY97 IEEI Program Process Measures

			Gross Realization Rate			Gross Stratum Realization Rate			Total Ex Ante Gross Impacts per Stratum			Ex Post Gross Impacts per Stratum		
Stratum	Survey	Project ID	kWh Savings	kW Reduced	Therm Savings	kWh Savings	kW Reduced	Therm Savings	kWh Savings	kW Reduced	Therm Savings	kWh Savings	kW Reduced	Therm Savings
1	yes	14201			1.3736	1.1142	0.2272	1.1511	602,561	95.75	1,726,364	671,346	21.75	1,987,273
	yes	48467			0.9915									
	yes	49180			1.0883									
	yes	47489	1.0189											
	yes	51143	1.2094	0.4544										
2	yes	46113	0.8757			0.9713	0.9711		3,775,494	546.42	0	3,667,276	531	0
	yes	49944	0.8669	0.7227										
	yes	44734	0.8745	0.8127										
	yes	50154	1.2420	0.9590										
	yes	50009	0.9583	0.9772										
	yes	47988	1.0105	1.3839										
3	yes	48562	1.4668	1.6853								1,254,460	253.30	0
	yes	46628	0.5004	0.2174								431,006	77.40	0
	yes	46697	0.9694	0.9194								906,184	107.57	0
	yes	48698	0.7563	0.7865								707,527	83.99	0
	yes	47445	0.1479	0.3081								145,936	28.86	0
	yes	48652	0.6812	0.4669								673,165	111.20	0
	yes	46572	0.5189	0.2833								694,740	79.31	0
	yes	48378	0.9813	1.0957								1,743,798	199.83	0
	yes	46324	1.0108	1.2994								2,777,300	266.37	0
	yes	48605	0.4345	0.3266								1,496,568	176.70	0
Ex Post Gross												**15,169,305**	**1,936.91**	**1,987,273**
Ex Ante Gross												**19,248,113**	**2,912.42**	**1,726,364**
Gross Realization Rate												**0.79**	**0.67**	**1.15**

4.3.2 Net Load Impacts

The net load impacts were estimated by calculating the ex post load impacts for the survey group. The ex post net load impacts were calculated by multiplying the ex post net-to-gross ratio by the ex post gross load impacts. The average net realization rate was calculated for each surveyed project. The average net realization rate was calculated for Strata 1 and 2. The ex post net load impacts were estimated for Strata 1 and 2 by multiplying the average net realization rate for the strata by the total ex ante net load impacts for the strata. The ex post net load impacts for Stratum 3 were calculated by summing the ex post net load impacts for each project in Stratum 3. The program ex post net-to-gross ratio was calculated by dividing the total ex post net load impacts by the total ex ante net load impacts. Table 4-6 shows the estimation of the net realization rates. Table 4-7 shows the calculation of the net load impacts and net-to-gross ratio.

Table 4-6
Net Realization Rates
PY97 IEEI Program Process Measures

			Ex Ante Net Load Impacts				Ex Post Net Load Impacts				Net Realization Rate		
Stratum	Survey	Project ID	Ex Ante NTGR	kWh Savings	kW Reduced	Therm Savings	Ex Post NTGR	kWh Savings	kW Reduced	Therm Savings	kWh Savings	kW Reduced	Therm Savings
1	yes	14201	0.90	0	0.00	407,484	1.00	0	0.00	621,909			1.5262
	yes	48467	0.90	0	0.00	451,581	0.40	0	0.00	199,004			0.4407
	yes	49180	0.90	0	0.00	626,082	1.00	0	0.00	757,049			1.2092
	yes	47489	0.90	15,606	0.00	0	0.40	7,067	0.80	0	0.4528		
	yes	51143	1.00	47,391	31.47	0	1.00	57,317	14.30	0	1.2094	0.4544	
2	yes	46113	0.90	132,150	0.00	0	1.00	128,587	0.00	0	0.9730		
	yes	49944	0.90	145,172	19.80	0	0.75	104,877	11.93	0	0.7224	0.6023	
	yes	44734	1.00	219,876	25.10	0	1.00	192,287	20.40	0	0.8745	0.8127	
	yes	50154	0.90	352,007	56.41	0	0.75	364,337	45.08	0	1.0350	0.7992	
	yes	50009	0.90	383,525	51.21	0	1.00	408,378	55.60	0	1.0648	1.0857	
	yes	47988	1.00	555,388	48.66	0	1.00	561,212	67.34	0	1.0105	1.3839	
3	yes	48562	1.00	855,249	150.30	0	1.00	1,254,460	253.30	0	1.4668	1.6853	
	yes	46628	1.00	861,326	356.00	0	1.00	431,006	77.40	0	0.5004	0.2174	
	yes	46697	1.00	934,800	117.00	0	1.00	906,184	107.57	0	0.9694	0.9194	
	yes	48698	1.00	935,480	106.79	0	1.00	707,527	83.99	0	0.7563	0.7865	
	yes	47445	1.00	986,911	93.67	0	1.00	145,936	28.86	0	0.1479	0.3081	
	yes	48652	1.00	988,222	238.15	0	1.00	673,165	111.20	0	0.6812	0.4669	
	yes	46572	1.00	1,338,949	280.00	0	1.00	694,740	79.31	0	0.5189	0.2833	
	yes	48378	1.00	1,777,020	182.38	0	1.00	1,743,798	199.83	0	0.9813	1.0957	
	yes	46324	1.00	2,747,712	205.00	0	1.00	2,777,300	266.37	0	1.0108	1.2994	
	yes	48605	1.00	3,444,389	540.96	0	1.00	1,496,568	176.70	0	0.4345	0.3266	

Table 4-7
Ex Post Net Load Impacts
PY97 IEEI Program Process Measures

			Net Realization Rate			Net Realization Rate per Stratum			Total Ex Ante Net Impacts per Stratum			Ex Post Net Impacts per Stratum		
Stratum	**Survey**	**Project ID**	**kWh Savings**	**kW Reduced**	**Therm Savings**	**kWh Savings**	**kW Reduced**	**Therm Savings**	**kWh Savings**	**kW Reduced**	**Therm Savings**	**kWh Savings**	**kW Reduced**	**Therm Savings**
1	yes	14201			1.5262	0.83	0.45	1.06	555,956	90.26	1,553,728	462,076	41.01	1,644,923
	yes	48467			0.4407									
	yes	49180			1.2092									
	yes	47489	0.4528											
	yes	51143	1.2094	0.4544										
2	yes	46113	0.9730			0.95	0.94	-	3,574,783	522.32	0	3,384,314	489.29	0
	yes	49944	0.7224	0.6023										
	yes	44734	0.8745	0.8127										
	yes	50154	1.0350	0.7992										
	yes	50009	1.0648	1.0857										
	yes	47988	1.0105	1.3839										
3	yes	48562	1.4668	1.6853					855,249	150.30	0	1,254,460	253.30	0
	yes	46628	0.5004	0.2174					861,326	356.00	0	431,006	77.40	0
	yes	46697	0.9694	0.9194					934,800	117.00	0	906,184	107.57	0
	yes	48698	0.7563	0.7865					935,480	106.79	0	707,527	83.99	0
	yes	47445	0.1479	0.3081					986,911	93.67	0	145,936	28.86	0
	yes	48652	0.6812	0.4669					988,222	238.15	0	673,165	111.20	0
	yes	46572	0.5189	0.2833					1,338,949	280.00	0	694,740	79.31	0
	yes	48378	0.9813	1.0957					1,777,020	182.38	0	1,743,798	199.83	0
	yes	46324	1.0108	1.2994					2,747,712	205.00	0	2,777,300	266.37	0
	yes	48605	0.4345	0.3266					3,444,389	540.96	0	1,496,568	176.70	0
Total Net Load Impacts									**19,000,797**	**2,882.83**	**1,553,728**	**14,677,074**	**1,915.83**	**1,644,923**
Total Ex Ante Net												19,000,797	2,882.83	1,553,728
Net Realization Rate												0.7724	0.6642	1.0587
Program Net-To-Gross Ratio												0.9676	0.9886	0.8277

4.4 PROJECT ID 14201 - DUCT BURNERS & HEAT RECOVERY STEAM GENERATOR RERATING

4.4.1 Summary of Findings

The savings for this site were based on the installation of larger duct burners in the customer's cogeneration heat recovery steam generator (HRSG) to generate steam to displace steam production from a less efficient 35 year old package boiler. Though the new burners were installed, gas input was restricted to pre-retrofit volumes by air pollution district operating permit conditions. However, the customer reports that APCD approval was obtained in January 1999, and full firing of the post retrofit equipment commenced January 20, 1999. Based on data gathered during the ex post site visit a reduction of 621,909 therms/year in natural gas use will be realized for 1999 and during subsequent years. These annual impacts are summarized in Table 4-8.

Table 4-8
Summary of Ex Post Load Impacts
Project No. 14201

	kWh	kW	Therms
Ex Ante	n/a	n/a	452,760
Ex Post	n/a	n/a	621,909
Realization Rate	n/a	n/a	137.4%

4.4.2 Facility Description

This site manufactures food additives. An onsite cogeneration plant consisting of three 8-MW gas turbine/generator sets with HRSG's equipped with duct burners generates all of the power, and most of the process steam consumed at the site. The 125 psig saturated steam produced is used in the plant for product drying, distillation heat, generating hot process water, and sterilizing equipment. Four package boilers supplement the steam production from the cogeneration HRSG's.

4.4.3 Overview of Facility Schedule

This facility operates 24 hours per day seven days per week, year round except for one 12 hour period when high voltage switch gear is serviced and cleaned. There are a series of maintenance shutdowns for each gas turbine each year, which taken together result in a total of 15 days down for each turbine each year. The plant runs at capacity, and production levels are consistently high throughout the year.

The current shift schedule is three eight-hour shifts per day, seven days per week for production workers, and one eight-hour shift per day, five days per week for office workers.

The ex post hours of operation are therefore:

$$\text{Ex Post Hours of Operation} = 8{,}760 \text{ hours / year} - (15 \text{ days} \times 24 \text{ hrs / day}) - 12 \text{ hours / yr}$$

$$= 8{,}388 \text{ hours / year}$$

4.4.4 Measure Description

Six new 3-inch diameter duct burners and associated piping, valves and controls were installed on the outlet ducts from the cogeneration gas turbines to provide additional heat input to the HRSG's and produce an additional 20,000 lbs/hr of 125 psig saturated steam to the plant. The post-retrofit duct burners replaced six depreciated 2-inch diameter burners. The increased steam production will displace steam production from existing package Boiler #6 which was shut down and removed. Boiler #6 is a 35 year old boiler built without a preheat economizer. Due to its age and current condition, it operates with a high blowdown rate which limits its output to 21,000 lbs/hr of 125 psig saturated steam, though its nameplate rating is 26,000 lb/hr. It's full load efficiency is measured to be 66.9%, while the measured efficiency of the HRSG with duct burners is 87.6%.

Natural gas purchased from SDG&E is fed as fuel to the cogeneration gas turbines at 350 psig from the utility transmission line. The gas is mixed with compressed air and burned. The hot products of combustion are used to spin the gas turbine rotors. Mechanical output from the rotating turbine shafts drives generators that produce virtually all of the power required to run the customer's plant. Excess power generated beyond that consumed on site is wheeled to the utility power grid. After exiting the turbine, the hot exhaust gases are admitted to a Heat Recovery Steam Generator (HRSG) to generate plant steam from the waste heat. Duct burners at the turbine exhaust provide additional heating of this stream to increase the steam output of the HRSG. Since the duct burners are located down stream of the turbines, no additional power is generated by firing these burners.

The efficiency of a distillation system was concurrently upgraded in a separate project rebated under Project No. 49180. Though Project No. 49180 reduced the plant consumption of 125 psig saturated steam, it had no interactive effects on Project No. 14201.

Pre-Retrofit Conditions

- Three 8-MW gas turbine/generator sets with HRSG's equipped with 2-inch duct burners producing all of the plant power demands and 160,000 lb/hr of saturated 125 psig steam.

- Three package boilers producing up to 140,000 lb/hr saturated 125 psig steam loading as necessary to supplement the cogeneration steam production.
- Production facility operates 24 hours per day, seven days per week, except during 12 hour maintenance period for high voltage switch gear servicing periods when the plant is shut down.
- Production workers work three eight-hour shifts per day, seven days per week, while office workers work one eight-hour shift per day, five days per week.
- The plant runs at capacity, and production levels are consistently high throughout the year.

Post-Retrofit Conditions

- Three 8-MW gas turbine/generator sets with HRSG’s equipped with 3-inch duct burners producing all of the plant power demands and 160,000 lb/hr of saturated 125 psig steam.
- Three package boilers producing up to 140,000 lb/hr saturated 125 psig steam loading as necessary to supplement the cogeneration steam production.
- Gas input to the duct burners is restricted to pre-retrofit levels by programming the positioners of the gas admission valves to not open past a position specified on the APCD permit to operate.
- Production facility operates 24 hours per day, seven days per week, except during one 12 hour maintenance period when the entire plant is shut down to service high voltage switch gear.
- Production workers work three eight-hour shifts per day, seven days per week, while office workers work one eight-hour shift per day, five days per week.
- The plant runs at capacity, and production levels are consistently high throughout the year.

4.4.5 Ex Ante Load Impact Estimates

The *ex ante* impact estimates were based on a site-specific study of the facility’s steam system conducted by a process industry consultant provided by SDG&E’s IEEI Program. The plant “pinch” study comprised a detailed audit, including an inventory of steam production system equipment, current operating procedures, measurements of existing system operating performance, evaluation of the plant requirements and performance (steam balance), and recommendations that would reduce steam system operating costs, including energy savings. Spot measurements were made to verify the current operating parameters of the system. The results of this monitoring revealed the opportunity to improve the system efficiency by generating more steam in the HRSG and eliminating Boiler #6 from the system.

The total ex ante load impact was 452,760 therms saved per year based on 8,400 hours per year of operation.

Electrical impacts from the shut down of Boiler #6 fans was not included in the program impacts because virtually no electrical power is purchased from SDG&E at this site.

Ex Ante Algorithms

Based on assumed pre-retrofit efficiencies of the boiler and the HRSG, a post-retrofit heat input reduction was calculated according to the following general equation:

$$\text{Average Heat Reduction} = (\text{Incremental Steam Prod}) \times (\text{Latent Heat of Evaporation}) \times \left(\frac{1}{\text{Boiler Eff}} - \frac{1}{\text{HRSG Eff}} \right)$$

$$= (20{,}000 \text{ lb / hr}) \times (1{,}000 \text{ Btu / lb}) \times \left(\frac{1}{0.75} - \frac{1}{0.94} \right)$$

$$= 5.39 \text{ MMBtu / hr}$$

Based on ex ante operating hours of 8,400 hours per year, annual gas savings was predicted to be:

$$\text{Annual Gas Savings} = (5.39 \text{ MMBtu / hr}) \times (8{,}400 \text{ hrs / yr}) \times (1 \text{ therm / } 100{,}000 \text{ Btu})$$

$$= 452{,}760 \text{ therms / yr}$$

Ex Ante Basecase Definition

For the ex ante basecase (pre-retrofit), the three 8-MW gas turbine HRSG's run simultaneously, producing 160,000 lb/hr of 125 psig saturated steam from the hot turbine exhaust supplemented by the heat from firing *six 2-inch diameter duct burners*. Additional steam is produced in *three package boilers* as necessary to satisfy plant steam needs.

Ex Ante Postcase Definition

For the ex ante postcase (post-retrofit), the three 8-MW gas turbine HRSG's run simultaneously, producing 180,000 lb/hr of 125 psig saturated steam from the hot turbine exhaust supplemented by the heat from firing *six 3-inch diameter duct burners*. Additional steam is produced in *two package boilers* as necessary to satisfy plant steam needs. *Boiler #6, the least efficient pre-retrofit package boiler was shut down* and demolished.

Ex Ante Operating Schedule

This facility operates 24 hours per day, seven days per week, year round except for a total of 15 days down for gas turbine and generator maintenance for each gas turbine train each year. The plant runs at capacity, and production levels are consistently high throughout the year.

The current shift schedule is three eight-hour shifts per day, seven days per week for production workers, and one eight-hour shift per day, five days per week for office workers.

The ex ante hours of operation of the duct burners are therefore:

$$\text{Ex Ante Hours of Operation} = (8{,}760 \text{ hours/year}) - (15 \text{ days} \times 24 \text{ hrs/day})$$

$$= 8{,}400 \text{ hours/year}$$

The plant runs at capacity, and production levels are consistently high throughout the year.

Key Ex Ante Assumptions

- Assumed that post-retrofit steam demand remains high enough to require full output of HRSG's.
- Assumed that pre- and post-retrofit production schedules would be the same.
- Assumed latent heat of evaporation of 1,000 Btu/lb.

Ex Ante Data Sources

- Compressor nameplate data and manufacturer's equipment data sheets.
- Spot measurements of equipment.
- Customer interviews.

4.4.6 Ex Post Load Impact Estimates

The efficiency of the pre- and post-retrofit equipment was calculated based on manufacturer's nameplate data and test run monitoring data. The efficiencies of the HRSG duct burners and boiler #6 were determined by dividing the calculated change in enthalpy in the steam produced by the input gas heat. These values were used to determine the gas savings using a methodology similar to the ex ante calculation.

Ex Post Postcase Definition

For the ex post postcase (post-retrofit), the three 8-MW gas turbine HRSG's run simultaneously, producing 160,000 lb/hr of 125 psig saturated steam from the hot turbine exhaust supplemented by the heat from firing six 3-inch diameter duct burners. Additional steam is produced in three package boilers as necessary to satisfy plant steam needs. Boiler #6 is the least efficient pre-retrofit package boiler was to be removed from operation when the duct burners were operating.

The customer's ex post APCD permit to operate the post-retrofit duct burners restricts the heat output of the new burners to pre-retrofit levels. Negotiations to mitigate the emission impacts from higher firing rates have been ongoing since the application for the permit to construct was submitted. The customer reported that a resolution was reached in January, 1999, and that full firing of the post-retrofit equipment commenced January 20, 1999. Until that time, the customer had to restrict firing of the post-retrofit burners to no more than the firing rate of the pre-retrofit burners by limiting the fuel gas flow to the burners to the pre-retrofit rates. This was accomplished by programming the positioners on the gas admission valves to not open past the point that allows more gas to flow than was allowed. Thus, from January 20, 1999, the installed measures were generating natural gas savings. Prior to January 20, 1999 the measures were installed but were not allowed to operate at a level that would generate savings.

Ex Post Operating Schedule

This facility operates 24 hours per day, seven days per week, year round except for one 12-hour period when high voltage switch gear is serviced and cleaned. There are a series of maintenance shutdowns for each gas turbine each year, which taken together result in a total of 15 days down for each turbine each year. The plant runs at capacity, and production levels are consistently high throughout the year.

The current shift schedule is three eight-hour shifts per day, seven days per week for production workers, and one eight-hour shift per day, five days per week for office workers.

The ex post hours of operation of the duct burners are therefore:

$$\text{Ex Post Hours of Operation} = (8{,}760 \text{ hours/year}) - (15 \text{ days} \times 24 \text{ hrs/day}) - (12 \text{ hours/yr})$$

$$= 8{,}388 \text{ hours/year}$$

The plant runs at capacity, and production levels are consistently high throughout the year.

Ex Post Production Level Changes

Installation of the energy efficiency measures did not affect the production level of the plant. Plant steam demand is less in the ex post environment due to other conservation initiatives. This lower level of demand is still high enough to require all of the output from the HRSG's supplemented by two package boilers. The third package boiler, Boiler #6, runs partially loaded most of the time and provides steam as necessary to satisfy high instantaneous demands.

Data Collected Ex Post

Test run data was obtained from a boiler efficiency check performed by the HRSG manufacturer on site in January of 1997. Additional test run data was obtained of the operation of Boiler #6 in January of 1999.

The test run data shown in Table 4-9 were used in the ex post analysis to determine the efficiency of the HRSG.

Table 4-9
Test Run Data For HRSG Efficiency Check
Project No. 14201

% Duct Burner		0%	50%	75%	100%
Duct Burner Fuel Flow	scf/hr	-	13,262	20,425	33,500
Boiler Feed Water Flow	Mlb/hr	35.2	45.8	52.2	62.4
Economizer Inlet Temp.	°F	220	220	220	220
Economizer Outlet Temp.	°F	338	334	322	321
Steam Drum Pressure	psig	126.8	135.2	139.3	144.2
Steam Header Pressure	psig	123.9	123.6	128.4	125.7
Steam Flow	Mlb/hr	35.9	45.8	52.2	62.4

The data shown in Table 4-10 were used in the efficiency check of Boiler #6.

Table 4-10
Test Run Data for Boiler #6
Project No. 14201

Boiler Load	25%	50%	75%	100%
Total Burner Fuel Flow, scfh	15,500	25,000	29,200	34,500
Total Steam Make, lb/hr	10,500	16,300	18,000	21,000
Feedwater Inlet Temp., °F	220	220	220	220
Steam Drum Pressure, psig	125.3	125.3	125.3	125.3
Enthalpy of Boiler Feedwater, Btu/lb	187.7	187.7	187.7	187.7
Enthalpy of Steam @ Steam Drum Pressure, Btu/lb	1,193.0	1,193.0	1,193.0	1,193.0

HRSG Enthalpy Analysis

Based on the above data, an enthalpy analysis was performed to determine the net heat input to the HRSG and the heat content of the steam production. Published standard enthalpy data for the various HRSG flow points were utilized and are shown in Table 4-11.

Table 4-11
Published Standard Enthalpy Data[1]
Project No. 14201

% Duct Burner		0%	50%	75%	100%
Enthalpy of Water @ Economizer Inlet	Btu/lb	187.7	187.7	187.7	187.7
Enthalpy of Water @ Economizer Outlet	Btu/lb	308.6	304.4	292.3	290.7
Enthalpy of Steam @ Steam Drum Pressure	Btu/lb	1,193.1	1,194.0	1,194.5	1,194.9

For each operating mode, the change in enthalpy of the stream was calculated by subtracting the enthalpy of the water at the economizer inlet from the enthalpy of the steam at the steam drum

[1] CRANE Technical Paper No. 410, *Flow of Fluids Through Valves, Fittings and Pipe,* Twenty Fifth Printing, Properties of Saturated Steam and Water, pages A-12 and A-14.

pressure to get the total change in enthalpy of the steam in Btu/hr. This value was multiplied by the change in water rate to get the Btu/hr imparted to the steam.

The heat input from the fuel gas was found by multiplying the fuel gas flow rate by the lower heating value of the natural gas (0.901 × Higher Heating Value).

The efficiency of the HRSG duct burners is the ratio of the heat output (MBtu's Steam/Water Out) divided by the heat input generated by burning the fuel gas (MBtu's Fuel In). This is summarized in Table 4-12.

Table 4-12
HRSG Duct Burner Efficiency Calculation
Project No. 14201

% Duct Burner		**0%**	**50%**	**75%**	**100%**
Fuel Higher Heating Value	Btu/scf	1,011.0	1,011.0	1,011.0	1,011.0
Change in Water Enthalpy	Btu/lb	120.9	116.7	104.6	103.0
Change in Steam Enthalpy	Btu/lb	884.5	889.6	902.2	904.2
MBtu's Steam/Water Out	Btu/hr	0	9,962.4	16,410.8	26,690.8
MBtu's Fuel In	Btu/hr	0	12,080.5	18,605.4	30,515.5
Efficiency	%	0%	82.5%	88.2%	87.5%

The ex post efficiency of the HRSG duct burners at full firing is therefore 87.5 %.

Boiler #6 Enthalpy Analysis

Based on the above findings, an enthalpy analysis was performed to determine the net heat input to Boiler #6 and the heat content of its steam production. Boiler #6 is a 35 year old boiler operating at a high blowdown rate due to its current mechanical condition. It was not equipped with an economizer. Published enthalpy data for the various boiler flow points were utilized and are shown in Table 4-11.

The Heat Output from the boiler, in Btu/hr, is the enthalpy of the steam minus the enthalpy of the boiler feed water times the steam rate. At full load:

$$\text{Heat Output}_{\text{full load}} = (21{,}000\ \text{lb/hr}) \times ((1{,}193.0\ \text{Btu/lb}) - (187.7\ \text{Btu/lb}))$$

$$= 21{,}111\ \text{Btu/hr}$$

The Heat Input from the fuel gas is found by multiplying the fuel gas flow rate by the lower heating value of the natural gas (0.901 × Higher Heating Value).

$$\text{Heat Input}_{\text{full load}} = (0.901) \times (1{,}015 \text{ Btu / scf}) \times (34{,}500 \text{ scf / hr})$$

$$= 31{,}551 \text{MBtu / hr}$$

The *efficiency of the boiler* is the ratio of the *heat output* divided by the *heat input*.

$$\text{Efficiency of Boiler 6}_{\text{full load}} = \frac{21{,}111 \text{ Btu / hr}}{31{,}551 \text{ Btu / hr}}$$

$$= 66.9\%$$

Following the same methodology, part load efficiencies were calculated and are summarized in Table 4-13.

Table 4-13
Boiler #6 Efficiency Calculation
Project No. 14201

Boiler Load	**25%**	**50%**	**75%**	**100%**
Heat Output	10,556	16,386	18,095	21,111
Heat Input	14,175	22,863	26,704	31,551
Efficiency	74.5%	71.7%	67.8%	66.9%

Ex Post Savings

Based on the measured post-retrofit efficiencies of the boiler and the HRSG, a post-retrofit heat input reduction was calculated, where ΔEnthalpy is the change in enthalpy/lb between the boiler feed water and the produced steam with a value of 1005.3 Btu/lb. As of January 20, 1999, the APCD permitting issues were resolved, and maximum firing rates was achieved in the HRSG duct burners. The average heat reduction is:

$$\text{Average Heat Reduction}_{\text{from Jan. 20, 1999}} = (21{,}000 \text{ lb / hr}) \times (1{,}005.3 \text{ Btu / lb}) \times \left(\frac{1}{0.669} - \frac{1}{0.875}\right)$$

$$= 7.4 \text{ MMBtu / hr}$$

Based on ex ante operating hours of 8,388 hours per year, annual gas savings are projected to be:

$$\text{Annual Gas Savings}_{\text{from Jan. 20, 1999}} = (7.4 \text{ MMBtu / hr}) \times (8{,}388 \text{ hrs / yr}) \times (1 \text{ therm / 100,000 Btu})$$

$$= 621{,}909 \text{ therms / yr}$$

Due to the permitting process by the APCD, the actual startup of the duct burners was delayed. It was anticipated that the permit could be transferred from the inefficient Boiler #6 to the very efficient duct burners. The APCD, though, required a more intensive process that delayed the permitting. Thus, for 1998 the

$$\text{Average Heat Reduction}_{1998} = \text{Incremental Steam Prod} \times \Delta\text{Enthalpy} \times \left(\frac{1}{\text{Boiler Eff}} - \frac{1}{\text{HRSG Eff}} \right)$$

$$= (0 \text{ lb/hr}) \times (1{,}005.3 \text{ Btu/lb}) \times \left(\frac{1}{0.669} - \frac{1}{0.875} \right)$$

$$= 0.00 \text{ MMBtu/hr}$$

This estimate equates to an ex post first year annual savings of 0 therms/year.

Annualization of Results

The average basecase and postcase therm savings were extended to the 8,760-hour annual period using the schedule discussed above in the ex post Operating Schedule section. According to customer staff, this facility operates a nearly identical schedule year-round. The only variation occurs during gas turbine/HRSG maintenance overhauls.

4.4.7 Summary of Gross Impacts

Table 4-14 shows a summary of the ex post load impacts and a comparison with the ex ante impact estimates.

Table 4-14
Summary of Ex Post Load Impacts
Project No. 14201

	kWh	kW	Therms
Ex Ante	n/a	n/a	452,760
Ex Post	n/a	n/a	621,909
Realization Rate	n/a	n/a	137.4%

This is higher than ex ante estimates because the measured ex post efficiency of Boiler #6 is 66.9% versus the ex ante estimate of 75%. This is partially offset by the following:

- The measured ex post efficiency of the HRSG is 87.5% versus the ex ante estimate of 94%.
- Ex post hours of operation are 8,388 versus ex ante estimates of 8,400 hours/year.

4.4.8 Net-To-Gross Ratio

The net-to-gross ratio for this project is 1.0. SDG&E had a high level of involvement having originated the project concept and apprising the customer of the potential for savings, provided the process consultant who did the monitoring and performed the engineering analysis. The customer performed all design, procurement and installation activities.

Motivation

The motivation for the project was inspired by the cost reduction opportunity. The project was initiated by SDG&E, who apprised the customer of the potential for savings, provided the process consultant who did the monitoring and performed the engineering analysis. The customer performed all design, procurement and installation activities. According to the customer, this equipment would not have been installed without the assistance of SDG&E. Though helpful, project economics were compelling enough that it probably would have been built without the program rebate.

Non-Energy Costs and Benefits

No non-energy costs or benefits resulted from the installation of the equipment.

Equipment Alternatives

The pre-retrofit duct burners would have been replaced like and kind had this project not been installed. An additional project to increase the firing rate of the gas turbines was considered but could not be justified with the additional requirements imposed by the APCD. However, following the January, 1999 agreement between the customer and the APCD, the customer reports that modification of the first gas turbine to increase firing rate is underway, and that the other two turbines are expected to be upgraded before the end of 1999.

4.5 Project ID 44734 - Install Storage, Cross-Connection and Pressure Controls; Operate Three 20-HP Reciprocating Compressors Rather Than One 100-HP Screw Compressor

4.5.1 Summary of Findings

Modifications were made to the compressed air plant of a manufacturing facility to allow the use of three 20-hp reciprocating compressors and controls to serve a load previously served by one 100-hp compressor operating under load/unload control strategy. Improved controls, increased storage and a "demand expander" also provided for more stable operating conditions.

Table 4-15 presents a comparison of ex ante and ex post gross kWh and kW impacts.

Table 4-15
Summary of Ex Ante and Ex Post Gross kWh and kW Impacts
Project No. 44734

	kWh	kW	Therms
Ex Ante	219,613	25.07	n/a
Ex Post	192,287	20.4	n/a
Realization Rate	87.6%	81.2%	n/a

The ex post kWh impacts are 192,287 kWh saved per year, 87.6% of the ex ante estimate of 219,613 kWh. The ex post kW impacts are 20.4 kW reduced, 81.2% of the ex ante estimate of 25.07 kW.

The primary reason for the kW and kWh discrepancies is a small difference between the measured ex post post-retrofit compressor operating kW versus the calculated kW used in the ex ante estimates.

The additional discrepancy in the kW value is caused by small variations in the seasonal and time-of-use loading patterns that result in slightly smaller than proportional kW impacts in the on-peak TOU period versus the semi-peak and off-peak TOU periods.

4.5.2 Facility Description

The building in which the modification took place is a cleanroom laboratory building. The building is part of a large defense weapons production, testing and storage facility.

4.5.3 Overview of Facility Schedule

The building systems operate continuously. The control and test systems require 100 psi continuously.

4.5.4 Measure Description

The pre-retrofit air compressor system consisted of one 100-hp screw compressor and three 20-hp reciprocating compressors connected in parallel, but operating independently. The controls were set such that the 100-hp compressor operated as the lead compressor and the 20-hp compressors operated only as back up if the 100-hp compressor failed. The measures installed consisted of a new central compressor control system, a new storage reservoir, and a "demand expander" that allows the system to provide the necessary air flow with reduced compressor horsepower and time of operation.

Prior to the retrofit the 100-hp compressor operated as the lead compressor and the three 20-hp compressors acted as backup. The 100-hp compressor operated continuously in unloaded mode, loading very infrequently to provide air at 100 psi as the system air was consumed.

The storage and "demand expander" was added, and system controls were revised such that the three 20-hp compressors cycled as the "lead" units and the 100-hp compressor setpoint was set at 90 psi so it operates as an emergency backup. The 20-hp reciprocating compressors cycle on and off periodically to provide the required pressure.

4.5.5 Ex Ante Load Impact Estimates

The ex ante load impact estimates were based on an engineering analysis of the air compressor system operations conducted by SDG&E. The kW demand of the 100-hp air compressor was monitored to estimate the basecase average kW demand. The postcase average kW demand was estimated for a single 20-hp reciprocating air compressor that was assumed to handle the plant's compressed air requirements after the installation of the storage and control systems. The difference in average kW demand between the basecase and postcase air compressors was multiplied by the hours of operation to estimate the ex ante kWh savings.

Ex Ante Basecase

The ex ante basecase equipment inventory is shown in Table 4-16.

Table 4-16
Ex Ante Basecase Equipment Inventory
Project ID 44734

Basecase
1 Ingersol Rand 100-hp screw compressor operating as "lead"
3 20-hp 3-cylinder recip compressors operating as back-up
The plant's compressed air requirement was met by the 100-hp compressor.
The air compressor operates 8,760 hours per year.

The ex ante basecase consisted of the 100-hp air compressor operating at a (measured) average kW demand of 42.12 kW to meet the compressed air requirements of the plant. The operation of this air compressor was monitored ex ante as the basis for the basecase system average operating kW demand. These data indicate an average compressor demand of 42.12 kW.

Ex Ante Postcase

The ex ante postcase equipment inventory is shown in Table 4-17. The operation of this system took advantage of high pressure storage and control systems, to enable the three 20-hp compressors to meet the plant's compressed air requirements.

Table 4-17
Ex Ante Postcase Equipment Inventory
Project ID 44734

System Changes Verified
Replaced an existing condensate drain valve with a non blow-by type to reduce air losses.
Installed pressure regulation valve to control high pressure storage.
Reduced end use pressure from 125 psi to 100 psi.
Converted 100-hp screw compressor from the primary compressor to back-up service.
Bank of 3-20-hp compressors is used to meet the plant load.

The *average operating kW demand* for one 20-hp reciprocating compressor was calculated, assuming full load amperage and power factor, to be 17.05 kW.

Ex Ante Operating Schedule

The 100-hp compressor was monitored at 1-minute intervals for several days prior to the retrofit. The data included in the project file indicate that the compressor operated continuously, i.e., 8,760 hours per year. The file data also indicate that the compressor operated at an average power of 42.17 kW.

Ex Ante Load Impact Calculations

The ex ante kW impact was calculated directly as the difference between the ex ante basecase kW and postcase kW. The kW impact was multiplied by the ex ante hours of operation to calculate the ex ante gross annual kWh impact, as shown in Table 4-18.

Table 4-18
Ex Ante Load Impact Calculations
Project ID 44734

Ex Ante Impact Calculations		
Demand Savings (kW)		
Existing kW demand	42.12	Average pre-retrofit demand measured for 100-hp screw compressor
Less proposed kW demand	17.05	Projected demand for 20-hp recip compressor
kW Savings	**25.07**	
	x 8,760	Operating Hours per Year
Annual kWh Savings	**219,613**	

Ex Ante Data Sources

- Monitored data of 100-hp air compressor kW demand at ten second intervals for one day.
- Nameplate data for 20-hp compressors.

4.5.6 Ex Post Load Impact Estimates

An engineering calculation methodology based on verified pre-retrofit kW, and monitored post-retrofit operating kW and operating load profile was used. Post-retrofit kW was monitored at 30 minute intervals for two weeks as a basis for post-retrofit compressor operating kW and loading schedule.

Ex Post Basecase

The basecase for the ex post analysis consisted of the pre-retrofit system operation and average power consumption as described in the ex ante analysis. The ex post basecase was not changed from that described in the ex ante analysis as the compressed air load had not changed according to the customer contact.

Ex Post Operating Schedule

Pre-retrofit: The 100-hp compressor operated continuously and loaded to 125 psi on demand 8,760 hours per year. The 20-hp compressors served as backup.

Post-retrofit: The three 20-hp compressors cycle on and off on demand for air at 100 psi 8,760 hours per year. The 100-hp compressor operates as backup.

Ex Post Production Level Changes

No production level changes occurred as a result of, or were caused by the equipment installation. The system improvements allowed the system distribution pressure to be decreased to provide the same level of service as prior to the retrofit. The quantity (flow) of compressed air remained the same as prior to the retrofit.

Data Collected Ex Post

Operating power of the three active 20-hp compressors at 30-minute intervals for 12 days.

Ex Post kWh Savings and TOU Impacts

The ex post kW reduced was calculated directly as the difference between the measured average pre-retrofit compressor operating kW and the measured average post retrofit compressor operating kW.

$$\text{Ex Post kW Reduced} = kW_{\text{pre-retrofit}} - kW_{\text{post-retrofit}},$$

where:

$$kW_{\text{pre-retrofit}} = \text{measured average pre-retrofit compressor operating kW; and}$$

$$kW_{\text{post-retrofit}} = \text{measured average post-retrofit compressor operating kW.}$$

The gross ex post annual kWh savings is calculated as the ex post kW reduced times the total operating hours per year (8,760 for continuous operation).

$$\text{Ex Post Annual kWh Savings} = (\text{Ex Post kW Reduced}) \times (\text{Annual Operating Hours})$$

Table 4-19 summarizes the ex post load impact calculation.

Table 4-19
Ex Post Load Impact Calculations
Project No. 44734

Existing Equipment 1 Ingersol Rand 100-hp screw compressor (continuous modulating operation) 3 20-hp 3 cylinder recip compressors (on/off cyclic operation)		
Assumptions		
Annual Operating Hours	8,760	The compressed air system operates continuously, year-round.
Ex Post Load Impact Calculations		
Demand Reduced (kW)		
$kW_{pre\text{-}retrofit}$	42.12	=Average demand measured for 100-hp screw compressor - pre-retrofit kW
$kW_{post\text{-}retrofit}$	20.17	=Average demand measured for 3-20-hp screw compressors post-retrofit kW
kW Reduced	**21.95**	=(Pre-Retrofit kW) - (Post-Retrofit kW)
Annual kWh Savings	**192,287**	= (Gross kW Reduced) x (Annual Operating hours)

kWh Impacts by TOU Period

Gross kWh impacts for costing period *c* were determined by calculating a factor that represents the proportion of annual savings that occurs during each time-of-use period based on the ex post monitoring results. The ex post monitoring period was considered to be representative of typical operations at this facility. The following steps were used:

1. The average post-retrofit kW (of all compressors) for each operating hour of each "Daytype" (Daytype 1 = Weekdays, Daytype 2 = Weekend/Holidays) was calculated from the monitoring data.
2. The total annual kWh for each hour of each Daytype was calculated by multiplying the average hourly kW by the 254 for weekdays (the number of working weekdays in 1998) and 111 (to account for 104 weekend days per year and 7 holiday weekdays).
3. The kWh for the daily hours in each seasonal TOU period were summed.
4. The kWh sum for the hours that occur during each summer time-of-use period was multiplied by 5/12 to reflect TOU consumption during the five summer season months.

The total kWh which occur during each winter TOU period were multiplied by 7/12 to calculate the total which applies to each TOU period during the winter season.

5. The kWh in each TOU period for the year were summed and divided by the total kWh to calculate a "TOU period kWh consumption weighting factor."
6. The ex post total annual kWh savings was multiplied by the TOU period weighting factor" to calculate the kWh savings for each TOU period.

The process for estimating the TOU factors and ex post load impacts by TOU period is shown in the following equations:

$$\left(\text{Total kWh Usage for Each Hour}_{\text{daytype}}\right) = \left(\text{Average Post - Retrofit kW for Each Hour}_{\text{daytype}}\right) \times \left(\text{No. Days}_{\text{daytype}}\right),$$

where:

$$\text{No. Days}_{\text{daytype}} = 254 \text{ days for weekdays}$$
$$= 111 \text{ days for weekends}$$

$$\left(\text{Sum of kWh Usage for Each TOU Period}\right) = \sum \begin{pmatrix} \text{Total kWH Usage for Each Hour}_{\text{daytype}} \text{ in} \\ \text{each summer and winter TOU period} \end{pmatrix}$$

$$\left(\text{Adjusted kWh Usage for Each TOU Period}\right) = \left(\text{Sum of kWh Usage for Each TOU Period}\right) \times \left(\text{Seasonal Adjustment Multiplier}\right)$$

where:

$$\text{Seasonal Adjustment Multiplier} = \left(\frac{5}{12}\right) \text{for summer; and}$$

$$= \left(\frac{7}{12}\right) \text{for winter.}$$

$$\left(\text{Total Annual kWh Usage}\right) = \sum_{p} \text{Adjusted kWh Usage for Each TOU Period},$$

where:

p = the six TOU periods.

$$\left(\text{TOU Adjustment Factor for Each TOU Period}\right) = \frac{\text{Adjusted kWh Usage for Each TOU Period}}{\text{Total Annual kWh Usage}}$$

$$(\text{Ex Post kWh Savings by TOU Period}) = (\text{Ex Post Gross kWh Savings}) \times (\text{TOU Adjustment Factor for Each TOU Period}).$$

The system at this site operates continuously and the compressed air demand is nearly constant, therefore, the TOU period impacts are *nearly* the same as the proportion of annual hours represented by each TOU period.

Table 4-20 shows the factor for each TOU period.

Table 4-20
Ex Post TOU kWh and kW Impacts
Project No. 44734

Season	Period	Total Hours	TOU Adjustment Factor	kWh Savings	Average kW
Column	B	C	D	E	F
Notes			based on monitoring from "Hr kW Data"	Total from Col. C ×(Total Annual kWh Savings)	Col. E/ Col. C
Summer	On-peal	749	0.0793	15,253	20.4
	Semi-peak	963	0.1059	20,359	21.1
	Off-peak	1,960	0.2313	44,470	22.7
Winter	On-peak	441	0.0460	8,847	20.1
	Semi-peak	1,911	0.2135	41,050	21.5
	Off-peak	2,736	0.3240	62,308	22.8
Total Annual kWh Saving				**192,287**	

Gross kW Impacts By TOU Period

Average gross kW impacts was calculated for each costing period by dividing the total kWh impacts for the TOU period by the total number of hours in the TOU period.

$$\text{Average kW Reduced}_c = \frac{\text{kWh Savings}_c}{\sum_{i \in c} \text{hours}_c}$$

The results are shown in Table 4-20.

Gross kW Impact Coincident with System Peak

The kW impacts coincident with the system maximum during each costing period is best-represented by the average kW impacts, because the impacts are nearly constant and vary only slightly within each TOU period. The average summer on-peak period kW reduced is reported as the ex post kW impact for this project. The ex post summer on-peak kW reduced was 20.4 kW, as shown in Table 4-20.

4.5.7 Summary of Gross Impacts

Table 4-21 presents a comparison of ex ante and ex post gross kWh and kW impacts.

Table 4-21
Comparison of Ex Ante and Ex Post Gross kWh and kW Impacts
Project No. 44734

	kWh	kW	Therms
Ex Ante	219,613	25.07	n/a
Ex Post	192,287	20.4	n/a
Realization Rate	87.6%	81.2%	n/a

The ex post kWh impacts are 192,287 kWh saved per year, 87.6% of the ex ante 219,613 kWh estimate. The ex post kW impacts are 20.4 kW reduced, 81.2% of the ex ante 25.07 kW impact estimate. The primary reason for the kW and kWh discrepancies is a difference between the measured ex post post-retrofit compressor operating kW versus the calculated kW used in the ex ante estimates.

The additional discrepancy in the kW value is caused by small variations in the seasonal and time-of-use loading patterns that result in slightly lower than proportional kW impacts in the on-peak TOU period versus the semi-peak and off-peak time-of-use periods.

4.5.8 Ex Post Net-To-Gross Ratio

The net-to-gross ratio is 1.00. SDG&E staff conducted an audit and identified the energy efficiency opportunity at this facility. They did the initial engineering and helped specify the system. SDG&E ‘s level of involvement was high. Thus, the 1.00 NTGR.

4.6 PROJECT NO. 46113 - INSTALLATION OF FIVE HORSEPOWER AIR COMPRESSOR TO REPLACE 60 HP COMPRESSOR DURING OFF-PRODUCTION HOURS

4.6.1 Summary of Findings

A new five horsepower reciprocating compressor with an on/off control was installed and tied into a compressed air system to provide nighttime control air pressure when larger production air compressors were not needed.

Table 4-22
Summary of Gross Ex Post Load Impacts
Project No. 46113

	kWh	kW	Therms
Ex Ante	146,832	0	n/a
Ex Post	128,587	0	n/a
Realization Rate	87.6%	-	n/a

The gross ex post annual impact was 128,587 kWh versus the 146,832 kWh ex ante estimate, for a gross realization rate of 87.6 %. The ex post estimate agrees with the 0 kW ex ante demand impact estimate. The primary reasons for the kWh discrepancy involved several minor offsetting factors. These included:

1. One hour less off-production time during weekday nights was found in the ex post monitoring resulting in 251 *fewer* annual effective hours for the measure.
2. Ten greater off-production days (240 *additional* effective operating hours) due the inclusion of ten annual holidays in the ex post calculations;
3. A smaller difference between the ex post basecase and retrofit compressor operating kW than was calculated for the ex ante estimate, due to a different ex post extrapolation of the basecase compressor performance curve than was used in the ex ante estimate.

4.6.2 Facility Description

The facility is a metal products chemical treating plant. The plant consists of several large tanks into which metal parts are dipped and held for various periods at elevated temperatures. Compressed air is used to operate pneumatic pumps and valves, tank agitation, mixing and cleaning/drying. During non-production hours, compressed air is required only to maintain system pressure and only minimal compressed air flow for control valves and other pneumatic equipment is required.

4.6.3 Overview of Facility Schedule - Ex Ante estimate

- The facility operates in production mode (typically) from 4 A.M. until 10 P.M. five days per week.
- The air compressor system operates in *non-production mode* all day on weekend days and holidays, and from 10 P.M. to 4 A.M. on weekdays.
- The project impacts occur only during the non-production hours.

4.6.4 Measure Description

This project involved the installation of a 5-hp reciprocating air compressor with an on/off control to replace a 60-hp rotary screw air compressor with modulating capacity control during non-production hours.

4.6.5 Ex Ante Load Impact Estimates

The ex ante analysis used an engineering calculation methodology, using calculated motor load factors and the observed off-production operating strategy for the pre-retrofit equipment. The energy use of the basecase 60-hp screw compressor operating in modulation (throttled) control mode and the postcase 5-hp reciprocating compressor operating under on/off (cycling) control mode was calculated for non-production hour operation. The ex ante estimates used calculated values of pre- and post-retrofit compressor power for the 10 cfm non-production airflow using typical compressor performance curves for the 60-hp screw-type compressor and the 5-hp reciprocating compressor.

Ex Ante Basecase

The ex ante basecase was the existing 60-hp screw air compressor operating in modulation mode (continuous motor operation with cyclic partial loading) during the non-production hours.

Ex Ante Postcase

The ex ante postcase was a new 5-hp air reciprocating air compressor operating in on/off cycling mode to provide the non-production-hour air flow and pressure requirement. The 60-hp screw compressor was manually shut down during this period. A 5-hp reciprocating air compressor with a nominal motor efficiency rating of 86.5% was installed.

Ex Ante Algorithms and Load Impact Estimates

Table 4-23 presents the ex ante impact estimate calculations. Assumptions and algorithms are shown in the right-hand column.

Table 4-23
Ex Ante Load Impact Estimates
Project No. 46113

Assumptions		
Night Air Requirement	10 SCFM	Customer's estimate
Hours of Operation - Annual	4584	Based on the following schedule: M-F 2200-0600; and Sat/Sun 0-2400
Pre-Retrofit Energy Consumption - 60-hp Screw Compressor		
Max Capacity (CFM)	240 CFM	Based on estimated 4 cfm/hp for typical screw compressor.
Compressor Motor HP	60	Site Data
Motor Efficiency	0.91	Site Data
Aftercooler Fan Motor HP	2	Site Data
Aftercooler Fan Motor Efficiency	0.77	Site Data
Operating Point (percent of capacity)	0.04	Operating point = Actual SCFM/Capacity SCFM (10 cfm/240 cfm)
Load Factor	0.67	Load Factor = %Motor Nameplate HP at %-Capacity, from part load curve for screw compressor in modulating mode. (Curve is included in Project File)
Aftercooler Load Factor	0.9	SDG&E Estimate
Pre-Retrofit *Compressor* Energy Consumption during off-production hours (kWh/year)	151,066	kWh = HP x 0.746/(Motor Eff.) x Load Factor x Operating Hours
Pre-Retrofit Aftercooler Energy Consumption (kWh/year)	7,994	kWh = HP x 0.746/Motor Eff. X 0.9 Load Factor x Operating Hours
Total Energy - Pre-retrofit	**159,060**	
Post-Retrofit Energy Consumption With 5-HP Pony Compressor		
Max Capacity (CFM)	17	Based on 3.4 CFM/HP for typical recip compressor
Compressor Motor HP	5	Site Data
Motor Efficiency	0.865	Site Data
Operating Point (percent of capacity)[4]	0.59	Operating point (Cycle Factor) = 10 Actual SCFM/ 17 Capacity SCFM
Load Factor (Cycle Factor)[5]	0.59	Load (Cycle) Factor = %Motor Nameplate HP at %-Capacity, (Linear load to input power relationship for cycling).
Existing Compressor Energy Consumption[6] (kWh/year)	12,228	KWh = HP x 0.746/Motor Eff. x Load Factor x Operating Hours
Total Energy - Post-retrofit	**12,228**	
Ex Ante Energy Savings		
Total Energy -Pre-retrofit	159,060	Energy Consumption with Existing Compressor
Total Energy - Post-retrofit	12,228	Energy Consumption with Pony Compressor
Ex Ante Energy Savings	**146,832**	Total Energy "Pre-retrofit" - Total Energy - Post-retrofit
Ex Ante Demand Savings	**0**	Savings occur off-peak, therefore there are no demand benefits

4.6.6 Ex Post Load Impact Estimates

An engineering calculation methodology was used to estimate the ex post load impacts of this measure. The ex post estimates were based on monitored power and energy of the pre- and post-retrofit air compressor system, and calculated pre-retrofit air compressor system operating power for the observed post-retrofit operating hours. The analysis took place in several steps:

1. The postcase compressor power was measured and recorded at 15-minute intervals for two weeks.

2. The post-retrofit compressor operating demand kW was calculated from the power measurements.
3. The airflow for the postcase compressor was calculated using the typical performance of the compressor type and control strategy.
4. The corresponding operating power for the same period was calculated using the basecase compressor performance curve and operating strategy described from pre-retrofit observations in the project file.
5. The difference between the pre-retrofit compressor operating power and the post-retrofit air compressor operating power was calculated for the hours during which the smaller post-retrofit compressor replaced the larger pre-retrofit compressor. A summary is shown in Table 4-24.
6. The average difference was applied to all hours during the year that the post-retrofit compressor replaced the pre-retrofit compressor.
7. The sum of the kWh for all the operating hours is the ex post gross kWh impact.
8. No gross kW impacts were projected ex ante or found ex post as the system operates only during the off-peak time-of-use period.

Table 4-24
Ex Post kW Impact Calculation
Project No. 46113

	Postcase kW	Basecase kW	kW Impact
Overall Avg.	3.03	35.25	32.22
Night Average	2.92	35.22	32.30
Weekend/Holiday Avg.	3.08	35.27	32.18

Ex Post Basecase

The ex post basecase system consisted of the pre-retrofit 60-hp screw compressor system and modulating control strategy. The basecase equipment was the same as used in the ex ante estimates, however the compressor operating power used in the ex post calculations was less than the input power used in the ex ante estimate due to a slightly different extrapolation of the compressor power curve at the low flow rate of the non-production hours.

Ex Post Operating Schedule

The ex post operating schedule differed slightly from the schedule used for the ex ante estimates. The ex post operating schedule was based on the following schedule information gathered during the ex post site visit.

- The facility operates in production mode typically from 4 A.M. until 11 P.M. five days per week.

- The compressor system operates in non-production mode all day on weekends and 10 annual holidays and from 11 P.M. to 4 A.M. on weekdays.
- The project impacts occur only during the non-production hours.

Ex Post Production Level Changes

No production changes apply to the analysis for this project. The savings impact occurs in the non-production operating hours of the facility.

Data Collected Ex Post

The operating amperage of the main compressor and the 5-hp reciprocating compressor that was installed under this project was measured and recorded at 15-minute intervals for two weeks. Hourly kW values for both compressors were calculated from the measured amperage.

Interviews were carried out with production management to determine the annual operating schedule and relate annual operation to the two week monitoring period. The monitoring period was representative of daily and hourly operating patterns across the year, including the holiday period .

Ex Post kWh Savings and TOU Impact Estimates

The ex post annual kWh savings were calculated by the following steps:

1. The 5-hp compressor power (*Post kW*) was calculated from 15-minute amperage readings using the formula:

$$\text{Postcase kW}_{\text{5-hp}} = \frac{A \times V \times \Phi \times (\text{Power Factor})}{1{,}000 \text{ Watts / kW}},$$

where:

A = average hourly measured amps during the monitoring period;

V = volts

= 460 volts;

Φ = Phase Adjustment Factor (= $\sqrt{2}$)

= 1.732

Power Factor = 0.85.

2. The operating kW of the basecase 60-hp compressor operating under the 10 cfm nighttime load was derived from tabular power/load curve for the compressor as described in the ex ante methodology. A slightly different value was derived for the ex post estimates than the ex ante.

3. The average operating kW of the 60-hp compressor (plus the 2 kW cooling fan when operating under the non-production hours) was calculated by the formula:

$$\text{Basecase kW}_{60\text{-hp}} = \frac{\left(\text{Pl}\times\text{hpc}+\left(1-\text{Pl}\right)\times\text{H}\times\text{hpc}\right)\times\left(0.746\text{ kW / hp}\right)}{\text{Ecm}} + \frac{\text{hpcool}\times\left(0.746\text{ kW / hp}\right)\times 0.95}{\text{Eclm}},$$

where:

H = Compressor Non-Production Load Factor (ranges from 0.02 to 0.06);

Pl = Lower limit of compressor power operating under modulation control = 0.7;

hpc = Compressor motor horsepower = 60 hp;

Ecm = Compressor motor efficiency = 0.91; and

Eclm = Cooler motor efficiency = 0.85.

4. The annual non-production operating hours during the winter and summer off-peak time-of-use periods were calculated from the monitoring data by direct extrapolation. No hours were found in the On-Peak and Semi-Peak TOU periods.

5. The kWh savings during the summer and winter Off-Peak periods was calculated by multiplying the difference in the postcase and basecase kW by the non-production operating hours.

$$\text{Ex Post kWh Savings} = \left(\text{Postcase kW}_{5\text{-hp}} - \text{Basecase kW}_{60\text{-hp}}\right)\times\left(\text{Non-Production Operating Hours}\right)$$

6. The annual kWh savings is the sum of the kWh for the winter and summer Off-Peak periods.

Table 4-25
Ex Post kWh Savings Calculation
Project No. 46113

Operating Data							Measure Operating Hours						kWh Impact					
A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**	**O**	**P**	**Q**	**R**	**S**
	Hours per Day	**Base kW 60-hp**	**Post kW 5-hp**	**kW Reduced**	**Annual Days/ Year**	**Annual Hours**	**Win. On Peak**	**Win. Semi Peak**	**Win. Off Peak**	**Sum. On Peak**	**Sum. Semi Peak**	**Sum. Off Peak**	**Win. On Peak**	**Win. Semi Peak**	**Win. Off Peak**	**Sum. On Peak**	**Sum. Semi Peak**	**Sum. Off Peak**
Source	Site Data	Ex Post Calc.	Ex Post Calc.	C–D	Site Data	Mon. Data	Site Data	Site Data	Site Data	Site Data	Site Data	Site Data	E×H	E×I	E×J	E×K	E×L	E×M
Weekday 4 AM to 11 PM	19	35.2	35.2	0	251		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Weekday 11 PM to 4 AM	5	35.2	2.9	32.3	251	1,255	0	0	523	0	0	732	0	0	16,892	0	0	23,649
Sat/Sun/ Holiday 24 hr/day	24	35.3	3.1	32.2	114	2,736	0	0	1,140	0	0	1,596	0	0	36,685	0	0	51,360
Subtotal - TOU Period						**3,991**	**0**	**0**	**1,663**	**0**	**0**	**2,328**	**0**	**0**	**53,578**	**0**	**0**	**75,009**
Total Annual kWh Savings																		**128,587**
kW Reduced (summer on-peak)																**0**		

Ex Post Gross kW Impact

The load impacts from this measure take place only during evening and weekend “non-production” hours. These hours are all occur during the Off-Peak TOU period. Although the overall average kW impact is a value greater than zero, the impact during the Summer On-Peak time-of-use period is zero kW. Therefore, the ex post gross kW impacts is 0 kW.

4.6.7 Summary of Gross Load Impacts

Table 4-26 provides a summary of the gross load impact estimates and a comparison of the ex post and ex ante estimates.

Table 4-26
Summary of Ex Post Load Impacts
Project No. 46113

	kWh	kW	Therms
Ex Ante	146,832	0	n/a
Ex Post	128,587	0	n/a
Realization Rate	87.6%	-	n/a

Table 4-27 provides a breakdown of the TOU period load impact estimates.

Table 4-27
Ex Post Load Impacts By Load Impacts
Project No. 46113

Season	Period	Total Hours	TOU Adjustment Factor	kWh Impact	Average kW
Col. A	**Col. B**	**Col. C**	**Col. D**	**Col. E**	**Col. F**
				Col. D x 128,587 kWh	Col. E/Col. C
Summer	On-peak	749	0	0	0
	Semi-peak	963	0	0	
	Off-peak	1,960	0.4167	53,578	
Winter	On-peak	441	0	0	0
	Semi-peak	1,911	0	0	
	Off-peak	2,736	0.4167	75,009	
Total				**128,587**	

The gross ex post annual kWh savings was 128,587 kWh versus the 146,833 kWh ex ante estimate, a gross realization of 87.5%. The ex post estimates agree with the 0 kW ex ante demand impact estimate.

The primary reasons for the discrepancy in annual kWh impact involved several minor offsetting factors. These included:

1. Three hours per night less non-production time during weekday nights was found in the ex post monitoring resulting in 753 *fewer* annual effective operating hours for the measure for the ex post estimates.
2. Ten greater non-production days (240 *greater* effective operating hours) due the inclusion of ten annual holidays in the ex post calculations. Overall annual operating hours in the ex post evaluation were 3,991 hours per year, versus ex ante hours of operation of 4,584. Thus, approximately 13% fewer hours were used for the ex post estimates than for the ex ante estimates.
3. A smaller difference between the ex post basecase and retrofit compressor operating kW than was calculated for the ex ante estimate, due to a different ex post extrapolation of the basecase compressor performance curve than was used in the ex ante estimate.

4.6.8 Net-To-Gross Ratio

The net-to-gross ratio for this project was estimated to be 1.0. The SDG&E IEEI Program was the reason the measures were installed. SDG&E conducted a study of the compressed air system. The recommendation to install the 5-hp compressor presented in the study was implemented at the facility under this project. The program incentive was a key aspect in the financial evaluation process. SDG&E's level of involvement was high.

SDG&E staff originated the project concept and provided all technical and engineering analysis.

4.7 PROJECT ID 46324 - AIR COMPRESSOR SYSTEM MODIFICATION WITH CONTROLS & STORAGE

4.7.1 Summary of Findings

The savings for this site were based on the installation of a 150-hp air compressor and two 25-hp air compressors to replace one 125-hp and one 75-hp compressor. The ex ante and ex post load impact estimates are shown in Table 4-28. The results of the ex post evaluation were different than those of the ex ante estimate due to differences in the ex post operation and basecase from the ex ante assumptions.

Table 4-28
Summary of Ex Post Load Impacts
Project No. 46324

	kWh	kW	Therms
Ex Ante	2,747,712	205	n/a
Ex Post	2,777,300	266.37	n/a
Realization Rate	101.1%	129.9%	n/a

4.7.2 Facility Description

This site manufactures gas turbine/generator sets for industrial applications. Compressed air is used for spin testing assembled turbine rotors, operating pneumatic machine tools such as grinders and drills, grit blasting, spray painting, and other miscellaneous uses. Spin test air must be delivered at 450 psig, while all other uses of air are supplied from a distribution system operating at 85 psig.

4.7.3 Overview of Facility Schedule

This facility operates 22 hours per day, seven days per week, except during four holiday periods when the plant is shut down. The plant generally runs at capacity, with production levels peaking in the fourth quarter each year.

The current shift schedule is two eleven-hour shifts per day, and one eight-hour shift per day, five days per week for office workers. Currently the plant is operating at capacity.

According to the customer, the compressors are not shut down on holidays, and ex post monitoring confirmed that they run 24 hours per day. Therefore, the ex post hours of compressor operation are 8,760 per year.

4.7.4 Measure Description

Piping, valves and controls were installed to tie the outputs of five existing air compressors and a new 150-hp air compressor together to supply 120 psig air to a central high pressure air receiver. This reservoir of high pressure air is then let down through a valve, called a demand expander, to feed a distribution system operating at 85 psig. Two new 25-hp air compressors also were installed to supply 200 psig air to a converted 30,000 gallon propane tank which also supplies the 85 psig distribution system through a separate demand expander. This configuration provides surge capacity to supply high instantaneous loads while the compressors operate in a fairly steady mode to keep the high pressure receivers full. By separating the demand/distribution system from the supply/storage system in this manner, several energy efficiency improvements are realized.

- Lower parasitic losses in piping system due to reduced pressure drop.
- Lower leakage losses in distribution and end use systems since pressure is lower.
- Fewer compressors running to supply demand, since high pressure receivers absorb demand swings.
- Higher overall compressor efficiency since compressors are fully loaded most of the time rather than part loaded.

In addition, one 125-hp compressor and one 75-hp compressor were removed, leaks were repaired, and new mist eliminators and air dryers were installed.

Pre-Retrofit Conditions

- Two 450-hp, Sullair, single stage, rotary screw, water-cooled, air compressors controlled by a sequencer which base loads these machines to supply 120 psig air to the plant distribution system.
- One 125-hp Gardner-Denver, and one 75-hp Gardner-Denver single stage, rotary screw, water cooled air compressors operating independently, when manually started, to supply 120 psig air to the plant distribution system.
- Two 75-hp Joy, and one 150-hp Joy double acting, reciprocating, air compressors controlled by a sequencer to boost the 120 psig air to 450 psig for use in rotor spin testing.
- Production facility operates 22 hours per day seven days per week, except during four holiday periods when the plant is shut down.
- Production workers work two eleven-hour shifts per day, seven days per week, while office workers work one eight-hour shift per day, five days per week.
- The plant runs at capacity, and production levels are consistently high throughout the year.

Post-Retrofit Conditions

- Two pre-retrofit 450-hp, Sullair, single stage, rotary screw, water-cooled, air compressors and one new 200-hp Quincy single stage, rotary screw, air cooled, air compressor all controlled by a PLC which base loads these machines to supply 120 psig air to the plant distribution system.
- Two Quincy 25-hp, single stage, rotary screw, air-cooled, air compressors controlled by a PLC which runs these machines to supply 200 psig air to a 30,000 gallon tank.
- Two pre-retrofit 75-hp Joy, and one pre-retrofit 150-hp Joy double acting, reciprocating, air compressors controlled by a PLC to boost the 120 psig air to 400 psig for use in rotor spin testing.
- Gardner-Denver compressors removed from the site.
- Low pressure distribution system pressure maintained at 85 psig by use of pressure regulating valve called demand expander.
- Production facility operates 22 hours per day, seven days per week, except during four holiday periods when the plant is shut down.
- Production work accomplished during two eleven-hour shifts per day, seven days per week, while office work accomplished during one eight-hour shift per day, five days per week.
- The plant runs at capacity, and production levels are consistently high throughout the year.

4.7.5 Ex Ante Load Impact Estimates

The *ex ante* load impact estimates were based on a site-specific study of the facility's compressed air system conducted by a compressed air system consultant provided by SDG&E's IEEI Program. The study comprised a detailed audit, including an inventory of air compressor system equipment, current operating procedures, measurements of existing compressor operating performance, evaluation of the plant requirements and performance (air balance), and recommendations that would reduce air compressor system operating costs, including energy savings. Spot measurements were made to verify the current operating parameters of the system. The results of this monitoring revealed that the compressors operated to satisfy three main demand levels: peak load, intermittent, and base load.

Tables 4-29, 4-30, and 4-31 show a summary of the compressed air and power requirements, the compressor demand profile, and load impact calculations, respectively. These tables show total *ex ante* load impacts of 2,747,712 kWh saved and 205.00 kW reduced.

Table 4-29
Ex Ante Compressed Air Power and Volume Summary
Project No. 46324

		Pre-Retrofit						Post-Retrofit					
		Base Load		Intermittent		Peak Load		Base Load		Intermittent		Peak Load	
Equipment	**Hp**	**Hp**	**Scfm**	**Hp**	**Scfm**	**Hp**	**Scfm**	**Hp**	**Scfm**	**Hp**	**Scfm**	**Hp**	**Scfm**
S. Sullair	426	349	817	349	817	349	817	0	0	0	0	426	2,008
N. Sullair	426	0	0	322	500	322	500	0	0	0	0	0	0
GD75	75	0	0	0	0	80	360	0	0	0	0	0	0
GD125	125	0	0	0	0	154	696	0	0	0	0	0	0
LP Dryer		10	0	10	0	10	0	3	0	4	0	14	0
Joy #1-125	125	0	0	130	556	130	556	0	0	130	556	130	556
Joy #2-75	75	0	0	45	182	45	182	0	0	0	0	69	295
Joy #3-75	75	69	295	69	295	69	295	69	295	69	295	69	295
HP Dryer		3	0	7	0	7	0	3	0	7	0	7	0
Quincy QSI-750	150	0	0	0	0	0	0	133	490	165	680	165	680
Quincy-25	25	0	0	0	0	0	0	0	0	24	466	24	466
Quincy-25	25	0	0	0	0	0	0	0	0	0	0	0	0
Total		431	1,112	932	2,350	1,166	3,406	208	785	399	1,997	904	4,300
Weighted kW		303		788		935		135		327		730	

From monitoring data, a seasonal demand profile was developed for the compressors. This is summarized in Table 4-30.

Table 4-30
Ex Ante Seasonal Compressor Demand Profile
Project No. 46324

	Pre-Retrofit			Post-Retrofit		
	Base	**Intermittent**	**Peak**	**Base**	**Intermittent**	**Peak**
Peak kW	347	788	935	135	327	730
Avg. kW	303	788	935	135	327	730
Aug-Oct	40%	50%	10%	40%	50%	10%
Nov-Jul	50%	45%	5%	50%	45%	5%

From the seasonal demand profile, the ex ante load impacts presented in Table 4-31 were calculated.

Table 4-31
4-4 Ex Ante Impact Calculation Summary
Project No. 46324

	Summer		Winter		Annual	
	Energy kWh	Demand kW	Energy kWh	Demand kW	Energy kWh	Demand kW
Basecase Energy Usage						
On-Peak	611,373	935	352,236	935	963,609	935
Semi-Peak	744,660		1,563,841		2,308,501	
Off-Peak	682,896		946,616		1,629,512	
Total	2,038,929	935	2,862,693	935	4,901,622	935
Postcase Energy Usage						
On-Peak	328,602	730	146,169	730	474,771	730
Semi-Peak	309,015		736,164		1,045,179	
Off-Peak	265,680		368,280		633,960	
Total	903,297	730	1,250,613	730	2,153,910	730
Annual Savings	**1,135,632**	**205**	**1,612,080**	**205**	**2,747,712**	**205**

Measured compressed air demands were recorded as shown in Table 4-32.

Table 4-32
Ex Ante Constituents of Air Demand
Project No. 46324

	Base Load		Intermittent Load		Peak Load		Total Demand
End Use	Pre-Retrofit	Post-Retrofit	Pre-Retrofit	Post-Retrofit	Pre-Retrofit	Post-Retrofit	Reduction
Misc. Production	131	131	131	131	131	131	-
Sand Blasting	-	-	252	252	432	432	-
Spin Tests	47	-	283	56	850	56	1,068
Boosters	295	147	516	258	1,033	1,146	293
Leaks	188	180	188	180	188	180	24
Artificial Demand	32	-	32	-	32	-	96
Total	**693**	**458**	**1,402**	**877**	**2,666**	**1,945**	**1,481**

The *leakage make up demand* is the output of the compressor required to overcome leakage in the system to maintain the system pressure. Since these leaks are always present, this demand is always present as well. However, during the times when the production line is shut down, this is the only demand on the compressed air system. Air consumption during this period was measured to be 188 scfm and this was therefore the assumed leakage make-up demand. Post retrofit leakage rate is reduced to 180 scfm because post-retrofit distribution system pressure is lower.

Artificial demand is the demand created by the distribution system when air has to be supplied at a pressure greater than that required by the end use in order to provide sufficient volume to satisfy the demand. Parasitic pressure drop losses are increased when distribution piping pressure is raised and leakage losses are higher due to the increased pressure in the distribution system.

The ex ante analysis was carried out based on measured air flows and the kW demand of pre-retrofit equipment and engineering estimation of the effects of the post retrofit equipment and operation on kW consumption. The ex ante analysis assumed the post-retrofit equipment would operate on the pre-retrofit production schedule, and that post-retrofit process air demand would be the same as pre-retrofit air demand, except for the reductions in air demand caused by the energy efficiency measure modifications.

The post-retrofit screw compressors are modulated using a common on-line/off-line control system. This control scheme is the most energy efficient means of operating rotary screw air compressors. These controls operate the compressors either fully loaded or totally unloaded. Thus, a machine is either producing its maximum output when fully loaded, or producing no output when totally unloaded. There is, therefore, no partial loading mode when a compressor delivers some fraction of its maximum capacity. It's either all, or nothing at all. This does not mean, however, that energy consumption is zero when compressor output is zero. Even unloaded, this type of compressor consumes approximately 25% of what it consumes when fully loaded. The control scheme is set up to start and load compressors based on the rate of change in pressure sensed in the distribution systems rather than fixed pressure decay points. This scheme allows the system to "stay ahead" of the high instantaneous demands created when spin testing is performed.

The post-retrofit reciprocating compressors are staged to run as follows. When the pressure of the 450 psig system falls to 430 psig, the #3 Joy, a 75-hp booster compressor, starts up and runs until the pressure rises to 445 psig. Should the pressure continue to fall, the #2 Joy, a 75-hp booster compressor comes on and runs until the pressure rises to 408 psig, and should the pressure fall to 340 psig, the #1 Joy, the 150-hp booster comes on and continues to run until the pressure rises to 360 psig.

Ex Ante Basecase Definition

For the ex ante basecase (pre-retrofit), the Sullair compressors run simultaneously, in various states of part to full loading, with the Gardner-Denver compressors manually started and stopped as necessary to supply pre-retrofit peak air demands only. The Joy booster compressors start and stop automatically as necessary to maintain the pressure of the high pressure system. Each compressor in the system had its own control system that ran its machine to maintain the pressure in the distribution system. If equipment at the "end-of-the-line" was starved for air, the set points of each compressor were raised until the demand could be satisfied. Nominal low pressure distribution system pressure was 120 psig.

Ex Ante Postcase Definition

For the ex ante postcase (post-retrofit), the control system was to base load the Sullair compressors and the 200-hp Quincy compressor to maintain the central air receiver pressure. Two 25-hp load shaping Quincy compressors were set to maintain a 30,000 gallon receiver at 200 psig. Demand expander valves regulate the flow of air from the high pressure receivers to maintain the low pressure distribution system at 85 psig. Three reciprocating Joy compressors, boost air from the 85 psig system to 450 psig for spin testing of turbine rotors. Pre-retrofit Gardner-Denver compressors are removed from the site.

Ex Ante Operating Schedule

This facility operates 22 hours per day seven days per week, except during 4 holiday periods when the plant is shut down. The plant generally runs at capacity, with production levels peaking in the fourth quarter each year.

The ex ante shift schedule is two eleven-hour shifts per day, seven days per week for production workers, and one eight-hour shift per day, five days per week for office workers. Currently the plant is operating at capacity.

The ex ante hours of compressor operation were 8,760 hours per year.

Key Ex Ante Assumptions

- Assumed that pre- and post-retrofit air demand from production machinery is identical.
- Assumed that pre- and post-retrofit production schedules would be the same.

Ex Ante Algorithms

Based on the measured pre-retrofit air demands, a post-retrofit air demand profile was developed. From this profile, the electrical power consumption was estimated based on the measured kW/cfm of the pre-retrofit machines at the various operating modes.

Hours of operation at the high and low demand modes were extrapolated from monitoring data. Annual kWh was obtained by multiplying kW at the base mode times hours of operation at the base mode, and adding that to the product of kW at the intermittent mode times the hours of operation at the intermittent mode and the product of the kW at the peak mode times the hours of operation at the peak mode. The results of these calculations are is summarized in Table 4-31.

The Annual ex ante energy savings is the difference between the pre-and post-retrofit kWh, or:

$$\text{Ex Ante Annual Energy Savings} = 4{,}901{,}622 \text{ kWh} - 2{,}153{,}910 \text{ kWh}$$

$$= 2{,}747{,}712 \text{ kWh}$$

and the ex ante demand reduction is the basecase peak demand minus the postcase peak demand:

Ex Ante Demand Reduction = 935 kW - 730kW

= 205.0 kW

Ex Ante Data Sources

- Compressor nameplate data and manufacturer's equipment data sheets.
- Spot measurements of equipment.
- Customer interviews.

4.7.6 Ex Post Load Impact Estimates

Monitoring data is analyzed to determine ex post power consumption patterns. These values are extrapolated to the 8,760 hour year assuming constant plant production levels, and accounting for planned production schedules.

Ex Post Basecase Definition

The ex post basecase (pre-retrofit), is the same as the ex ante basecase. The Sullair compressors run simultaneously, in various states of part to full loading, with the Gardner-Denver compressors manually started and stopped as necessary to supply pre-retrofit peak air demands only. The Joy booster compressors start and stop automatically as necessary to maintain the pressure of the high pressure system. Each compressor in the system had its own control system that ran its machine to maintain the pressure in the distribution system. If equipment at the "end-of-the-line" was starved for air, the set points of each compressor were raised until the demand could be satisfied. Nominal distribution system pressure was 120 psig.

Ex Post Postcase Definition

The ex post postcase (post-retrofit) is the same as the ex ante postcase. The Sullair compressors and the 200-hp Quincy compressor are base loaded to maintain the central air receiver pressure. Two 25-hp load shaping Quincy compressors were set to maintain a 30,000 gallon receiver at 200 psig. Demand expander valves regulate the flow of air from the high pressure receivers to maintain the low pressure distribution system at 85 psig. Three reciprocating Joy compressors, boost air from the 85 psig system to 400 psig for spin testing of turbine rotors. Pre-retrofit Gardner-Denver compressors are removed from the site.

Ex Post Operating Schedule

This facility operates 22 hours per day, seven days per week, except during four holiday periods when the plant is shut down. The plant generally runs at capacity, with production levels peaking in the fourth quarter each year.

The current shift schedule is two eleven-hour shifts per, seven days per week for production workers, and one eight-hour shift per day, five days per week for office workers. Currently, the plant is operating at capacity.

From the monitoring data, it is evident that the compressors run 24 hours/day. According to the customer, the compressors are not shut down on holidays. Therefore, ex post hours of operation are 8,760 hours per year.

Ex Post Production Level Changes

Installation of the energy efficiency measures did not affect the production level of the plant. The overall ex post production levels are the same as the ex ante levels.

Data Collected Ex Post

The energy consumption of each of the running compressors was measured using portable power monitoring equipment. Measurements were taken using a Pacific Science & Technology Energy Logger. This instrument measures true RMS kW. The following data was collected on-site:

- Runtime data for six compressors;
- Measured voltage, amperage, power factor and kW for six compressors;
- Motor and compressor nameplate data;

Data was collected on one minute intervals over a three week period in December of 1998. Thirty minute averages for each operating compressor were recorded for actual voltage, amperes, power factor and kW. A table of the raw data is presented in Attachment 1.

Ex Post Algorithms

The customer allowed monitoring of all of the ex post compressors except the two 25-hp load shaping machines. In order to estimate the impact of these machines, information from the manufacturer's data sheet is used along with motor hour readings.

Both load shaping compressors went into service on December 18, 1997. Through January 20, 1999 (398 days), the compressors' motor hour meters had logged runtime hours as shown in Table 4-33.

Table 4-33
QSB-25 Run Time Data
Project No. 46324

	12/18/97	01/20/99	Hrs/Day
A Hours	0	2,100	5.3
B Hours	0	2,237	5.6
Total	0	4,337	10.9

From the information in Table 4-33,

$$\text{Avg. hrs/day} = \frac{(4{,}337 \text{ hours})}{(398 \text{ days})}$$

$$= 10.9 \text{ hours/day}$$

The load shaping compressors come on and run fully loaded until the 30,000 gallon receiver pressure is restored to 200 psig. Full load demand can be estimated from the general equation:

$$\text{Full Load kW} = (\text{Voltage}) \times (\text{Full Load Amps}) \times (\sqrt{3}) \times (\text{Power Factor}) \times (1 \text{ kW}/1{,}000 \text{ watts}), \qquad \text{Equation 6-1}$$

where:

$$\text{Power Factor} = \frac{(0.746) \times (\text{Motor hp})}{(\sqrt{3}) \times (\text{Voltage}) \times (\text{Full Load Amps}) \times (\text{Motor Efficiency})} \qquad \text{Equation 6-2}$$

The following information was obtained from the manufacturer's data sheet for the motor:

Motor hp	25
Voltage	460
Full Load Amps	32.5

The baseline motor efficiency obtained from Motor Master for a 25 hp TEFC 1,800 rpm motor is 89.8%. Using this efficiency and substituting into Equations 6-1 and 6-2 gives a Full Load kW of 20.77 kW. Since these compressors average approximately 10.9 hours run time per day, and can run at any time of the day and any day of the week, it was assumed that the average hourly kW demand for the QSB-25 compressors was:

$$\text{Average Hourly kW}_{\text{QSB-25}} = \left[(10.9 \text{ hrs/day})/(24 \text{ hrs/day})\right] \times 20.77 \text{ kW}$$

$$= 9.4 \text{ kW}$$

Average hourly kW was calculated from the monitoring data for each hour of the day for each monitored compressor. A total average hourly kW was calculated for each hour of the day for each day of the monitoring period by summing the monitored kW's for each hour with the calculated hourly average kW for the QSB-25 compressors. This is presented in Attachment 1. The *total average hourly kW* for each hour of an average day was found by averaging all the total average kW's for a specific hour of the day in the monitoring period. The average kW calculated for the monitoring period was 242.5 kW.

Annual ex post postcase energy use was then calculated by multiplying the average hourly kW times the annual hours of operation:

$$\text{Ex Post Annual kWh}_{\text{postcase}} = 242.5\text{ kW} \times 8{,}760\text{ hrs / yr}$$

$$= 2{,}124{,}322\text{ kWh}$$

The annual ex post kWh impact was the difference between the annual basecase energy and the annual postcase energy:

$$\text{Ex Post Annual kWh Imapct} = 4{,}901{,}622\text{ kWh} - 2{,}124{,}322\text{ kWh}$$

$$= 2{,}777{,}300\text{ kWh}$$

Ex Post Load Impacts By Time-Of-Use Period

The operating characteristics of the compressed air system for this facility was fairly consistent, with little variability. Thus, the allocation of kWh savings to the time-of-use (TOU) periods was based on the operating hours in each TOU period. The results are shown in Table 4-34.

Table 4-34
Ex Post kW and kWh Impacts by Time-of-Use Period
Project No. 46324

Time-of-Use Period	kWh Adjustment Factor	kWh Savings	Average kW Reduced	kW Reduced Coincident with System Peak Period
Summer On-peak	0.0855	237,466	317.04	266.37
Summer Semi-peak	0.1099	305,313	317.04	
Summer Off-peak	0.2237	621,405	317.04	
Winter On-peak	0.0503	139,816	317.04	302.16
Winter Semi-peak	0.2182	605,870	317.04	
Winter Off-peak	0.3123	867,431	317.04	
Total	1.0000	2,777,300		

The kW reduced coincident with system peak was calculated by subtracting the postcase average kW for the summer and winter on-peak periods from the basecase kW for the high demand operating mode.

$$\text{kW Impact}_{\text{ex post,summer}} = \left(\text{kW}_{\text{basecase,high demand}}\right) - \left(\text{Average kW}_{\text{postcase,summer on-peak}}\right)$$

$$= 559.55\text{ kW} - 293.17\text{ kW}$$

$$= 293.17\text{ kW}$$

$$\text{kW Impact}_{\text{ex post,winter}} = \left(\text{kW}_{\text{basecase,high demand}}\right) - \left(\text{Average kW}_{\text{postcase,winter on-peak}}\right)$$

$$= 559.55\text{kW} - 257.39\text{ kW}$$

$$= 302.16\text{ kW}$$

4.7.7 Net-To-Gross Ratio

The net-to-gross ratio for this project is 1.0. SDG&E had a high level of involvement in this project through the concept and implementation assistance. The customer had initiated the planning for controls on the compressed air system. SDG&E had a chance to review the plans and recommended having a compressed air system consultant conduct a study to provide a more cost-effective solution. The study was conducted and the recommendations were implemented.

Motivation

Motivation for this project was inspired by the cost reduction opportunity and the promise of a more reliable compressed air supply system, and cleaner, drier compressed air. A project to improve only the individual controllers on the compressed air system was initiated by the customer. However, SDG&E became involved well in advance of implementation and apprised the customer that a more efficient design was possible that had potential for higher savings than the changes planned by the customer. SDG&E provided a compressed air consultant who did monitoring and performed design engineering of the system eventually installed by the customer. The postcase system included a central controller, pressure air receivers, dryers, and low horsepower load shaping compressors. According to the customer, they were unaware of the benefits of the postcase technology and this equipment would not have been installed without the assistance of SDG&E. The customer also reported that, though the program rebate was not the primary motivation for the work, it was necessary to get management approval for a larger project that what had been planned and budgeted, thus the rebates provided by the program facilitated approval of the project.

Non-Energy Costs and Benefits

The customer believes that delivered post-retrofit compressed air is drier and cleaner than the pre-retrofit compressed air. The customer also indicated that the reliability of the system is better than the pre-retrofit system.

Equipment Alternatives

The pre-retrofit compressor system would have remained in service had this project not been installed with improvements to its control system, and replacement of the older compressors with compressors of equivalent capacity.

4.8 PROJECT ID 46572 - COMPRESSED AIR SYSTEM MODIFICATIONS

4.8.1 Summary of Findings

The savings for this site were based on the installation of additional storage capacity and a control system to optimize the use of existing air compressors. The results of the ex post evaluation was different than those of the ex ante estimate due to differences in the ex post operation from the ex ante postcase assumptions.

Table 4-35
Summary of Ex Post Load Impacts
Project No. 46572

	kWh	kW	Therms
Ex Ante	1,338,949	280	n/a
Ex Post	694,740	79.31	n/a
Realization Rate	51.9%	28.3%	n/a

4.8.2 Facility Description

This site is a metal forming operation, manufacturing metal stampings and forgings for jet engines. There are many typical machine shop processes taking place utilizing presses, lathes, milling machines, welders, rolling mills, drill presses, etc. Assembly and testing is also performed using the components manufactured onsite. Compressed air is used for several processes in the production area, including grit blasting, spray painting, impact tools, riveting, drop hammers and air agitation. Compressed air from a separate air compressor system is also used in the test area to generate air for spin testing of jet engine assemblies.

4.8.3 Overview of Facility Schedule

This facility operates 24 hours per day, six days per week, except during holiday periods when the plant is shut down. Air consumption typically peaks during the day shift, Monday through Friday. Production levels vary during the year, but the operation during the monitoring period was considered typical by plant staff.

The current shift schedule is three eight-hour shifts per day, six days per week for production workers, and one eight-hour shift per day, five days per week for office workers. Weekend work load is generally lower than weekday levels. Saturday shifts are reserved for must-work jobs only, and occasional Sunday shifts are worked for only the most critical jobs.

Hours of operation are therefore:

$$\text{Annual Hours of Operation} = 8{,}760 \text{ hours/yr} - \left(\left(52 \text{ Sundays/yr} + 14 \text{ Holidays/yr}\right) \times 24 \text{ hours/Day}\right)$$

$$= 7{,}126 \text{ hours/yr}$$

4.8.4 Measure Description

Piping, valves and controls were installed to tie the output from two existing 350-hp air compressors and a 200-hp air compressor together to supply plant air demands from central high pressure air receivers. The controls were set to fill one new 2,000 gallon, and two existing 2,150 gallon air receivers with 120 psig air from the compressors. The flow from the combined 6,300 gallons of high pressure air storage is then let down through a new valve, called a demand expander, to feed a distribution system operating at 95 psig. This configuration provides surge capacity to supply high instantaneous loads while the compressors operate in a fairly steady mode to keep the high pressure receivers full. By separating the demand/distribution system from the supply/storage system in this manner, several energy efficiency improvements are realized.

- Lower parasitic losses in piping system due to reduced pressure drop.
- Lower leakage losses in distribution and end use systems since pressure is lower.
- Fewer compressors running to supply demand, since high pressure receiver absorbs demand swings.
- Higher overall compressor efficiency since compressors are fully loaded most of the time rather than part loaded.

In addition, three 650-gallon air receivers were installed near high instantaneous demand operations and numerous leaks were repaired.

Pre-Retrofit Conditions

- The Production Area was supplied with 115 psig compressed air by one continuously loaded 350-hp, Quincy, single stage, rotary screw, water cooled, air compressor and one 200-hp, Ingersoll-Rand, double acting, reciprocating, air compressor that loaded and unloaded as necessary to maintain distribution system pressure.
- One 350-hp, Quincy, single stage, rotary screw, water cooled, air compressor was shut down, but remained as a connected backup maintenance spare.
- The Production Area compressors operated independently to satisfy demand.
- Numerous piping leaks in buried compressed air distribution system.
- Production facility operated 24 hours per day, six days per week, except during 14 holiday periods when the plant was shut down. The plant was normally shut down on Sundays.

- Production workers worked three eight-hour shifts per day, six days per week, while office workers worked one eight-hour shift per day, five days per week.
- Production levels varied with customer demands, but was fairly steady throughout the year. Compressed air use was highest on day shift, Monday through Friday.
- The Test Area compressed air system compressors were connected to the Production Area system but are valved off so that the two systems run independently.

Post-Retrofit Conditions

- The Production Area is supplied with 95 psig compressed air from central air receivers supplied with 120 psig air by one 350-hp, Quincy, single stage, rotary screw, water cooled, air compressor and one 200-hp, Ingersoll-Rand, double acting, reciprocating, air compressor.
- One 350-hp, Quincy, single stage, rotary screw, water cooled ,air compressor is shut down, but remains as a connected backup maintenance spare.
- The Production Area compressors are controlled by a central PLC that optimizes their loading to maintain 120 psig pressure in the new central high pressure air receiver.
- 95 psig air is supplied to the Production Area through a new pressure regulating valve on the outlet of the high pressure air receivers.
- Production facility operates 24 hours per day, six days per week, except during 14 holiday periods when the plant is shut down. The plant is normally shut down on Sundays.
- Production workers work three eight-hour shifts per day, six days per week, while office workers work one eight-hour shift per day, five days per week.
- Production levels vary with customer demands, but is fairly steady throughout the year. Compressed air use is highest on day shift, Monday through Friday.
- The Test Area compressed air system is connected to the Production Area system but is valved off so that the two systems run independently.

4.8.5 Ex Ante Load Impact Estimates

The *ex ante* load impact estimates were based on a site-specific study of the facility's compressed air system conducted by a compressed air system consultant provided by SDG&E's IEEI Program. The study comprised a detailed audit, including an inventory of air compressor system equipment, current operating procedures, measurements of existing compressor operating performance, evaluation of the plant requirements and performance (air balance), and recommendations that would reduce air compressor system operating costs, including energy savings. Spot measurements were made to verify the current operating parameters of the system. The results of this monitoring revealed that the compressors operated to satisfy three main demand levels: high capacity, low capacity and leakage make-up.

Table 4-36 shows a summary of the load impact estimates, and the air balance and savings calculations. The table shows total *ex ante* load impacts of 1,338,949 kWh saved and 280 kW reduced.

Table 4-36
Ex Ante Pre-Retrofit and Post-Retrofit Load Impacts
Project No. 46572

Compressor	Pre-Retrofit			Post-Retrofit			Total Annual Savings	
	Demand, kW	Annual Hours	Energy, kWh	Demand, kW	Annual Hours	Energy, kWh	Demand, kW	Energy, kWh
Qsi 1500	280	8,760	2,455,340	0	0	-	280	2,455,340
IR XLE (FL)	192	578	110,976	192	6,332	1,215,744	0	(1,104,768)
IR XLE (UL)	100	2,312	231,662	100.2	2,428	243,286	0	(11,623)
Total			**2,797,979**			**1,459,030**	**280**	**1,338,949**

Leakage make up demand is the output of the compressor required to overcome leakage in the system to maintain the system pressure. Since these leaks are always present, this demand is always present as well. However, during the times when the production line is shut down, this is the only demand on the compressed air system. Air consumption during this period was measured to be 1,200 scfm and this was, therefore, the assumed leakage make-up demand. Repairs were made in an attempt to lower this to 200 scfm.

Artificial demand is the demand created by the distribution system when air has to be supplied at a pressure greater than that required by the end use in order to provide sufficient volume to satisfy the demand. Parasitic pressure drop losses are increased when distribution piping pressure is raised and leakage losses are higher due to the increased pressure in the distribution system.

The ex ante basecase was based on measured air flows and the kW of pre-retrofit equipment and engineering estimation of the effects of the post-retrofit equipment and operation on energy use. The ex ante analysis assumed the post-retrofit equipment would operate on the pre-retrofit production schedule, and that post-retrofit process air demand would be the same as pre-retrofit air demand, except for the reductions in air demand caused by the energy efficiency measure modifications.

Table 4-37 summarizes the nameplate and measured operating parameters of the pre- and post-retrofit compressors.

Table 4-37
Air Compressor Nameplate Data
Project No. 46572

Compressor	Mfr	Model	Motor Nameplate hp	Bhp	Voltage	Rated Capacity, ACFM	Design Discharge Pressure, psig	Operating Discharge Pressure, psig
Comp 1-9	I-R	XLE	200		480	1,000	110	115
Comp 1-10	Quincy	QVC-1500	350	364	480	1,504	125	
Comp 1-11	Quincy	QVC-1500	350	364	480	1,504	125	120

The output of the pre-retrofit rotary screw compressor was modulated with inlet throttling and a discharge blow-off valve. By restricting the amount of air entering the compressor, the amount of air supplied by the compressor can be regulated, but only to a point. When air demand is less than the compressor capacity, the discharge blow off valve opens to vent excess air to the atmosphere. In the unloaded mode with this type of control scheme, the compressor consumes approximately 70% of full load power.

The output of the post-retrofit rotary screw compressor is modulated using an on-line/off-line control system. This control scheme is the most energy efficient means of operating rotary screw air compressors. These controls operate the compressor either fully loaded or totally unloaded. Thus a machine is either producing its maximum output when fully loaded, or producing no output when totally unloaded. There is therefore no partial loading mode when a compressor delivers some fraction of its maximum capacity. It's either all, or nothing at all. This does not mean, however, that energy consumption is zero when compressor output is zero. Even unloaded, this type of compressor consumes approximately 25% of the energy it consumes when fully loaded.

Both the pre- and post-retrofit reciprocating compressors are equipped with a five step unloading system that allows partial loading of the compressor cylinders to match the compressor output to the system demand.

Ex Ante Basecase Definition

For the ex ante basecase, one 350-hp Quincy compressors runs fully loaded continuously with the 200-hp I-R compressor in a load/unload mode (two step loading scheme) to supply pre-retrofit peak air demands only. Each compressor in the system had its own control system that ran its machine to maintain the pressure in the distribution system. If equipment at the "end-of-the-line" was starved for air, the set points of each compressor were raised until the demand could be satisfied. Nominal distribution system pressure was 115 psig.

Ex Ante Postcase Definition

For the ex ante postcase, the 200-hp I-R compressor was loading and unloading in five steps as necessary to maintain the central high pressure air receiver pressure at 125 psig, with one 350-hp Quincy compressor standing by to come on in load/unload modulation to maintain the central air receiver pressure at 125 psig. A second 350-hp Quincy compressor is shut down, but is maintained as a maintenance spare.

Ex ante postcase compressor discharge pressure was to have been 125 psig into the high pressure air receivers. The demand expander valve was to have regulated flow out of the receiver to maintain the distribution system at 85 psig.

Ex Ante Operating Schedule

This facility operates 24 hours per day, six days per week, except during holiday periods when the plant is shut down. Air consumption typically peaks during the day shift, Monday through Friday. Production levels vary during the year, but the operation during the monitoring period was considered average by plant staff.

The current shift schedule is three eight-hour shifts per day, six days per week for production workers, and one eight-hour shift per day, five days per week for office workers. Weekend work load is generally far lower that weekday levels. Saturday shifts are reserved for must-work jobs only, and occasional Sunday shifts are worked for only the most critical jobs.

Hours of operation are therefore:

$$\text{Ex Ante Hours of operation} = 8{,}760 \text{ hours / yr} - \left(\left(52 \text{ Sundays / yr} + 14 \text{ Holidays / yr}\right) \times 24 \text{ hours / Day}\right)$$

$$= 7{,}126 \text{ hours / yr}$$

Key Ex Ante Assumptions

- Assumed that pre- and post-retrofit air demand from production machinery is identical.
- Assumed that pre- and post-retrofit production schedules would be the same.

Ex Ante Algorithms

Based on the measured pre-retrofit air demands, a post-retrofit air demand profile was developed. From this profile, the electrical power consumption was estimated based on the measured kW/cfm of the pre-retrofit machines at the various operating modes.

Hours of operation at the high and low demand modes were extrapolated from monitoring data. Annual kWh consumption was obtained by multiplying the *kW at the low mode* by the *hours of operation at the low mode*, and adding that to the product of the *kW at the high mode* by the *hours of operation at the high mode*. This is summarized in Table 4-36.

Annual energy savings is the difference between the pre-and post-retrofit kWh, or:

$$\text{Ex Ante Annual Energy Savings} = 2{,}797{,}979 \text{ kWh} - 1{,}459{,}030 \text{ kWh}$$

$$= 1{,}338{,}949 \text{ kWh}$$

The average hourly running kW is the sum of the products of the measured running kW for each compressor and its the fraction of time run per year:

$$\text{Ex Ante Average Hourly kW} = \frac{(280 \text{ kW} \times 8{,}760 \text{ hrs/yr}) + (192 \text{ kW} \times 578 \text{ hrs/yr}) + (100 \text{ kW} \times 2{,}312 \text{ hrs/yr})}{8{,}760 \text{ hrs/yr}}$$

$$= 319.4 \text{ kW}$$

and the peak demand reduction is the *peak pre-retrofit demand* minus the *peak post-retrofit demand* or:

$$\text{Ex Ante Peak Demand Reduction} = (280 \text{ kW} + 192 \text{ kW}) - (192 \text{ kW})$$

$$= 280 \text{ kW}$$

Ex Ante Data Sources

- Compressor nameplate data and manufacturer's equipment data sheets.
- Spot equipment measurements.
- Customer interviews.

4.8.6 Ex Post Load Impact Estimates

Ex post monitoring data was analyzed to determine ex post power consumption patterns. These values are extrapolated to the 8,760 hour year assuming constant plant production levels, and accounting for planned production schedules.

Monitoring data for both running compressors was obtained over a three week period in November and December, 1998. The third compressor was not monitored as it was observed to be off line with its circuit breaker locked open. Interviews with plant staff indicated that this compressor is only run as a maintenance spare, and is locked out to prevent the control system from starting it up. After initial startup of the post-retrofit controls, this compressor experienced nearly 600 startups and shutdowns in less than two months without ever loading. Because of this circumstance, it was concluded that this compressor would not be necessary and it was locked out to prevent further cycling.

Customer logs of post-retrofit run times were reviewed to determine long term running and loading patterns of the compressors. Data from these logs were used in the extrapolation of monitored kW to the 8,760 hour year. Also reviewed were the results of post-retrofit air demand monitoring . This data includes a continuous one week recording of system consumption in scfm and system pressure in psig.

Ex Post Basecase

After the onsite visit it was determined that the ex post basecase was the same as the ex ante basecase.

Ex Post Postcase

For the ex post postcase, one 350-hp Quincy compressor is in load/unload modulation with the 200-hp I-R compressor loading and unloading in five steps as necessary to maintain the central high pressure air receiver pressure at 120 psig. A second 350-hp Quincy compressor is shut down, but is maintained as a maintenance spare.

Ex post postcase compressor discharge pressure was 121 psig into the high pressure air receivers. The demand expander valve then regulated flow out of the receiver to maintain the distribution system at 95 psig.

Ex Post Operating Schedule

This facility operates 24 hours per day, six days per week, except during holiday periods when the plant is shut down. Air consumption typically peaks during the day shift, Monday through Friday. Production levels vary during the year, but the operation during the monitoring period was considered average by plant staff.

The current shift schedule is three eight-hour shifts per day, six days per week for production workers, and one eight-hour shift per day, five days per week for office workers. Weekend work load is generally far lower that weekday levels. Saturday shifts are reserved for must work jobs only, and occasional Sunday shifts are worked for only the most critical jobs.

The compressors operate every day of the year regardless of the shop floor activity, so annual hours of operation are therefore 8,760. It is evident from the monitoring data that there are three air demand modes, high, intermediate and low. Air demands are high during weekday day shifts. Intermediate level air demands occur during weekday swing shifts and air demand is relatively low at all other times. Thus, hours of operation at each demand level are:

$$\text{High Demand Hours} = \left[\left(52 \text{ weeks} \times 5 \text{ days/week}\right) - 10 \text{ Holidays}\right] \times \left(8 \text{ hrs/day}\right)$$

$$= 2{,}000 \text{ hrs/year}$$

$$\text{Intermediate Demand Hours} = \left[\left(52 \text{ weeks} \times 5 \text{ days/week}\right) - 10 \text{ Holidays}\right] \times \left(8 \text{ hrs/day}\right)$$

$$= 2{,}000 \text{ hrs/year}$$

$$\text{Low Demand} = \left(8{,}760 \text{ hrs/yr}\right) - \left(\text{High Demand Hours}\right) - \left(\text{Intermediate Demand Hours}\right)$$

$$= 4{,}760 \text{ hrs/yr}$$

Ex Post Production Level Changes

Installation of the energy efficiency measures did not effect the production level of the plant. The overall ex post production levels are the same as the ex ante levels.

Data Collected Ex Post

The energy consumption of each of the running compressors was measured using portable power monitoring equipment. Measurements were taken using a Pacific Science & Technology Energy Logger. This instrument measures true RMS kW. The following data was collected on-site:

- Runtime data;
- Measured voltage, amperage, power factor and kW; and
- Motor and compressor nameplate data.

Voltage, amperage, power factor and kW data were collected on one minute intervals over a three week period during November through December of 1998. Thirty minute averages for each operating compressor were recorded for kW, actual voltage, amperes, and power factor. A table of the raw data is included in Attachment 1.

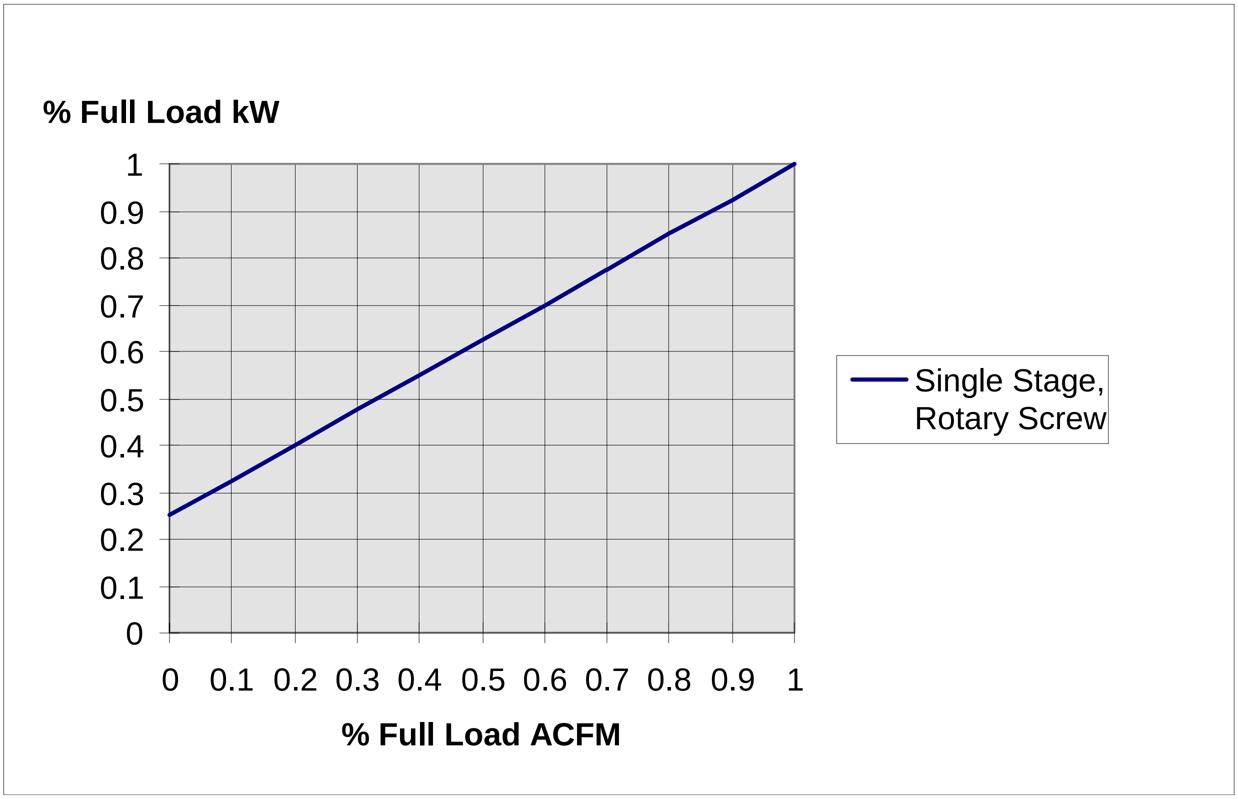
Customer recorded run time logs from post retrofit startup through November 18, 1998, the day of the ex post site visit, were obtained. These data were collected daily by the plant compressor mechanic and includes total run time for each compressor from the motor hour meter. Also noted are the total number of motor starts for each compressor, and the number of times each compressor loaded during the period. This is included as Attachment 2.

Also obtained was the results of air demand monitoring for the post-retrofit period beginning February 19,1998 and ending February 26, 1998. These data include a continuous recording of system consumption in scfm and system pressure in psig. This is included as Attachment 3.

Ex Post kWh Savings and TOU Impact

As was stated previously, rotary screw air compressors operating in the on-line/off-line mode consume power at 100% of rated capacity at full load and approximately 25% of capacity when unloaded. From these data, compressor manufacturers construct a performance curve for their compressors which looks like the curve shown in Figure 4-1 for a single stage, rotary screw air compressor.

Figure 4-1
Typical Air Compressor Performance Curve
Project No. 46572



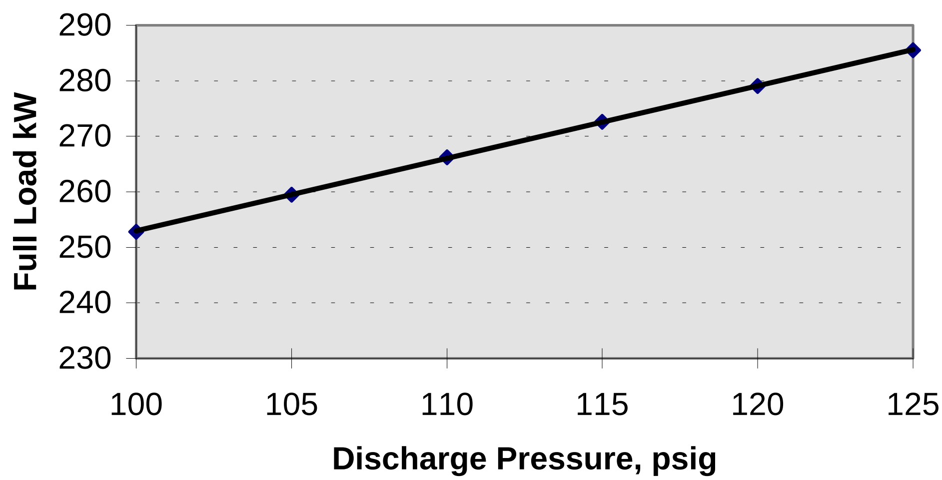
As can be seen from the curve in Figure 4-1, rotary screw air compressors in the load/unload control mode exhibit a linear relationship between the *actual air volume drawn into the machine inlet* (ACFM) and *the shaft horsepower*, in kW. The points on this curve fit the general equation:

$$\text{\% Full Load kW} = \left(0.75 \times \left(\text{\% Full Load ACFM}\right)\right) + 0.25 \qquad \text{(Equation 1)}$$

In a load/unload control scheme, the compressor is either producing compressed air at full capacity or nothing at all, and the volume demand is satisfied by the duration of the loaded mode. Consequently, flow from the machine occurs in bursts that last until the demand is satisfied, and then the machine unloads to zero output. This on/off pattern was evident in the monitoring data recorded.

From the manufacturer's data sheet, full load kW for Compressor 1-11, the Quincy QSI 1500 screw compressor, at different discharge pressures was charted as shown in Figure 4-2.

Figure 4-2
Model QSI 1500 kW
Demand versus Discharge Pressure
Project No. 46572



From Figure 4-2, at the observed ex-post discharge pressure of 121 psig, full load kW is 280.3 kW. However, during the monitoring period, average kW was found to be 221 kW. Therefore, the % Full Load kW is:

$$\%\ \text{Full Load kW}_{\text{ex post}} = \frac{221\ \text{kw}}{280.3\ \text{kW}}$$

$$= 78.9\%$$

Substituting in Equation 1, and solving for % Full Load ACFM,

$$\%\ \text{Full Load ACFM}_{\text{ex post}} = \frac{(0.789 - 0.25)}{0.75}$$

$$= 71.9\%$$

This means that 71.9% of the time the compressor output is 1,500 ACFM and 0 ACFM the remaining 28.9% of the time. Therefore, the average compressor output is 71.9% of 1,500 ACFM, or 1,078.5 ACFM at 120 psig. From the air consumption monitoring data, it is clear that the distribution system operates at a steady 95 psig regardless of the volume demand. The compressor output can be converted to scfm at the distribution pressure by multiplying the ACFM by the ratio of the absolute pressures of the compressor discharge and the distribution system:

$$\text{Compressor Output} = 1{,}078.5 \times \left(\frac{120 \text{ psig} + 14.7 \text{ psia}}{95 \text{ psig} + 14.7 \text{ psia}} \right)$$

$$= 1{,}332 \text{ scfm}$$

Customer run time log data from February 2, 1998 through November 18, 1998 showed that this compressor ran nearly continuously, and averaged 23.4 run hours per day. Steady state operation of the post-retrofit equipment was achieved in February of 1998. Data prior to February 7^{th} was not considered valid due to numerous maintenance and commissioning problems. Air consumption in the low air demand periods was a fairly steady 1,200 scfm. This is assumed to be the ex post leakage rate in the plant, and represents nearly all of the output of the QSI 1500 compressor. Part of the ex ante savings estimate were based on reducing system leakage to less than 200 scfm.

The balance of the demand was picked up by compressor 1-9, the reciprocating Ingersoll-Rand compressor. This was evident in the monitoring data that showed the I-R compressor running on during the day shift and off during most of the remaining times Run time logs show that this compressor averaged 9.1 hours per day of run time since the system startup. Average kW for this machine while running was 64.2 kW.

Average hourly running kW was obtained by multiplying the measured running kW by the fraction of time run per day for each compressor:

$$\text{Average Hourly kW} = \left[221 \text{ kW}_{\text{ex post}} \times \left(\frac{23.4 \text{ hrs/day}}{24 \text{ hrs/day}} \right) \right] + \left[64.2 \text{ kW} \times \left(\frac{9.1 \text{ hrs/day}}{24 \text{ hrs/day}} \right) \right]$$

$$= 240.1 \text{ kW}$$

Multiplying the measured *average demand* for each compressor by the calculated *average time of operation* gave the annual energy consumed:

$$\text{Annual kWh}_{\text{post-retrofit}} = [221 \text{ kW} \times (23.4 \text{ hrs/day}) + 64.2 \text{ kW} \times (9.1 \text{ hrs/day})] \times 365 \text{ days/yr}$$

$$= 2{,}103{,}239 \text{ kWh}$$

Annual savings are found by subtracting ex post postcase values from ex post basecase values.

Annual kWh Savings = 2,797,979 kWh - 2,103,239 kWh

= 694,740 kWh

Average kW Reduced = 319.4 kW - 240.1 kW

= 79.3 kW

Time-Of-Use Period Impact Calculations

The annual load impacts for this measure were allocated to SDG&E 's time-of-use (TOU) periods based on the hours of operation of the measure within the TOU periods. This method is appropriate because the compressed air system exhibited a flat operating profile through the ex post monitoring. Table 4-38 shows the results of this calculation.

Table 4-38
Ex Post kW and kWh Impacts by Time-of-Use Period
Project 46572

Time-of-Use Period	Hours	kWh Adjustment Factor	kWh Savings	Average kW Reduced
Summer On-peak	763	0.0871	60,512	79.3
Summer Semi-peak	981	0.1120	77,801	79.3
Summer Off-peak	1,928	0.2201	152,906	79.3
Winter On-peak	456	0.0521	36,165	79.3
Winter Semi-peak	1,976	0.2256	156,713	79.3
Winter Off-peak	2,656	0.3032	210,643	79.3
Total	8,760	1.0000	694,740	

4.8.7 Summary of Gross Impacts

Table 4-39 shows a summary of the gross ex post load impacts and a comparison with the ex ante load impacts.

Table 4-39
Summary of Ex Post Load Impacts
Project No. 46572

	kWh	kW	Therms
Ex Ante	1,338,949	280	n/a
Ex Post	694,740	79.31	n/a
Realization Rate	51.9%	28.3%	n/a

Ex post impacts are lower than ex ante estimates because ex post air demands are higher than predicted in the ex ante basecase. The primary reasons for this discrepancy are:

- Ex post leakage appears to be 1,200 scfm while ex ante estimates of postcase leakage were 200 scfm. This causes a 435-hp compressor to run most of the time to maintain system pressure. The ex ante postcase was based on this compressor being shut down most of the time while the smaller 200-hp compressor ran.
- Also, the ex post distribution system pressure is 95 psig versus the ex ante estimate of 85 psig. The extra pressure increases losses in the distribution system, and magnifies the amount of compressed air lost to leakage.

4.8.8 Net-To-Gross Ratio

The net-to-gross ratio for this project was estimated to be 1.0. The SDG&E IEEI Program was the reason the measures were installed.

SDG&E arranged to have a program-sponsored compressed air consultant prepare a study of the system. The recommendations presented in the study were implemented at the facility under this project. SDG&E staff (consultants) had a high level of involvement with this project, having originated the project concept and provided all technical and engineering analysis.

Motivation

Motivation for the project was inspired by the cost reduction opportunity and the promise of improved system reliability. The project was initiated by SDG&E, who apprised the customer of the potential for savings, provided the compressed air consultant who did the monitoring and performed the design engineering. According to the customer, this equipment would not have been installed without the assistance of SDG&E and the program rebate. The project was only approved and built because the rebate was large enough to improve the project economics to meet the customer’s internal payback criteria.

Equipment Alternatives

The pre-retrofit distribution system and controls would have remained in service had this project not been installed. No other alternatives other than the ex post equipment were considered.

4.9 PROJECT ID 46628 - COMPRESSED AIR SYSTEM MODIFICATIONS

4.9.1 Summary of Findings

The compressed air system at this site was modified substantially by the addition of air demand and loss-reducing equipment, new dryers, additional storage and improved controls.

Table 4-40 compares the ex ante gross impact estimates with the ex post study results.

Table 4-40
Results and Comparison with Ex Ante Estimates
Project No. 46628

	kWh	kW	Therms
Ex Ante	861,326	356.00	n/a
Ex Post	431,006	77.4	n/a
Realization Rate	50.0%	21.7%	n/a

The ex post gross annual energy impact was 431,006 kWh, 50.0% of the ex ante estimate of 861,326 kWh. The ex post gross peak demand impact was 77.4 kW, 21.7% of the ex ante estimate, 356 kW.

The primary reason for the large discrepancy was overly optimistic expectation of the impacts of the measures installed at the site in reducing demand for compressed air, due in part to the setting of the distribution pressure to 100 psi, rather than 90 psi as assumed in the ex ante estimates. The ex ante projection assumed that the 300-hp compressor and one of the 150-hp compressors would be shut down entirely, primarily as a result of the efforts to reduce the demand for compressed air. The ex post calculations showed that the hours of operation for the three compressors was reduced, but not nearly to the degree projected in the ex ante estimates.

4.9.2 Facility Description

The facility is a manufacturer of electrical and communication connectors. The individual pins are punched, pressed or machined from blank stock of conductive material. The pins are then assembled into connection devices for a wide number of uses. The project involved modifications to the compressed air system serving the plant, which consists primarily of two 150-hp and one 300-hp compressors. The compressors are located outside to the north side of the building. Compressed air end uses include pneumatic drives for machinery and hand tools, blow-off, and vacuum eduction.

4.9.3 Overview of Facility Schedule

The plant operates three shifts per day, five days per week year-round with approximately 10 holidays each year. Full production activity and air demand occurs during the first shift: 7 A.M. to 3 P.M.. Slightly reduced activity occurs during second shift (3 P.M. to 11 P.M.) and a few processes operate during third shift depending on production requirements. Customer reports that activity has increased significantly. Compressed air (useful) demand has increased by about 10% during 1997/1998 according to customer estimates.

4.9.4 Measure Description

The measure installed was designed to reduce the amount of electricity consumed by the compressed air system by:

- Reducing compressed air losses through leaks and installing low-loss drains.
- Installing and using high-pressure blowers or vacuum pumps where appropriate to reduce demand for compressed air.
- Adding controls and storage to optimize the compressor system operation.
- Installing a "demand expander" to allow reduction of distribution pressure (from 125 psi to 100 psi) to reduce losses further while stabilizing distribution pressure.
- Installing a more efficient refrigerated dryer.
- Repiping, relocating certain filters, etc. to reduce internal pressure drop.

Table 4-41 lists the equipment that was installed.

Table 4-41
Equipment Purchased and Installed
for Compressed Air System Improvements
Project 46628

Quantity	Equipment Installed	Description
1	Quincy 15-hp vacuum	265 cfm @ 29-inch hg & 14.6 bhp
1	4012 MD blower w/ VFD	PD Blower 400 cfm @ 5 psi & 15.0 bhp
1	2000-HSDM Zeks dryer	2,000 cfm refrig. Cycling type
1	1500-HDF Zeks filter	1,500 cfm mist eliminator
1	400-LC Zeks filter	400 cfm coalescing
1	Receiver tank	2,520 gallon, vertical
1	AVP-1500	3-inch demand expander with PID Intermediate Controller
7	GD Evacuator	large zero-loss drains
1	AB1606C6 aftercooler	water-cooled aftercooler w/ separator

In addition the following system actions were taken:

- A PID control system was installed.

- The compressor- dryer piping was revised to reduce pressure drop and friction losses.
- Some compressed air blow-off systems were replaced with a low pressure blower system.
- Compressed air eductors were connected to a central vacuum system.
- Replace 20 Vortec eductors with low pressure blower system.
- The compressor setpoint and storage pressure was reduced from 125 psi to 110 psi; distribution system pressure was reduced from 110 psi to 100 psi.

4.9.5 Ex Ante Load Impact Estimates

The *ex ante* load impact estimates were based on a site-specific study of the facility's compressed air system conducted by a compressed air system consultant provided by SDG&E's IEEI Program. The study comprised a detailed audit, including an inventory of air compressor system equipment, current operating procedures, measurements of existing compressor operating performance, evaluation of the plant requirements and performance (air balance), and recommendations that would reduce air compressor system operating costs, including energy savings. Spot power measurements were made, loading cycle times were observed and the customer's compressor operating logs were reviewed to identify the pre-retrofit operating schedule and loading parameters.

The compressor (or blower vacuum pump or dryer) average operating power was calculated by the general formula:

$$kW_i = \frac{A_{o,i} \times V \times \Phi \times PF}{1{,}000},$$

where:

kW_i = operating kW of the compressor (or blower) i at the site loading condition;

$A_{o,i}$ = measured average operating amps of compressor i, for loaded and unloaded condition of the 300-hp compressor;

V = system voltage, 480 volts;

Φ = three phase multiplier ($\sqrt{3}$) = 1.732;

PF = power factor (estimated to be 0.91 in the ex ante estimates).

The compressor (or blower vacuum pump or dryer) annual energy use was calculated by the general formula for both pre-retrofit and post-retrofit conditions:

$$\text{Annual kWh}_i = kW_i \times AH_i,$$

where:

Annual kWh_i = annual kWh for compressor (or blower) i at loading condition;

kW_i = operating kW of the compressor (or blower) i at the site loading condition; and

AH_i = annual operating hours of compressor (or blower) i at loading condition.

The gross ex ante annual kWh impact was calculated as the difference between the pre-retrofit calculated annual energy use and the projected post-retrofit energy use:

$$\text{Ex Ante Annual kWh Impact} = \sum_{i=1}^{3}\left(\text{Annual kWh}_{\text{i,pre}} - \text{Annual kWh}_{\text{i,post}}\right)$$

The peak kW impact was calculated as:

$$\text{Ex Ante kW Reduced} = \sum_{i=1}^{3}(\text{kW}_{\text{i,pre}} - \text{kW}_{\text{i,post}})$$

Table 4-42 lists the key assumptions used in estimating the ex ante load impacts.

Table 4-42
Key Assumptions for Ex Ante Load Impact Estimates
Project No. 46628

Assumptions	
Motor power factor	0.91
Hours of operation	6,240
Required line pressure (PSI)	85
Leaks reduced to 20% cfm	
Compressors currently operate at their optimum pounds mass/hp point	

Ex Ante Basecase Description

The ex ante basecase equipment was:

- Two Ingersol-Rand 150-hp SSR rotary screw compressors
- One Ingersol-Rand 300-hp screw compressor
- One Sullair 40-hp compressor
- Two Zeks refrigerated air dryers, 700 scfm each

The ex ante operating hours of these air compressors and ex ante kW demand are shown in Table 4-42.

Ex Ante Postcase Description

The list of equipment in Section 4.8.4, Measure Description describes the ex ante postcase equipment which was added. The operation of the system was also discussed in Section 4.8.4. Table 4-43 shows the ex ante pre-retrofit hours of operation (from customer logs) and kW demand (from spot measurements) and the corresponding estimated values for post-retrofit operation for each compressor which were used to estimate the ex ante load impacts.

Ex Ante Load Impact Calculations

Table 4-43 shows a summary of the pre-retrofit and post retrofit energy power and energy calculations and impact estimate.

Table 4-43
Ex Ante Load Impact Estimate
Project No. 46628

HP	Condition	Volts	Phase Multiplier	Amps	Power Factor	kW	Hours/Year	kWh
Pre-Retrofit Operating Schedule and Energy Use								
150	Loaded	460	1.732	180	0.91	131	3,328	434,313
150	Unloaded	460	1.732	108	0.91	78	2,080	162,867
300	Loaded	460	1.732	396	0.91	287	3,952	1,134,643
40	Loaded	460	1.732	58.1	0.91	42	4,576	192,757
Total						**538**		**1,924,580**
Post-Retrofit Operating Schedule and Energy Use								
150	Loaded	460	1.732	180	0.91	131	6,240	814,337
150	Off	460	1.732	0	0.91	0	2,080	0
300	Off	460	1.732	0	0.91	0	3,952	0
40	Loaded	460	1.732	58.1	0.91	42	4,576	192,757
(6) 1.5-hp units	Loaded					9	6,240	56,160
Total						**182**		**1,063,254**
Demand and Energy Savings						**356**		**861,326**

The ex ante estimates are based on the premise that the use of the 300-hp compressor and one of the 150-hp compressors could be eliminated entirely by the system demand-reduction improvements.

4.9.6 Ex Post Load Impact Estimates

The ex post analysis was carried out using an engineering calculation methodology similar to the ex ante estimate calculations. The ex post analysis, however used direct measurements from customer operating logs as the basis for equipment pre- and post retrofit operating hours, and compressor and dryer operating power monitored at hourly intervals for two weeks as the basis for the daily and weekly power input and load profile.

Ex Post Basecase

The ex post analysis equipment basecase consisted of the pre-retrofit compressed air plant as described in the ex ante basecase operating at 125 psi. The basecase operating hours were increased by 10 percent to reflect the customer's estimate that equipment demand for compressed air had increased by 10 percent since the project was completed due to the addition of process equipment.

Ex Post Postcase

The ex post postcase consisted of the compressor system with the equipment and control modifications added through the incentive project as operated during the evaluation site visit in December 1998. The compressed air storage pressure was set at 110 psi and the distribution pressure was set at 100 psi. The facility engineer anticipated reducing the pressure to 90 psi in the future (as was suggested in the ex ante consultant report) but this had not been attempted as yet. The added equipment and changes are the same as described in the ex ante postcase.

Table 4-44
Ex Post Postcase Installed Equipment
Project No. 46628

Qty	Equipment	Description
1	Quincy 15-hp vacuum	265 cfm @ 29-inch hg and 14.6 bhp
1	4012 MD blower w/ VFD	PD blower 400 cfm @ 5 psi & 15.0 bhp
1	2000-HSDM Zeks dryer	2000 cfm refrig. Cycling type
1	1500-HDF Zeks filter	1500 cfm mist eliminator
1	400-LC Zeks filter	400 cfm coalescing
1	2,520 gallon vertical receiver	
1	AVP-1500	3-inch demand expander
7	GD Evacuator	large zero-loss drains
1	AB1606C6 aftercooler	water-cooled aftercooler with separator

Ex Post Operating Schedule

The ex post operating schedule is the same as described in the ex ante operating schedule, however, some second shift activity has increased and compressed air operation has increased as a result of added equipment and production requirements.

Ex Post Production Level Changes

The production at the plant increased. The facility maintenance staff estimated that the demand for compressed air had increased during first and second shift by about 10% due to the addition of a production robot and several other machining stations. The basecase operating hours were increased by 10% to reflect the additional energy which would have been required under the pre-retrofit plant configuration with the additional air flow.

As the increased production neither caused nor occurred as a result of the compressed air system modifications conducted under this incentive project, the post-retrofit compressed air demand, as reflected in the post retrofit power and energy use was used as the basis for the ex post gross impact calculation. The basecase power compressor operating hours were increased 10% above the actual (logged) pre-retrofit operating hours to reflect the increased air demand.

Data Collected Ex Post

- Input power to the three compressors was monitored at one hour intervals for the period December 9, 1998 through December 18, 1998.
- Compressor and other equipment weekly operating-hour logs for June 1996 through December 1998 were obtained from the customer.
- Spot power measurements of equipment which was not monitored were obtained from the customer.
- Pre-retrofit compressor operating power was obtained from the ex ante consultant's notes.

Ex Post Load Impact Calculations

The project impacts were calculated on an annual basis using hourly average power measurements obtained via post-retrofit monitoring combined with annual operating hours obtained from the customer's maintenance logs. The time-of-use period impacts and average, and peak-coincident demand impacts were calculated by apportioning the compressor system energy use to the time-of-use periods according to the proportions of use in each period shown by the post-retrofit hourly monitoring, and dividing the kWh impacts by the total hours in the TOU period.

Annual Gross kWh Impact

The compressor (or dryer, vacuum pump or blower) post-retrofit average operating power was calculated by the general formula:

$$\text{Post - retrofit average } kW_{post,i} = \frac{\sum kW_{monitoring,i}}{\sum H_{monitoring,i}},$$

where:

$kW_{monitoring,i}$ = measured kW for each hour the compressor operated during the monitoring period;

$H_{monitoring,i}$ = operating hours (hours with non - zero measured kW values) during monitoring period.

The compressor (or dryer, vacuum pump or blower) average pre-retrofit operating power was calculated from ex ante measured power data but using operating-hour data obtained ex post by the general formula:

$$kW_i = \frac{A_{o,i} \times V \times \Phi \times PF}{1{,}000},$$

where:

kW_i = operating kW of the compressor (or blower) i at the site loading condition;

$A_{o,i}$ = measured average operating amps of compressor i, for loaded and unloaded condition of the 300-hp compressor;

V = system voltage, 480 volts;

Φ = three phase multiplier ($\sqrt{3}$) = 1.732; and

PF = power factor (estimated to be 0.91 in the ex ante estimates).

The ex post equipment pre-retrofit annual energy use was calculated by:

$$\text{Annual kWh}_i = kW_i \times AH_i,$$

where:

Annual kWh_i = annual kWh for compressor (or blower) i at loading condition;

kW_i = operating kW of the compressor (or blower) i at the site loading condition; and

AH_i = annual operating hours of compressor (or blower) i at loading condition.

The ex post pre-retrofit operating hours were multiplied by a factor of 1.1 to adjust for the 10% demand increase for compressed air by production equipment estimated by the customer.

The gross annual kWh impacts were estimated as:

$$\text{Ex Post Annual kWh Impact} = \sum_{i=1}^{3} \left(\text{Annual kWh}_{i,pre} - \text{Annual kWh}_{i,post} \right)$$

Table 4-45 shows the operating hours data derived from plant records which was used in the ex post impact calculations.

Table 4-45
Ex Post Compressor Operating Hour Data
Project No. 46628

Date		Hours Meter	Elapsed Days	Compressor Oper. Hours	Hours/Day	Average Hours Per Day	Annual Operating Hours
Compressor #1 Total							
4/14/97	Pre-retrofit	12,657.0					
12/1/97		14,354.0	231	1697	7.35	7.35	2,681.4
12/29/97	Post-retrofit	14,566.0					
12/7/98		17,083.0	343	2517	7.34	7.34	2,678.4
Compressor #1 Loaded							
4/14/97	Pre-retrofit	11,133.0					
12/1/97		12,782.0	231	1649	7.14	7.14	2,605.6
12/29/97	Post-retrofit	12,987.0					
2/9/98		13,281.0	42	294	7.00	7.00	2,555.0
Compressor #2							
6/1/96	Pre-retrofit	20,563.0					
12/1/97		26,878.5	549	6315.5	11.50	11.50	4,198.8
12/29/97	Post-retrofit	27,102.1					
12/7/98		31,267.5	343	4165.4	12.14	12.14	4,432.6
Compressor #3							
8/26/96	Pre-retrofit	2,215.6					
12/1/97		8,194.0	462	5978.4	12.94	12.94	4,723.2
12/29/97	Post-retrofit	8,434.2					
12/7/98		12,794.5	343	4360.3	12.71	12.71	4,640.0

Table 4-46 shows the ex post impact calculations.

Table 4-46
Ex Post Load Impact Calculations
Project No. 46628

Compressor	Average Operating kW	Source of Data on kW	Total Annual Operating Hours	Source of Operating Hour Data	Annual kWh
PRE-RETROFIT					
AC #1:300-hp (+15hp cool fan)	291.9	Ex Ante Obs./Cust. Maint. Log	2,950	Customer Maint. Log x 1.1 (Note 1)	860,939
AC #2: 150-hp	131.7	Ex Ante Spot Obs.	4,619	Customer Maint. Log x 1.1 (Note 1)	608,284
AC #3:150-hp	130.7	Ex Ante Spot Obs.	5,196	Customer Maint. Log x 1.1 (Note 1)	679,054
Dryer	8.8	Ex Post Calculation (10-hp x 0.746kW/hp /0.85 eff)	2,510	Ex Post Estimate (251 days x 10hr/day)	22,029
Total-Pre-Retrofit					**2,170,306**
POST-RETROFIT					
AC #1:300-hp	241.7	Ex Post Monitoring	2,678	Cust. Maint. Log/Ex Post Mon.	647,448
AC #2: 150-hp	102.1	Ex Post Monitoring	4,433	Cust. Maint. Log/Ex Post Mon.	452,563
AC #3:150-hp	117.1	Ex Post Monitoring	4,640	Cust. Maint. Log/Ex Post Mon.	543,471
Blowers	9.2	6@1.5-hp,Eff=0.78, LF=0.8	4,016	Cust. Est. (2 shifts/wkday)	36,873
Quincy Vacuum (15-hp)	12.4	Customer Observation	4,016	Cust. Est. (2 shifts/wkday)	49,932
MD Blower (15-hp VSD)	12.4	Customer Estimate (Not presently used- process modified)	0	Cust. Est.	0
Dryer	3.9	Ex Post Monitoring	2,339	Ex Post Monitoring	9,013
Total - Post-Retrofit					**1,739,300**
Gross kWh Impact					**431,006**

Notes:
(1) The 1.1 Multiplier reflects customer estimate of 10% increase in consumptive air demand.

(2) 40-hp compressor use has not changed so is not included in impact calculation.

Ex Post TOU Period kWh Impacts

Gross kWh impacts for costing period *c* were determined by calculating a factor which represents the proportion of annual savings which occurs during each time-of-use period from the ex post monitoring results. The following steps were used:

1. The average post-retrofit kW (of the three 20-hp compressors) for each operating hour of each “Daytype” (Daytype 1 = Weekdays, Daytype 2 = Weekend/Holidays) was calculated from the monitoring data.
2. The total annual kWh for each hour of each daytype were calculated by multiplying the average hourly kW by the number of equivalent full production operating days occurred curing the first post-installation year. The monitoring data indicated 248 equivalent full production weekdays and 117 part production weekend holiday operating days including 104 weekend days per year and 13 holiday or partial operation days that occur on weekdays.
3. The kWh for the hours in each seasonal TOU period were summed.
4. The sum for the hours which occur during each summer time-of-use period was multiplied by 5/12, the *Seasonal Adjustment Multiplier* for summer, to reflect TOU consumption during the five summer season months. The total kWh which occur during each winter TOU period were multiplied by 7/12 to calculate the total which applies to each TOU period during the winter season.
5. The kWh in each TOU period for the year were summed and the kWh for each TOU period divided by the total to calculate the *TOU Adjustment Factor*.
6. The total annual kWh impact was multiplied by the *TOU Adjustment Factor* to calculate the kWh impact in each TOU period.

The process for estimating the TOU factors and ex post load impacts by TOU period is shown in the following equations:

$$\left(\text{Total kWh usage for each hour}_{\text{daytype}}\right) = \left(\text{Average post-retrofit kW for each hour}_{\text{daytype}}\right) \times \left(\text{No. Days}_{\text{daytype}}\right),$$

where:

$$\text{No. Days}_{\text{daytype}} = 248 \text{ days for weekdays}$$
$$= 117 \text{ days for weekends}$$

$$\left(\text{Sum of kWh usage for each TOU period}\right) = \sum \begin{pmatrix} \text{Total kWH usage for each hour}_{\text{daytype}} \text{ in} \\ \text{each summer and winter TOU period} \end{pmatrix}$$

$$\left(\text{Adjusted kWh usage for each TOU period}\right) = \left(\text{Sum of kWh usage for each TOU period}\right) \times \left(\text{Seasonal Adjustment Multiplier}\right),$$

where:

$$\text{Seasonal Adjustment Multiplier} = \left(\frac{5}{12}\right) \text{ for summer; and}$$

$$= \left(\frac{7}{12}\right) \text{ for winter.}$$

$$\left(\text{Total Annual kWh Usage}\right) = \sum_{p} \text{Adjusted kWh usage for each TOU period},$$

where:

p = the six TOU periods.

$$\left(\text{TOU Adjustment Factor for each TOU period}\right) = \frac{\text{Adjusted kWh Usage for each TOU period}}{\text{Total Annual kWh Usage}}$$

$$\left(\text{Ex Post kWh Savings by TOU period}\right) = \left(\text{Ex Post Gross kWh savings}\right) \times \left(\text{TOU Adjustment Factor for each TOU period}\right).$$

The results are summarized in Table 4-47.

Average Gross kW Impacts

Average gross kW impacts were calculated for each costing period by dividing the total kWh impacts for the costing period by the total number of hours in the TOU period:

$$\text{Average Ex Post kW Reduced}_c = \frac{\text{Ex Post kWh Savings}_c}{\text{Hours}_c}$$

These results are shown in Table 4-47.

Table 4-47
Ex Post Load Impacts By TOU Period
Project No. 46628

Season	**Period**	**TOU Adjustment Factor**	**kWh Savings**	**Total Hours**	**Average kW**
Column A	Column B	Column C	Column D	Column E	Column F
			Col. C x 431,006 kWh/yr		Col. D/Col. E
Summer	**On-peak**	0.1344	57,945	749	77.4
	Semi-peak	0.1645	70,902	963	73.6
	Off-peak	0.1177	50,739	1,960	25.9
Winter	**On-peak**	0.0691	29,777	441	67.5
	Semi-peak	0.3494	150,608	1,911	78.8
	Of-peak	0.1648	71,035	2,736	26.0
Total			**431,006**		

Gross kW Impact Coincident with System Peak

The impact across the daytime hours is reasonable constant. The summer on-peak TOU period average kW impact is reported as the ex post peak coincident kW impact.

4.9.7 Summary of Gross Impacts

Table 4-48 compares the ex ante gross impact estimates with the ex post study results.

Table 4-48
Results and Comparison with ex ante Estimate
Project No. 46628

	kWh	kW	Therms
Ex Ante	861,326	356.00	n/a
Ex Post	431,006	77.4	n/a
Realization Rate	50.0%	21.7%	n/a

The ex post gross annual energy impact was 431,006 kWh, 50.0% of the ex ante estimate of 861,326 kWh. The ex post gross peak demand impact was 77.4 kW, 21.7% of the ex ante estimate, 356 kW.

The primary reason for the large discrepancy was overly optimistic expectation of the impacts of the measures installed at the site in reducing demand for compressed air, due in part to the setting of the distribution pressure to 100 psi, rather than 90 psi as assumed in the ex ante estimates. The ex ante projection assumed that the 300-hp compressor and one of the 150-hp compressors would be shut down entirely, primarily as a result of the efforts to reduce the demand for compressed air. The ex post calculations showed that the hours of operation for the three compressors was reduced, but not nearly to the degree projected in the ex ante estimates.

4.9.8 Net-To-Gross Ratio

The net-to-gross ratio for this project was estimated to be 1.0. The SDG&E IEEI Program was the reason the measures were installed.

The site contact indicated he knew he had some problems with his compressed air system, but had no idea how to go about fixing them until he was contacted by SDG&E. SDG&E arranged to have a program-sponsored compressed air consultant prepare a study of the system. The customer felt that this study was excellent and gave him the cost savings information he needed to go to management with the project proposal. The recommendations presented in the study were implemented at the facility under this project.

SDG&E staff (consultants) had a high level of involvement in this project, having originated the project concept and provided all technical and engineering analysis.

4.10 PROJECT ID 46697 - COMPRESSED AIR SYSTEM MODIFICATIONS WITH CONTROLS & STORAGE

4.10.1 Summary of Findings

The savings for this site were based on the installation of a 75-hp air compressor to replace two oversized 200-hp compressors. The results of the ex post evaluation were different than those of the ex ante estimate due to differences in the ex post operation and basecase from the ex ante assumptions.

Table 4-49
Summary of Ex Post Load Impacts
Project No. 46697

	kWh	kW	Therms
Ex Ante	934,800	117.00	n/a
Ex Post	906,184	107.57	n/a
Realization Rate	96.9%	91.9%	n/a

4.10.2 Facility Description

This site manufactures plastic components used for 3-1/2” floppy disk cartridges, audio cassette housings, and plastic audio cassette cases. There are 40 Nigata and Sumitomo injection molding machines that manufacture the various components. Assembly of floppy disks is also performed at this site using the cartridge halves and shutters manufactured onsite. Compressed air is used as a motive force in air cylinders that operate the robotic arms and heads on the injection molding machines to transport finished plastic components from the molds to stackers.

4.10.3 Overview of Facility Schedule

This facility operates 24 hours per day seven days per week, except during holiday periods when the plant is shut down. The plant runs at capacity, utilizing four floppy disk assembly lines and production levels are consistently high throughout the year. Slow downs only occur when injection molding equipment is taken down for repair.

The current shift schedule is two twelve-hour shifts per day, seven days per week for production workers, and one eight-hour shift per day, five days per week for office workers. Currently, the plant is operating four floppy disk assembly lines.

The ex post hours of operation are:

$$\text{Hours of Operation}_{\text{ex post}} = 8{,}760 \text{ hours / year} - (14 \text{ Holidays / year} \times 24 \text{ hours / Holiday})$$

$$= 8{,}424 \text{ hours / year}$$

4.10.4 Measure Description

Piping, valves and controls were installed to tie the outputs of four existing 125-hp air compressors and one new 75-hp air compressor together to supply plant air demands from a central high pressure air receiver for 32 injection molding machines and the floppy disk assembly area. The controls were set to fill the 1,020 gallon air receiver with 115 psig air from the compressors. This reservoir of high pressure air is then let down through a valve, called a demand expander, to feed a distribution system operating at 80 psig. This configuration provides surge capacity to supply high instantaneous loads while the compressors operate in a fairly steady mode to keep the high pressure receiver full. The separation of the demand/distribution system from the supply/storage system in this manner results in the realization of several energy efficiency improvements, including:

- Lower parasitic losses in piping system due to reduced pressure drop.
- Lower leakage losses in distribution and end use systems since pressure is lower.
- Fewer compressors running to supply demand, since high pressure receiver absorbs demand swings.
- Higher overall compressor efficiency since compressors are fully loaded most of the time rather than part loaded.

In addition, two 200-hp compressors were removed, leaks were repaired, and a new 400 gallon receiver was installed at the end of the low pressure distribution piping to provide “end-of-the-line” surge capacity.

Pre-Retrofit Conditions

- Four 125-hp, Sullair, single stage, rotary screw, air-cooled, air compressors operating independently supplying 125 psig air to the plant distribution system.
- Two 200-hp, Joy, double acting, reciprocating, air compressors in stand by service to independently provide peak flow air demand at 125 psig.
- Compressed air being used in vacuum ejector devices to generate vacuum for process needs.
- Production facility operates 24 hours per day, 7 days per week, except during 14 holiday periods when the plant is shut down.
- Injection molding accomplished during two 12-hour shifts per day, seven days per week, and floppy disk assembly accomplished during three 8-hour shifts per day, five days per

week, while office work accomplished during one eight-hour shift per day, five days per week.

- The plant runs at capacity, utilizing six floppy disk assembly lines, and production levels are consistently high throughout the year. Slow downs only occur when injection molding equipment is taken down for repair.
- Thirty two Nigata and Sumitomo injection molding machines manufacture plastic floppy disk cartridge components, audio cassette housings and audio cassette cases.

Post-Retrofit Conditions

- Two pre-retrofit 125-hp, Sullair, single stage, rotary screw, air-cooled, air compressors supply 115 psig air to a central air receiver for use in the plant distribution system. These compressors are controlled by a new PLC which stages them to operate as necessary to maintain high pressure receiver pressure.
- Two pre-retrofit 125-hp, Sullair, single stage, rotary screw, air-cooled, air compressors shut down, but available for service. The plant rotates these compressors into service from April through September, while the other two compressors run only from October to March each year.
- One new 75-hp, Sullair, single stage, rotary screw, air cooled ,air compressors supplies 115 psig air to the central air receiver for use in the plant distribution system. This compressor is also controlled by a new PLC which stages it to operate as necessary to maintain high pressure receiver pressure.
- Two pre-retrofit 200-hp, Joy, double acting, reciprocating, air compressors removed from the site.
- Process vacuum being generated by new vacuum pumps (rebated separately under Project No. 48698). Vacuum ejectors removed.
- Production facility operates 24 hours per day, seven days per week, except during 14 holiday periods when the plant is shut down.
- Injection molding and floppy disk assembly production work accomplished during two 12-hour shifts per day, seven days per week, while office work accomplished during one eight-hour shift per day, five days per week.
- The plant runs at capacity, utilizing four assembly lines, and production levels are consistently high throughout the year. Slow downs only occur when injection molding equipment is taken down for repair.
- Forty Nigata and Sumitomo injection molding machines manufacture plastic floppy disk cartridge components, audio cassette housings and audio cassette cases.

4.10.5 Ex Ante Load Impact Estimates

The *ex ante* load impact estimates were based on a site-specific study of the facility's compressed air system conducted by a compressed air system consultant provided by SDG&E's IEEI Program. The study comprised a detailed audit, including an inventory of air compressor system equipment, current operating procedures, measurements of existing compressor operating performance, evaluation of the plant requirements and performance (air balance), and recommendations that would reduce air compressor system operating costs, including energy savings. Spot measurements were made to verify the current operating parameters of the system. The results of this monitoring revealed that the compressors operated to satisfy two demand levels depending on the day of the week: high demand and, low demand.

Tables 4-2 and 4-3 show a summary of the load impact estimates, and the air balance and savings calculations, respectively. These tables show total *ex ante* load impacts of 934,800 kWh saved and 117.00 kW reduced.

Table 4-50
Ex Ante Pre-Retrofit versus Post-Retrofit Power Demands
Project No. 46697

	Pre-Retrofit		Post-Retrofit		Total
	Low Demand	High Demand	Low Demand	High Demand	Impact
Horsepower	277	424	158	280	263
kW	225	344	128	227	117
Hours	2,400	6,000	2,400	6,000	0
kWh	540,000	2,064,000	307,200	1,362,000	934,800

Table 4-51
Ex Ante Constituents of Air Demand
Project No. 46697

	Low Demand (scfm)		High Demand (scfm)		Total Demand Reduction (scfm)
	Pre-Retrofit	Post-Retrofit	Pre-Retrofit	Post-Retrofit	
Good Applications	485	485	834	834	0
Other Applications	259	150	259	150	218
Bad Applications	0	0	91	91	0
Leakage	232	50	355	75	462
Artificial Demand	103	0	157	0	260
Total	**1,079**	**685**	**1,696**	**1,150**	**940**

The leakage make up demand is the output of the compressor required to overcome leakage in the system to maintain the system pressure. Since these leaks are always present, this demand is always present as well. However, during the times when the production line is shut down, this is the only demand on the compressed air system. Air consumption during this period was measured to be 355 scfm and this was therefore the assumed leakage make-up demand. Repairs were made in an attempt to lower this to 75 scfm. However, one high volume leak was observed during the ex post site visit.

Artificial demand is the demand created by the distribution system when air has to be supplied at a pressure greater than that required by the end use in order to provide sufficient volume to satisfy the demand. Parasitic pressure drop losses are increased when distribution piping pressure is raised and leakage losses are higher due to the increased pressure in the distribution system.

The ex ante analysis was carried out based on measured air flows and the kW demand of pre-retrofit equipment and engineering estimation of the effects of the post retrofit equipment and operation on kW consumption. The ex ante analysis assumed the post-retrofit equipment would operate on the pre-retrofit production schedule, and that post-retrofit process air demand would be the same as pre-retrofit air demand, except for the reductions in air demand caused by the energy efficiency measure modifications.

Table 4-52 summarizes the nameplate and measured operating parameters of the pre- and post-retrofit compressors.

Table 4-52
Ex Ante Air Compressor Nameplate Data
Project No. 46697

Item	Mfr	Model	Motor HP	Voltage	Rated Capacity (ACFM)	Design Discharge Pressure (psig)	Operating Discharge Pressure (psig)	Discharge Temp. (°F)
Comp #1	Sullair	20/16-125H AC/AC	125	480	635	100		
Comp #2	Sullair	20/16-125H AC/AC	125	480	635	100	106	185
Comp #3	Sullair	20/16-125H AC/AC	125	480	635	100	106	195
Comp #4	Sullair	20/16-125H AC/AC	125	480	635	100		
Comp #5	Sullair	CS16-75H AC/AC	75	480	326	100	120	170

All of the post-retrofit compressors are of the same type, single stage, air cooled, rotary screw, and the outputs of all are modulated using a common on-line/off-line control system. This control scheme is the most energy efficient means of operating rotary screw air compressors. These controls operate the compressors either fully loaded or totally unloaded. Thus a machine is either producing its maximum output when fully loaded, or producing no output when totally unloaded. There is, therefore, no partial loading mode when a compressor delivers some fraction of its maximum capacity. It’s either all, or nothing at all. This does not mean, however, that energy consumption is zero when compressor output is zero. Even unloaded, this type of compressor consumes approximately 25% of what it consumes when fully loaded.

Ex Ante Basecase Definition

For the ex ante basecase (pre-retrofit), the four 125-hp Sullair compressors ran simultaneously, in various states of part to full loading, with the Joy compressors running as necessary to supply pre-retrofit peak air demands only. Each compressor in the system had its own control system that ran its machine to maintain the pressure in the distribution system. If equipment at the "end-of-the-line" was starved for air, the set points of each compressor were raised until the demand could be satisfied. Nominal distribution system pressure was 125 psig.

Compressed air was used by 32 injection molding machines in the injection molding room and six floppy disk assembly lines in the floppy disk assembly area.

Ex Ante Postcase Definition

For the ex ante postcase (post-retrofit), the control system was to base load the four 125-hp Sullair compressors to maintain the central air receiver pressure. Controls were set to load the 125-hp compressors when the high pressure air receiver pressure fell to 117 psig and run them until the high pressure receiver reached 125 psig. One 75-hp compressor was set to load when high pressure air fell to 112 psig and then run until pressure was restored to 117 psig in the high pressure receiver. The second 75-hp compressor was staged to load when the high pressure system fell to 110 psig and then run until pressure was restored to 115 psig in the high pressure receiver.

Compressed air was used by 32 injection molding machines in the injection molding room and six floppy disk assembly lines in the floppy disk assembly area. Postcase compressor discharge pressure was to have been 125 psig into the high pressure air receiver. The demand expander valve was to have then regulated flow out of the receiver to maintain the distribution system at 90 psig. Postcase vacuum generation for the injection molding area is accomplished by new vacuum pumps which were concurrently installed in a separate project rebated under Project No. 48698.

Ex Ante Operating Schedule

The ex ante injection molding operation runs 24 hours per day, seven days per week, except for 15 holiday periods when the plant is shut down.

Floppy disk assembly occurs 24 hours per day, five days per week, except for 15 holiday periods when the plant is shut down. Floppy disk assembly is also shut down on weekends.

Production workers work three eight-hour shifts per day, seven days per week in injection molding, and three eight-hour shifts per day, five days per week in floppy disk assembly, while office workers work one eight-hour shift per day, five days per week.

The ex ante hours of operation are therefore:

$$\text{Ex Ante Annual Hours of Operation} = 8{,}760\ \text{hrs/yr} - \left[\left(15\ \text{Holidays/yr}\right)\times\left(24\ \text{hrs/day}\right)\right]$$

$$= 8{,}400\ \text{hrs/yr}$$

The plant runs at capacity, utilizing six assembly lines, and production levels are consistently high throughout the year. Slow downs only occur when injection molding equipment is taken down for repair.

Key Ex Ante Assumptions

- Assumed that pre- and post-retrofit air demand from production machinery is identical.
- Assumed that pre- and post-retrofit production schedules would be the same.

Ex Ante Algorithms

Based on the measured pre-retrofit air demands, a post-retrofit air demand profile was developed. From this profile, the electrical power consumption was estimated based on the measured kW/scfm of the pre-retrofit machines at the various operating modes.

Hours of operation at the high and low demand modes were extrapolated from monitoring data. Annual kWh was obtained by multiplying kW at the low mode times hours of operation at the low mode, and adding that to the product of kW at the high mode time the hours of operation at the high mode. This is summarized above in Table 4-50.

Annual energy savings is the difference between the pre-and post-retrofit kWh, or:

$$\text{Annual Energy Savings}_{\text{ex ante}} = \left(\text{kWh}_{\text{low demand}} + \text{kWh}_{\text{high demand}}\right)_{\text{pre-retrofit}} - \left(\text{kWh}_{\text{low demand}} + \text{kWh}_{\text{high demand}}\right)_{\text{post-retrofit}}$$

$$= (540{,}000\ \text{kWh} + 2{,}064{,}000\ \text{kWh}) - (307{,}200\ \text{kWh} + 1{,}362{,}000\ \text{kWh})$$

$$= 934{,}800\ \text{kWh}$$

The average demand reduction is the annual energy savings at the high demand mode divided by the hours of operation at the high demand mode, or:

$$\text{Average Demand Reduction}_{\text{ex ante}} = \frac{\left(2{,}064{,}000\ \text{kWh} - 1{,}362{,}000\ \text{kWh}\right)}{6{,}000\ \text{hours}}$$

$$= 117.0\ \text{kW}$$

Ex Ante Data Sources

- Compressor nameplate data and manufacturer's equipment data sheets.
- Spot measurements of equipment.
- Customer interviews.

4.10.6 Ex Post Gross Load Impact Estimates

Monitoring data was analyzed to determine ex post power consumption patterns of the compressed air system supplying the 40 injection molding machines and four floppy disk assembly lines using the ex post operating schedule. These values were extrapolated to the 8,760 hour year assuming constant plant production levels, and accounting for planned production schedules.

Monitoring data for all three running compressors were aggregated to find the average operating kW for each hour of the day. These demands were extrapolated to the 8,760 hour year.

The customer concurrently installed vacuum pumps which reduced demand on the air compressors. An evaluation of the load impacts of the vacuum system was completed and reported separately as Project No. 48698. Concurrent monitoring of both systems was performed and did establish a significant decrease in the total combined horsepower required to operate the compressed air system and the vacuum system.

Ex Post Basecase

The ex post basecase was assumed to be the same as the ex ante basecase adjusted for the current production schedule.

Ex Post Postcase

For the ex post postcase (post-retrofit), the control system base loads two pre-retrofit 125-hp Sullair compressors to maintain the central air receiver pressure at 115 psig. Controls were set to load and unload the post-retrofit 75-hp compressor as necessary to maintain the central air receiver pressure. This reservoir of high pressure air is then let down through a valve, called a demand expander, to feed a distribution system operating at 80 psig, and satisfy the air demand of 32 injection molding machines and four floppy disk assembly lines. Two other pre-retrofit compressors are kept as maintenance standby machines and are rotated into service every six months. Vacuum generation for the injection molding area is accomplished by new vacuum pumps that were concurrently installed under a separate project rebated under Project No. 48698.

Ex Post Operating Schedule

This facility operates 24 hours per day seven days per week, except during holiday periods, totaling 14 days per year, when the plant is shut down. The plant runs at capacity, utilizing four floppy disk assembly lines and production levels are consistently high throughout the year. Slow downs only occur when injection molding equipment is taken down for repair.

The current shift schedule is two 12-hour shifts per day, seven days per week for production workers, and one eight-hour shift per day, five days per week for office workers. Currently, the plant is operating four floppy disk assembly lines.

Ex post hours of operation are therefore:

$$\text{Ex Post Hours of Operation} = 8{,}760 \text{ hours / year} - \left(14 \text{ Holidays / year} \times 24 \text{ hours / Holiday}\right)$$

$$= 8{,}424 \text{ hours / year}$$

Ex Post Production Level Changes

Installation of the energy efficiency measures did not affect the production level of the plant. However, the overall ex post air consumption levels are higher than the ex ante levels due to installation of additional injection molding equipment on the plant production line. The addition of eight injection molding machines increased air demand by 25% over ex ante demands.

Data Collected Ex Post

The energy consumption of each of the running compressors was measured using portable power monitoring equipment. Measurements were taken using a Pacific Science & Technology Energy Logger. This instrument measures true RMS kW. The following data were collected on-site:

- Runtime data for all three compressors;
- Measured voltage, amperage, power factor and kW for the three compressors; and
- Motor and compressor nameplate data.

Data were collected on one-minute intervals over a three week period in November and December of 1998. Thirty-minute averages for each operating compressor were recorded for actual voltage, amperes, power factor and kW.

Ex Post Algorithms

Ex post power consumption of the two baseload 125-hp compressors was steady and varied only slightly over the entire ex post monitoring period. Power consumption of the 75-hp compressor varied considerably from hour to hour as it loaded and unloaded to maintain the pressure in the high pressure receiver. Ex post power monitoring data was averaged for each hour of the day. Average observed power consumption for a 24 hour period was 253.1 kW and total observed average ex post power consumption for the three operating compressors varied between 248.6 kW and 257.8 kW on an average day.

Since the number of injection molding machines increased by 25%, observed air demand is 25% higher than the postcase demand for 32 injection molding machines. The average postcase kW is therefore 75% of the observed average ex post kW.

$$\text{Average kW}_{\text{postcase}} = 0.75 \times 253.1 \text{ kW}$$

$$= 202.5 \text{ kW}$$

Annual ex post energy savings is the difference between basecase kWh consumption and postcase kWh consumption. The average basecase and postcase kW were multiplied by the operating hours consistent with the schedule discussed above in the Ex Post Operating Schedule section to estimate the annual consumption and savings. According to customer staff, this facility operates a nearly identical schedule year-round. The annual kWh savings was calculated as shown in the following equation and Table 4-53.

$$\text{Annual kWh Savings}_{\text{ex post}} = \text{kWh}_{\text{basecase}} - \left(\text{Average kW}_{\text{postcase}} \times \text{Annual Hours of Operation}\right)$$

$$= 2{,}072{,}256 \text{ kWh} - \left(202.5 \text{ kW} \times 8{,}424 \text{ hrs/yr}\right)$$

$$= 906{,}184 \text{ kWh}$$

Table 4-53
Ex Post kWh Savings
Project No. 46697

	Pre-Retrofit			**Total Annual**
	Low Demand	**High Demand**	**Post-Retrofit**	**Usage Reduction**
kW	225.00	344.00	202.5	
Hours	2,400	6,024	8,424	
kWh	**540,000**	**2,072,256**	**1,706,072**	**906,184**

From Table 4-53, the average ex post kW reduction was then the total annual usage reduction divided by the annual hours of operation:

$$\text{Average kW Reduced}_{\text{expost}} = \frac{906{,}184 \text{ kWh/yr}}{8{,}424 \text{ hrs/yr}}$$

$$= 107.57 \text{ kW}$$

Ex Post Load Impacts By Time-Of-Use Period

The operating characteristics of the compressed air system for this facility was fairly consistent, with little variability. Thus, the allocation of kWh savings to the time-of-use (TOU) periods was based on the operating hours in each TOU period. The results are shown in Table 4-54.

Table 4-54
Ex Post kW and kWh Impacts by Time-of-Use Period
Project No. 46697

Time-of-Use Period	Annual Hours	kWh Adjustment Factor	kWh Savings	Average kW Reduced	kW Reduced Coincident with System Peak Period
Summer On-peak	735	0.0873	79,065	107.57	142.04
Summer Semi-peak	945	0.1122	101,655	107.57	
Summer Off-peak	1,944	0.2308	209,119	107.57	
Winter On-peak	405	0.0481	43,567	107.57	141.13
Winter Semi-peak	1,755	0.2083	188,788	107.57	
Winter Off-peak	2,640	0.3134	283,989	107.57	
Total	**8,424**	**1.0000**	**906,184**		

The kW reduced coincident with system peak was calculated by subtracting the monitored postcase average kW for the summer and winter on-peak periods from the basecase kW for the high demand operating mode.

$$\text{kW Impact}_{\text{ex post,summer}} = \left(\text{kW}_{\text{basecase,high demand}}\right) - \left(\text{Average kW}_{\text{postcase,summer on-peak}}\right)$$

$$= 344 \text{ kW} - 201.96 \text{ kW}$$

$$= 142.04 \text{ kW}$$

$$\text{kW Impact}_{\text{ex post,winter}} = \left(\text{kW}_{\text{basecase,high demand}}\right) - \left(\text{Average kW}_{\text{postcase,winter on-peak}}\right)$$

$$= 344 \text{ kW} - 202.87 \text{ kW}$$

$$= 141.13 \text{ kW}$$

4.10.7 Net-To-Gross Ratio

The net-to-gross ratio for this project was estimated to be 1.0, due to the high level of involvement by SDG&E and the impact of the incentives on the internal decision-making process. The SDG&E IEEI Program was the reason the measures were installed.

SDG&E arranged to have a program-sponsored compressed air consultant prepare a study of the system. The recommendations presented in the study were implemented at the facility under this project. The consultant provided implementation assistance to the customer. The customer had a very tight budget and the program incentives helped this project pass financial hurdles. A number of iterations were made in trying to gain management approval for the project.

SDG&E staff (consultants) originated the project concept and provided all technical and engineering analysis.

Non-Energy Costs and Benefits

No non-energy costs or benefits resulted from the installation of the equipment.

Equipment Alternatives

The pre-retrofit compressor system would have remained in service had this project not been installed. No other alternatives other than the ex post equipment were considered.

Motivation

Motivation for the project was inspired by the cost reduction opportunity and the promise of a more reliable compressed air supply system. The project was initiated by SDG&E, who apprised the customer of the potential for savings, provided the compressed air consultant who did the monitoring and performed the design engineering. According to the customer, this equipment would not have been installed without the assistance of SDG&E and the program rebate. Moreover, the project was only approved and built because the rebate was large enough to improve the project economics to meet the customer's internal payback criteria.

4.11 PROJECT ID 47445 - OPTIMIZED COMPRESSED AIR SYSTEM

4.11.1 Summary of Findings

The savings for this site were based on the installation of improved controls and one new 100-hp compressor to replace one 50-hp compressor on an compressed air system at this manufacturing facility. The results of the ex post evaluation were different than those of the ex ante estimate due to differences in the ex post operation from the predicted ex ante operation.

Table 4-55
Summary of Ex Post Load Impacts
Project No. 47445

	kWh	kW	Therms
Ex Ante	986,912	93.67	n/a
Ex Post	145,419	20.61	n/a
Realization Rate	14.7%	22.0%	n/a

4.11.2 Facility Description

This site manufactures computer grade circuit board blanks for third parties. Layered boards are produced on an assembly line and then custom drilled to accept electronic components. The blank boards are sold to third party assemblers for installation of electronic components. Compressed air is used to supply the air bearings in the circuit board drills, to drive the waste water diaphragm pumps, and to purge waste water filters. Compressed air is also used in a hot air leveler to achieve solder flatness tolerances on the boards.

4.11.3 Overview of Facility Schedule

This facility operates 24 hours per day, seven days per week year round. The plant runs at capacity, and production levels are consistently high throughout the year.

The current shift schedule is two twelve-hour shifts per day, seven days per week for production and maintenance workers, and one eight-hour shift per day, five days per week for office workers.

Annual hours of operation are therefore 8,760 hours per year.

4.11.4 Measure Description

Piping, valves and controls were installed to tie the output from an existing 75-hp air compressors and a 125-hp air compressor together with the outputs of a relocated 150-hp air compressor and a new 100-hp air compressor to supply plant air demands from a central high pressure air receiver. The new 100-hp compressor replaced an existing 50-hp machine. The controls were set to fill one new 2,520 gallon air receiver with 120 psig air from the compressors. This reservoir of high pressure air is then let down to the high pressure (105 psig) distribution system through a valve, called a demand expander, and through a separate demand expander to feed a low pressure distribution system operating at 85 psig. This configuration provides surge capacity to supply high instantaneous loads while the compressors operate in a fairly steady mode to keep the high pressure receiver full, and it avoids having to maintain the entire distribution system at 105 psig when only the drill room needs the higher pressure. By separating the demand/distribution system from the supply/storage system in this manner, several energy efficiency improvements are realized.

- Lower parasitic losses in piping system due to reduced pressure drop.
- Lower leakage losses in distribution and end use systems since pressure is lower.
- Fewer compressors running to supply demand, since high pressure receiver absorbs demand swings.
- Higher overall compressor efficiency since compressors are fully loaded most of the time rather than part loaded.

In addition, a new 400 gallon receiver was installed at the hot air leveler and a new 60 gallon receiver was installed at the Spencer dust collector to provide local surge capacity for high instantaneous demands.

Pre-Retrofit Conditions

- One 50-hp Gardner-Denver, one 150-hp Gardner-Denver, one 125-hp Ingersoll-Rand, and one 75 hp Ingersoll-Rand single stage, rotary screw, air cooled, air compressors operating independently supplying 125 psig air to the central plant distribution system.
- Production facility operates 24 hours per day, seven days per week.
- Production and maintenance workers work two twelve-hour shifts per day, seven days per week, while office workers work one eight-hour shift per day, five days per week.
- The plant runs at capacity, and production levels are consistently high throughout the year.
- Twenty eight drills operate in the drill area.

Post-Retrofit Conditions

- One new 100-hp Gardner-Denver, one pre-retrofit 150-hp Gardner Denver, one pre-retrofit 125-hp Ingersoll-Rand, and one pre-retrofit 75-hp Ingersoll-Rand single stage, rotary screw, air cooled, air compressors operating to supply 125 psig air to a central air receiver for use in the plant distribution system. These compressors are individually controlled by onboard PLC's that are set up to stage their operation to maintain high pressure receiver pressure.

- The pre-retrofit 50-hp compressor is removed from the site.
- Production facility operates 24 hours per day, seven days per week.
- Production and maintenance work accomplished during two twelve-hour shifts per day, seven days per week, while office work accomplished during one eight-hour shift per day, five days per week.
- The plant runs at capacity, and production levels are consistently high throughout the year.
- Thirty four drills operate in the drill area.

4.11.5 Ex Ante Load Impact Estimates

The *ex ante* load impact estimates were based on a site-specific study of the facility's compressed air system conducted by a compressed air system consultant provided by SDG&E's IEEI Program. The study comprised a detailed audit, including an inventory of air compressor system equipment, current operating procedures, measurements of existing compressor operating performance, evaluation of the plant requirements and performance (air balance), and recommendations that would reduce air compressor system operating costs, including energy savings. Spot measurements were made to verify the current operating parameters of the system. The results of this monitoring revealed that the compressors operated to satisfy three main demand levels: high capacity, low capacity and leakage make-up.

Tables 4-2 and 4-3 show a summary of the load impact estimates, and the air balance and savings calculations, respectively. Basecase demands were measured, while postcase demands were estimated based on the horsepower rating of the new 100-hp postcase compressor and the postcase duty of the pre-retrofit 150-hp compressor. These tables show total *ex ante* load impacts of 986,911 kWh saved and 93.67 kW reduced.

Table 4-56
Ex Ante Load Impacts
Project No. 47445

	Power Adjusted Flow (scfm)	Density at Operating Pressure (lb/cu-ft)	Demand (kW)	Annual Operating Hours	Annual Energy Consumption (kWh)	Annual Air Usage (lb/yr)
Col. A	Col. B	Col. C	Col. D	Col. E	Col. F	Col. G
					Col. D x Col. E	Col. B x 60 x Col. C x Col. E
Basecase Supply						
SSR EP 75	285	0.635185	67.56	8,500	574,271	92,481,261
SSR EPH 125	407	0.635185	98.16	7,752	760,952	120,316,617
GD 150 hp	528	0.686124	106.44	8,500	904,715	184,686,445
GD 50 hp	133	0.584247	32.72	8,500	278,144	39,663,211
Dryers			13.20	8,500	112,200	
Basecase Total			**318.08**		**2,630,283**	**437,147,534**
Postcase Supply						
GD 100 hp	440	0.711593	88.24	6,888	607,773	129,398,433
GD 100 hp unloaded		0.0	26.47	600	15,883	-
GD 150 hp	620	0.711593	129.38	7,488	968,797	198,216,922
Dryer			6.80	7,488	50,918	
Postcase Total			**224.42**		**1,643,372**	**327,615,355**
Ex Ante Load Impacts			**93.67**		**986,911**	**109,532,179**

Table 4-57
Constituents of Air Demand
Project No. 47445

	Constituent of Demand	Air Demand (scfm)	Air Demand Pressure (psig)	Density at Utilized Pressure (lb/cu-ft)	Actual Mass Flow (lb/min)	Actual Mass Flow (lb/hr)	Annual Hours of Operation	Annual Air Usage (lb/yr)
Col. A	Col. B	Col. C	Col. D	Col. E	Col. F	Col. G	Col. H	Col. I
				(0.0051) x (Col. D+ 14.7)	Col. C x Col. E	Col. F x 60		Col. G x Col. H
Basecase Demand								
Drill area	Drilling	843	110	0.63519	535	32,128	7,488	240,572,047
HAL	Blowing	160	110	0.63519	102	6,098	7,488	45,660,175
Plating	Pumps	90	60	0.38049	34	2,055	7,488	15,385,263
WWTP	Pumps	160	85	0.50784	81	4,875	748	3,646,687
Cyl. Eject	Air Cyl Eject	88	85	0.50784	45	2,681	4,160	11,154,573
Leaks	Production	170	110	0.63519	108	6,479	8,760	56,755,085
Artificial Demand	Production	224	110	0.63519	142	8,543	7,488	63,973,701
Total Basecase		**1,735**			**1,048**	**62,859**		**437,147,532**
Postcase Demand								
Drill area	Drilling	843	100	0.58425	493	29,551	7,488	221,279,364
HAL	Blowing	160	85	0.50784	81	4,875	7,488	36,505,877
Plating	Pumps	90	40	0.27861	25	1,505	4,160	6,258,794
WWTP	Pumps	160	85	0.50784	81	4,875	748	3,646,687
Var. Cyl.	Cylinders	88	100	0.58425	51	3,085	6,440	19,866,257
Leaks	Production	150	85	0.50784	76	4,571	8,760	40,037,996
Artificial Demand		-						
Total Postcase		**1,491**			**808**	**48,462**		**327,594,974**
Reduced Air Demand		**244**						**109,552,558**

The *leakage make up demand* is the output of the compressor required to overcome leakage in the system to maintain the system pressure. Since these leaks are always present, this demand is always present as well. However, during the times when the production line is shut down, this is the only demand on the compressed air system. Air consumption during this period was measured to be 170 scfm and this was therefore the assumed leakage make-up demand. Leakage in the post-retrofit system was assumed to be 150 scfm due to lower post-retrofit distribution system pressure.

Artificial demand is the demand created by the distribution system when air has to be supplied at a pressure greater than that required by the end use in order to provide sufficient volume to satisfy the demand. Parasitic pressure drop losses are increased when distribution piping pressure is raised and leakage losses are higher due to the increased pressure in the distribution system.

The ex ante basecase analysis was carried out based on measured air flows and the kW of pre-retrofit equipment and engineering estimation of the effects of the post retrofit equipment and operation on kW consumption. The ex ante analysis assumed the post-retrofit equipment would operate on the pre-retrofit production schedule, and that post-retrofit process air demand would be the same as pre-retrofit air demand, except for the reductions in air demand caused by the energy efficiency measure modifications.

Table 4-58 summarizes the nameplate and measured operating parameters of the pre- and post-retrofit compressors.

Table 4-58
Air Compressor Nameplate Data
Project No. 47445

Compressor Manufacturer	Motor HP	Voltage	Rated Capacity (ACFM)	Design Discharge Pressure (psig)	Operating Discharge Pressure (psig)	Discharge Temp. (°F)
Ingersoll-Rand	75	480	320	125	127	181
Ingersoll-Rand	125	480	540	125	128	188
Gardner-Denver	150	480	620	125	128	184
Gardner-Denver	100	480	440	125	125	189

All of the post-retrofit compressors are of the same type: single stage, air cooled, rotary screw, and the outputs of all are modulated using an on-line/off-line control system. This control scheme is the most energy efficient means of operating rotary screw air compressors. These controls operate the compressors either fully loaded or totally unloaded. Thus, a machine is either producing its maximum output when fully loaded, or producing no output when totally unloaded. There is, therefore, no partial loading mode when a compressor delivers some fraction of its maximum capacity. It's either all, or nothing at all. This does not mean, however, that energy consumption is zero when compressor output is zero. Even unloaded, this type of compressor consumes approximately 25% of what it consumes when fully loaded.

The output of the pre-retrofit rotary screw compressor was modulated with inlet throttling and a discharge blow off valve. By restricting the amount of air entering the compressor, the amount of air supplied by the compressor can be regulated, but only to a point. When air demand is less than the compressor must supply, the discharge blow off valve opens to vent excess air to the atmosphere. In the unloaded mode with this type of control scheme, this type of compressor consumes approximately 60% of full load power.

Ex Ante Basecase

For the ex ante basecase (pre-retrofit), the four compressors run simultaneously, in various states of part to full loading. Each compressor in the system had its own control system that ran its machine to maintain the pressure in the distribution system. If equipment at the "end-of-the-line" was starved for air, the set points of each compressor were raised until the demand could be satisfied. Nominal distribution system pressure was 125 psig.

Ex Ante Postcase

For the ex ante postcase (post-retrofit), the control system was to base load the 100-hp G-D compressors to maintain the central air receiver pressure. Controls were set to load the 100-hp compressor when the high pressure air receiver pressure fell to 122 psig and run it until the high pressure receiver reached 135 psig. The 125-hp I-R compressor was staged to load when the high pressure system fell to 120 psig and then run until pressure was restored to 130 psig in the high pressure receiver. The 150-hp G-D compressor was set to load when high pressure air fell to 113 psig and then run until pressure was restored to 125 psig in the high pressure receiver. The 75-hp I-R compressor was set to load when the high pressure receiver fell to 110 psig and run until pressure was restored to 121 psig.

Postcase compressor discharge pressure was to have been 125 psig into the high pressure air receiver. The demand expander valves were to have then regulated flow out of the receiver to maintain the high pressure distribution system at 100 psig, and the low pressure distribution system at 85 psig.

Ex Ante Operating Schedule

The ex ante manufacturing operation runs 24 hours per day, seven days per week with a 97% annual capacity factor.

Production workers work three eight-hour shifts per day, seven days per week, while office workers work one eight-hour shift per day, five days per week.

The ex ante hours of operation were therefore:

$$\text{Ex Ante Hours of Operation} = 0.97 \times 8{,}760 \text{ hrs / year}$$

$$= 8{,}500 \text{ hrs / yr.}$$

The plant runs at capacity, and production levels are consistently high throughout the year.

Key Ex Ante Assumptions

- Assumed that pre- and post-retrofit air demand from production machinery is identical.
- Assumed that pre- and post-retrofit production schedules would be the same.

Ex Ante Algorithms

Based on the measured pre-retrofit air demands, a post-retrofit air demand profile was developed. From this profile, the electrical power consumption was estimated based on the measured kW/cfm of the pre-retrofit machines at the various operating modes.

Hours of operation were extrapolated from monitoring data. Annual kWh was obtained by multiplying kW times hours of operation for each compressor and totaling the kWh for all the compressors. This is summarized in Table 4-59.

Annual ex ante energy savings was the difference between the pre-and post-retrofit annual energy consumption:

$$\text{Ex Ante Annual Energy Savings} = 2{,}630{,}282 \text{ kWh} - 1{,}643{,}371 \text{ kWh}$$

$$= 986{,}911 \text{ kWh}$$

The average demand reduction was the difference between the pre- and post-retrofit demand:

$$\text{Ex Ante Average Demand Reduction} = 318.08 \text{ kW} - 224.42 \text{ kW}$$

$$= 93.67 \text{ kW}$$

Ex Ante Data Sources

- Compressor nameplate data and manufacturer's equipment data sheets.
- Spot measurements of compressor flows.
- Logging of continuously monitored pre-retrofit kW over a three week period.
- Customer Interviews.

4.11.6 Ex Post Load Impact Estimates

Monitoring data were analyzed to determine ex post power consumption patterns. These values were extrapolated to the 8,760 hour year assuming constant plant production levels, and accounting for planned production schedules. Data was collected on one minute intervals over a three week period in December of 1998. Thirty minute averages for each operating compressor were recorded for actual voltage, amperes, power factor and kW. Due to technical difficulties, data collection for the 100-hp Gardner-Denver compressor was limited to three days of monitoring. The kW data gathered, however were nearly constant, with little variation. Therefore, the average of the collected data for this compressor was assumed to exist for the balance of the monitoring period for this compressor only. Data was not collected for the new air dryer, however its consumption was considered small compared to the consumption of the compressors, and the average consumption for the post-retrofit dryer used in the ex ante analysis was assumed in the ex post analysis.

Ex post plant air demand is higher due to the addition of six drills to the plant production line which consume 25 scfm each of 100 psig air. Monitored ex post power consumption was reduced proportionately to account for the increase in plant air demand.

Ex Post Basecase

Ex post basecase (pre-retrofit) was found to be the same as the ex ante basecase except for the annual hours of operation. According to the customer, the plant has operated continuously since the installation of the post-retrofit equipment. Ex ante basecase calculations were modified for the ex post hours of operation.

Ex Post Postcase

The ex post postcase (post-retrofit) is the four post-retrofit compressors operating to satisfy the ex post basecase air demand. The observed post-retrofit operation includes the effects of the added air drills. The observed post-retrofit kW was corrected in proportion to the added demand through the application of the Demand Correction Factor.

Postcase compressor discharge pressure was 125 psig at the high pressure air receiver. The demand expander valves regulate flow out of the receiver to maintain the high pressure distribution system at 105 psig, and the low pressure distribution system at 85 psig.

Ex Post Operating Schedule

This facility operates 24 hours per day, seven days per week. The plant runs at capacity, and production levels are consistently high throughout the year.

The current shift schedule is two twelve-hour shifts per day, seven days per week for production and maintenance workers, and one eight-hour shift per day, five days per week for office workers.

Hours of operation are therefore 8,760 hours per year.

Ex Post Production Level Changes

Installation of the energy efficiency measures did not affect the production level of the plant. However, the overall ex post air consumption levels are higher than the ex ante levels due to installation of additional drilling equipment on the plant production line. The addition of six drills increased air demand by 150 scfm over ex ante demands. Air demand is anticipated to increase further in 1999 when more production equipment comes on line. As the existing compressed air system is running near its capacity, it is anticipated that additional air compressor capacity will be added.

Data Collected Ex Post

The energy consumption of each of the four running compressors was measured using portable power monitoring equipment. Measurements were taken using a Pacific Science & Technology

Energy Logger. This instrument measures true RMS kW. The following data was collected on-site:

- Runtime data for all four compressors.
- Measured voltage, amperage, power factor and kW for the four compressors.
- Motor and compressor nameplate data.

Data was collected on one minute intervals over a three week period in December of 1998. Thirty minute averages for each operating compressor were recorded for actual voltage, amperes, power factor and kW. A table of the raw data is presented in electronic form. As noted above, only three days of data were collected for the 100-hp Gardner-Denver compressor due to technical difficulties.

Ex Post Algorithms

Ex Post Basecase Energy Use

The ex post basecase is calculated in the same manner as the ex ante basecase using the ex post hours of operation. This is summarized in Table 4-59.

Table 4-59
Ex Post Basecase Energy Use
Project No. 47445

Basecase Supply	Power Adjusted Flow (scfm)	Density at Operating Pressure (lb/cu-ft)	Demand (kW)	Ex Ante Annual Operating Hours	Ex Post Annual Operating Hours	Annual Energy Consumption (kWh)	Annual Air Usage (lb/yr)
Col. A	Col. B	Col. C	Col. D	Col. E	Col. F	Col. G	Col. G
						D x F	B x 60 x C x F
SSR EP 75	285	0.635185	67.56	8,500	8,760	591,837	92,481,261
SSR EPH 125	407	0.635185	98.16	7,752	7,989	784,228	120,316,617
GD 150hp	528	0.686124	106.44	8,500	8,760	932,389	184,686,445
GD 50 hp	133	0.584247	32.72	8,500	8,760	286,652	39,663,211
Dryers			13.20	8,500	8,760	115,632	
Basecase Total			**318.08**			**2,710,738**	**437,147,534**

Ex Post Postcase Energy Use

Ex post postcase air demand is the observed air demand minus the increased demand due to the additional drills. A total of eight drills were added, but when accounting for diversity of use it was estimated that six drills are in use at any given time. The annual increase in air demand due to the additional drills is:

$$\text{Air Demand}_{\text{drills}} = (6\ \text{Drills}) \times (25\ \text{scfm / drill}) \times (60\ \text{min / hr}) \times (8{,}760\ \text{hrs / yr})$$

$$= 78{,}840{,}000\ \text{scfy}$$

Observed ex post air demand is:

$$\text{Observed Air Demand}_{\text{ex post}} = 515{,}987{,}534\ \text{scfy}$$

$$= \text{Postcase Air Demand} + \text{Air Demand}_{\text{drills}}$$

$$\text{Postcase Air Demand} = \text{Observed Air Demand}_{\text{ex post}} - \text{Air Demand}_{\text{drills}}$$

$$= 515{,}987{,}534 - 78{,}840{,}000$$

$$437{,}147{,}534\ \text{scfy}$$

The observed air demand was 15.3% higher than the postcase demand. The postcase demand is the observed minus the incremental air demand from the six new drills. Thus, the observed kW was multiplied by the demand correction factor which is the ratio of the postcase air demand divided by the observed air demand to obtain the ex post postcase kW demand:

$$\text{Ex Post kW Demand}_{\text{postcase}} = (\text{Demand Correction Factor}) \times (\text{Observed kW Demand})$$

where:

$$\text{Demand Correction Factor} = \left[\frac{\text{Postcase Air Demand}}{\text{Observed Air Demand}}\right] \qquad \text{Eqn. 1}$$

The ratio in Equation 1, the demand correction factor, was calculated to be 0.847.

Observed ex post power consumption of the air compressors and the drier was steady and varied only slightly from day to day over the entire ex post monitoring period except for unplanned plant downtime of 19 hours toward the end of the monitoring period. During this abnormal period only one of the compressors remained running.

Hourly averages for each compressor were calculated and summed to get an hourly average kW for each hour of the monitoring period. Steady state ex post power monitoring data obtained before the unplanned shutdown was averaged for each hour of an average day. After the demand correction factor was applied (to essentially remove the compressed air demand of the six new air drills), average postcase kW demand of the compressors and the drier for a 24 hour period of the steady state operation was found to be 292.84 kW, and total average ex post kW demand varied between 284.65 kW and 308.55 kW on an average steady state day.

Annual ex post postcase energy usage was the average daily postcase kW times the annual hours of operation:

$$\text{Ex Post Annual kWh}_{\text{postcase}} = \left(\text{Average kW}_{\text{postcase}}\right)\times\left(\text{Annual Hours of Operation}\right)$$

$$= 292.84\ \text{kW}\times 8{,}760\ \text{hrs / yr}$$

$$= 2{,}565{,}319\ \text{kWh}$$

Annual ex post energy savings was the difference between basecase kWh consumption and postcase kWh consumption:

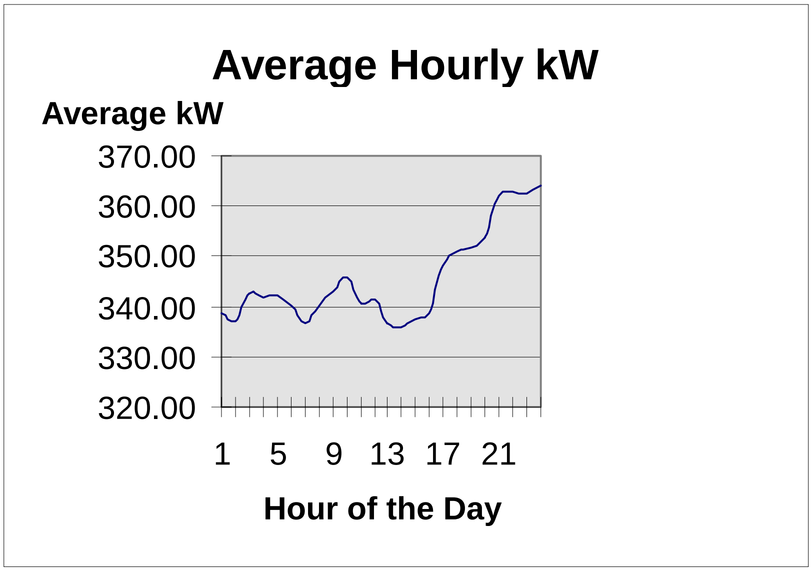
$$\text{Annual kWh Savings}_{\text{ex post}} = 2{,}710{,}738\ \text{kWh} - 2{,}565{,}319\ \text{kWh}$$

$$= 145{,}419\ \text{kWh}$$

Ex Post Load Impacts By Time-Of-Use Period

Monitoring data revealed a daily pattern of fairly steady daytime usage and higher night time usage. This is shown in Figure 4-3.

Figure 4-3
Average Hourly kW
Project No. 47445



It was assumed that this pattern was the same during the basecase period, with little variability. Thus, the allocation of kWh savings to the time-of-use (TOU) periods was based on the operating hours in each TOU period times the difference between the average basecase kW and the average postcase kW. The results are shown in Table 4-60.

The kW reduced coincident with system peak was calculated by subtracting the monitored postcase average kW for the summer on-peak periods from the average basecase kW.

$$\text{kW Reduced}_{\text{ex post,summer}} = \left(\text{kW}_{\text{basecase}}\right) - \left(\text{Average kW}_{\text{postcase,summer on-peak}}\right)$$

$$= 318.08 \text{ kW} - 297.47 \text{ kW}$$

$$= 20.61 \text{ kW}$$

Table 4-60
Ex Post kW and kWh Impacts by Time-of-Use Period
Project No. 47445

Time-of-Use Period	Annual Hours	kWh Adjustment Factor	kWh Savings	Average kW Reduced	kW Reduced Coincident with System Peak Period
Summer On-peak	749	0.0855	12,434	16.60	20.61
Summer Semi-peak	963	0.1099	15,986	16.60	
Summer Off-peak	1,960	0.2237	32,537	16.60	
Winter On-peak	441	0.0503	7,321	16.60	18.28
Winter Semi-peak	1,911	0.2182	31,723	16.60	
Winter Off-peak	2,736	0.3123	45,419	16.60	
Total	**8,760**	**1.0000**	**145,419**		

4.11.7 Summary of Gross Load Impacts

Table 4-61 provides a summary of the ex post load impacts and a comparison with the ex ante load impact estimates.

Table 4-61
Summary of Ex Post Load Impacts
Project No. 47445

	kWh	kW	Therms
Ex Ante	986,912	93.67	n/a
Ex Post	145,419	20.61	n/a
Realization Rate	14.7%	22.0%	n/a

Ex post impacts are lower than ex ante impacts because:

- The ex post operation is different than the ex ante operation; and
- Ex ante savings stemming from the reduction in artificial demand were over estimated.

Air from the ex post high pressure distribution system is consumed at 105 psig rather than the 100 psig setting used in the ex ante estimates. This increases the ex post demand by 23 lb/min when substituted into Table 4-59. Also, the ex ante postcase operation had only the 100-hp and 150-hp compressors running at an average specific power demand of 0.29 kW/lb/min. However, the ex post site visit showed that, in addition to those two compressors, the actual ex post operation continues to use the 75-hp and 125-hp compressors which have an average specific power demand of 0.38, which is more than 30% higher than the ex ante compressors. Assuming the added high pressure consumption is supplied by the less efficient compressors adds 8.7 kW of demand to the ex ante postcase demand.

From Table 4-59, the ex ante analysis claims an artificial demand savings of 142 lb/min from operating the post-retrofit distribution systems at pressures lower than the pre-retrofit system. This is nearly 60% of the predicted ex ante savings, and represents 53.6 kW of ex post demand. The theory behind the ex ante artificial demand savings claim is that since the post-retrofit distribution system pressure is lower than the ex ante distribution pressure, losses in the piping are lower. Though true, the ex ante analysis ignored the losses across the demand expander valves. In the case of the ex ante high pressure distribution system, this is 25 psig, and for the ex ante low pressure distribution system, this is 40 psig. These pressure drops represent energy that was input by the air compressors and consumed by the distribution system without producing useful work. Thus, there is no pressure drop savings from artificial demand.

Because of these two items, ex post postcase demand is approximately 1/3 the ex ante 93.67 kW savings, and explains most of the discrepancy between the ex ante and ex post estimates.

4.11.8 Net-To-Gross Ratio

The net-to-gross ratio for this project is 1.0. The SDG&E IEEI Program was the reason the measures were installed. SDG&E arranged to have an SDG&E-sponsored compressed air consultant prepare a study of the system. The recommendations presented in the study were implemented at the facility under this project. The customer indicated that the program incentive got the project to a 1-year payback hurdle that the company has for these types of improvements.

SDG&E staff (consultants) originated the project concept and provided all technical and engineering analysis.

Motivation

Motivation for the project was inspired by the cost reduction opportunity and the promise of improved compressed air quality. The project was initiated by SDG&E, who apprised the customer of the potential for savings, provided the compressed air consultant who did the monitoring and performed the design engineering. According to the customer, this equipment would not have been installed without the assistance of SDG&E.

Non-Energy Costs and Benefits

Filtering equipment installed as part of this project solved the customer's chronic wet/dirty compressed air problems.

Equipment Alternatives

The pre-retrofit compressor system would have remained in service had this project not been installed. Facility staff felt that the plant was suffering from a perceived lack of air capacity and would have added compressor capacity.

4.12 PROJECT NO. 47489 - PROCESS FLUID TEMPERATURE CONTROL EQUIPMENT

4.12.1 Summary of Findings

Three new high precision process temperature control devices were installed to better control the temperature of cooling fluids used in a product cooling drums. The device reduced the amount of cooling and reheat required.

Table 4-62
Summary of Gross Ex Post Load Impacts
Project No. 47489

	kWh	kW	Therms
Ex Ante	17,340	0.0	n/a
Ex Post	17,667	2.0	n/a
Realization Rate	101.9%	-	n/a

The gross ex post energy savings was 17,667 kWh per year versus the 17,340 kWh per year for the ex ante estimate, a gross realization rate of 101.9 %. The ex post kW reduced was estimated to be a 2.0 kW peak coincident impact versus 0 kW projected in the ex ante estimate.

The primary reasons for the discrepancy in annual kWh impact involved two key offsetting factors. These were:

1. The operating hours of the equipment increased from a projected 6,000 hours per year in the ex ante estimate to 8,424 hours per year during the ex post operating year.
2. The ex post calculations used a lower cycle factor of the heater based on customer observations (50% versus 75%).
3. The ex post calculations used 1.4 kW/ton for the air cooled chiller overall performance versus the conservative (for an air cooled chiller) 1.0 kW/ton used in the ex ante estimate.

The reason for this discrepancy is that the ex ante estimates did not calculate a demand impact for this measure. The average kW impact during the on-peak period is most representative of the impact that this measure will have at the system peak coincident time.

4.12.2 Facility Description

This facility is a plastic products manufacturing facility. Raw plastic beads are melted, then the extruded plastic is stamped or formed as a continuous plastic "web" of product pieces. The web passes over rollers that are heated to various temperatures to control the cooling rate of the product web. For some products the product temperature is highly critical because the application of a coating in a succeeding step requires a precise temperature. The device that controls the temperature of the cooling water for these drums is the subject of this project.

4.12.3 Measure Description

This project involved the installation of two SENTRA 2000 SE process water temperature control devices. The units use microprocessor based controls that sense product and cooling water temperatures and anticipate demands for warmer or cooler water and reduce compensatory heating and cooling, thereby reducing the need for (electrically) heated or (mechanically refrigerated) chilled water.

4.12.4 Ex Ante Load Impact Estimates

The ex ante analysis used an engineering calculation methodology based on estimates of annual hours of operation, an assumed operating load factor of 75%, a reduction in electric heating energy of 10%, and savings resulting from reduced chilled water requirement. It was assumed the water chilling system operated at 1.0 kW/ton chilled water.

Ex Ante Basecase

The ex ante basecase consisted of production equipment (cooling drums) with product thermal tempering system controlled by solenoid valves which, in turn, controlled the flow of cooling water to the drums. The response of the independent valves allowed overshooting of the drum temperatures. This resulted in lower product quality control as well as greater energy use.

Ex Ante Postcase

The ex ante postcase consisted of the same pre-retrofit product cooling system with the solenoid valves removed and the Sentra product cooling units installed for each of three product lines.

Ex Ante Algorithms and Load Impacts

The ex ante load impact assumptions and calculations are show in Table 4-63.

Table 4-63
Ex Ante Load Impact Estimates
Project No. 47489

Assumptions 1. Savings Factor = 10% 2. Unit SK1035 Heater Element 10 kW 3. 6,000 hours of operation / year 4. Heater Load Factor = 75% 5. Cooling Efficiency 1.0 kW/ton 6. Three affected units.	
Ex Ante Savings Calculation	
Heater Savings (per unit)	= 10 kW x 0.75 x 6,000 hr/yr x 0.1 = 4,500 kWh/yr
Cooling Savings (per units)	= 4,500kWh x 3,413 Btu/hr/kWh / 1,200 Btu/hr/ton = 1,280 ton-hr/yr = 1,280 kWh/yr @ 1.0 kW/ton
Total kWh Savings (per machine)	= 4,500 + 1,280 = 5,780 kWh/yr
For 3 machines: kWh Savings = 3 x 5,780 kWh/yr = 17,340 kWh/yr kW Reduced = 0 kW savings	

4.12.5 Ex Post Load Impact Estimates

An engineering methodology was used to estimate the ex post load impacts of this measure. The methodology and calculations were identical to the ex ante calculations, however, the equipment operating schedule and operating practices were based on data and information gathered during an onsite visit conducted during 1998. Inputs to the ex post load impact calculations were based on operations during the 1998 production year, as described by the customer's Vice President of Engineering. This individual was responsible for the design, selection and day-to-day operation of the equipment, and had observed its operation especially closely during the commissioning of the installation. The equipment specifications and design parameters were verified and the operating parameters and operating schedule were revised based on the experience reported by the customer's engineer. The analysis took place in several steps:

1. The reduction in heat input to the equipment was calculated using the rated input power, and load factors and improvement reported by the customer.
2. The equivalent of refrigeration energy to counteract the added heat was calculated by multiplying the kWh heat energy input by the conversion 3,413 Btu/hr/kWh.

3. The energy (kWh) input to provide the cooling was calculated by multiplying the heat energy by the estimated cooling system performance (air cooled chiller - overall performance including condenser fan operation was estimated to be 1.4 kW / ton).
4. The annual kWh impact was calculated as the sum of the reduction in heating energy and corresponding chiller power input which would be required to reject the added heat energy.
5. The energy savings during each time-of-use period were calculated by averaging the energy use over the hours of operation in each time-of-use period.

Ex Post Basecase

The ex post basecase is the same as the ex ante basecase. The basecase consists of the pre-retrofit drum cooling system with fluid temperature control provided by solenoid valves.

Ex Post Operating Schedule

The hours of use of the units has increased substantially due to higher annual production requirements. The three units all operate continuously, 24 hours per day, seven days per week except for two one week shutdowns in summer and winter.

Ex Post Production Level Changes

No changes in production level apply to the analysis for this project. The equipment provides greater quality control and improved efficiency and increased production output due to longer production hours, but the equipment did not cause or result from the equipment installation.

Data Collected Ex Post

Due to the low level of impacts at this site this was designated a non monitoring site. The data collection consisted of visual verification and interview with the facility vice president of engineering to discuss the equipment operation since its installation.

Ex Post kWh Savings and TOU Impact

The ex post load impacts were calculated using formula similar to the ex ante analysis, however operating hours, equipment load factors and the savings factor were used based on customer observations and experience rather than measurements. Table 4-64 shows the ex post load impact estimates.

Table 4-64
Ex Post Load Impact Estimates
Project No. 47489

Data/Observations	
1. Unit SK1035 Heater Element 10 kW (Verified Mfr. Spec.)	
2. 8,424 hours of operation / year = 8,760 - 2 x 168 (per VP Engineering 12/10/98)	
3. Cooling Efficiency: (Air Cooled Chilled Water Cooling at 44 DegF Plus Condenser Fans): Average 1.4 kW/ton	
Assumptions	
1. Heater Load Factor	= 33%
2. Load Improvement Factor - Control over standard solenoid valve	=10%
Savings Calculation	
Heater Savings	= 10 kW x .50 x 8424 hr/yr x 0.1
(per unit)	= 4,212 kWh/yr
Cooling Savings	= 2,780 kWh x 3,413 Btu/hr/kWh / 12,000 Btu/hr/ton
(per unit)	= 1,198 ton-hr/yr
	= 1,677 kWh/yr @ 1.4 kW/ton
Total kWh Savings	= 4,212 kWh/yr +1,677 kWh/yr
(per unit)	= 5,889 kWh/yr
For 3 units:	= 3 x 5,889 kWh/yr
	= 17,667 kWh / Year

Ex Post Impacts By Time-Of-Use Period

Gross kWh impacts for costing period *c* were determined by calculating a factor that represents the proportion of annual savings that occur during each time-of-use period. Because the impacts are constant for each operating hour, the savings are proportional to the number of operating hours that occur during each time of use period. The factor for each time-of-use period is calculated by dividing the hours of operation during the time-of-use period by the total operating hours over the year. The kWh impacts during the TOU period were calculated by multiplying the total annual kWh impacts calculated above by the factor for each TOU period.

$$\text{TOU Factor}_c = \frac{\text{Operating Hours TOU}_c}{\text{Annual Operating Hours}}$$

$$\text{kWh Savings}_c = \text{Annual kWh Savings} \times \text{TOU Factor}_c$$

Table 4-65 provides a breakdown of the TOU period impact results.

Gross kW Impacts

Average gross kW impacts will be developed for each TOU period by dividing the total kWh impacts for the TOU period by the total number of hours in the TOU period:

$$\overline{\text{kW impact}_c} = \frac{\text{kWh Savings}_c}{\sum_{i \in c} \text{hours}_c}$$

Table 4-65
Time-of-Use Period Load Impact Estimates
Project No. 47489

Season	Period	Total Hours	Weighting Factor	kWh Impact	Average kW
Col. A	Col. B	Col. C	Col. D	Col. E	Col. F
				C×(17,667 kWh)	E÷C
Summer	On-Peak	749	0.0855	1,511	2.0
	Semi-Peak	963	0.1099	1,942	2.0
	Off-Peak	1,960	0.2237	3,953	2.0
Winter	On-Peak	441	0.0503	889	2.0
	Semi-Peak	1,911	0.2182	3,854	2.0
	Off-Peak	2,736	0.3123	5,518	2.0
Total		**8,760**		**17,667**	**2.0**

4.12.6 Summary of Gross Impacts

Table 4-66 provides a summary of the gross impact results and a comparison with the ex ante estimates.

Table 4-66
Summary of Ex Post Load Impacts
Project No. 47489

	kWh	kW	Therms
Ex Ante	17,340	0.0	n/a
Ex Post	17,667	2.0	n/a
Realization Rate	101.9%	-	n/a

The gross ex post annual impact was 17,667 kWh versus the 17,340 kWh ex ante estimate, a gross realization of 101.9 %. The ex post kW reduction was 2.0 kW peak coincident demand impact versus 0 kW projected in the ex ante estimate.

The primary reasons for the discrepancy in annual kWh impact involved two key offsetting factors. These were:

1. The operating hours of the equipment increased from a projected 6,000 hours per year in the ex ante estimate to 8,424 hours per year during the ex post operating year.
2. The ex post calculations used a lower cycle factor of the heater based on customer observations (50% versus 75%).
3. The ex post calculations used 1.4 kW per ton for the air cooled chiller overall performance versus the conservative (for an air cooled chiller) 1.0 kW/ton used in the ex ante estimate.

The reason for this discrepancy is that the ex ante estimates did not calculate a demand impact for this measure. The average kW impact during the on peak period is most representative of the impact that this measure will have at the system peak coincident time.

4.12.7 Net-To-Gross Ratio

The net-to-gross ratio for this project is 0.40. SDG&E had a low level of involvement, while the incentives played a role in influencing the decision to install the measure. The customer reported that they did virtually all of the work on the project. There was a low level of involvement from SDG&E. The customer reported that the incentives was not a major influence in the decision to install the measure, but they did play a role. The customer stated that the control units were primarily installed to improve product quality control.

4.13 PROJECT NO. 47988 - COMPRESSED AIR SYSTEM IMPROVEMENTS: REPLACE COMPRESSOR, ADD STORAGE; UPGRADE CONTROLS

4.13.1 Summary of Findings

The compressed air system at this facility was improved by the: replacement of one 150-hp compressor with two smaller compressors totaling 75-hp; replacement of timed solenoid drain valves with six "zero leak" drains; and the addition of 400 gallons of storage and a "demand expander." The demand expander enabled the resetting of distribution air pressure from about 120 psi to 87.5 psi.

Table 4-67 shows a comparison of the ex ante gross impact estimates with the ex post estimates.

Table 4-67
Results and Comparison with Ex Ante Estimate
Project No. 47988

	kWh	kW	Therms
Ex Ante	555,388	48.66	n/a
Ex Post	561,212	67.34	n/a
Realization Rate	101.0%	138.4%	n/a

The ex post gross annual energy impact was 561,212 kWh, 101% of the ex ante estimate 555,388 kWh. The ex post gross peak demand impact was 67.34 kW, 138.4 % of the ex ante estimate of 48.65 kW.

The kWh discrepancy was small. The ex ante estimate did not include the post-retrofit power of the blower or Zeks dryer that were added as part of the project. Also, the ex ante analysis used 7,488 annual hours of operation of the pre-project compressor. This was increased to 8,760 hours because the average operating power over the entire year was used as the ex ante pre-retrofit operating kW.

There is a large discrepancy in the kW estimates. The primary reason for this discrepancy is the difference between the ex ante and ex post calculation methodology. The ex ante analysis calculated the peak operating kW for the pre- and post-retrofit compressors at full load and took the difference. The ex post estimates used the average kW impact for the summer on-peak period.

4.13.2 Facility Description

This is a metal products manufacturing facility. Process equipment include punch presses, brakes, drills, lathes, milling machines. Small batch ovens for tempering or stress relieving.

There are also several tanks for degreasing and chemical plating. Compressed air is used primarily for blowing.

4.13.3 Overview of Facility Schedule

The facility operates two full shifts per day and a third partial shift seven days per week, year-round. Although production staff is lower during third shift, air demands remain nearly as high as first and second shift. Production management told the evaluation team that production intensity and air demand has increased since August, 1988 due to increased orders.

4.13.4 Measure Description

The measure involved improvements to several related aspects of the compressed air system. The details are provided in the ex ante basecase and postcase description in the following sections. In general, the verified improvements include.

- A 150-hp screw compressor was deactivated. It was replaced with a 50-hp compressor and a 25-hp compressor.
- Additional storage was added to the compressed air system and a “demand expander” and associated controls were installed. The system pressure was lowered from 120 psi to about 87 psi.
- A 2.5 bhp blower was installed to provide agitation for several dip tanks instead of compressed air.
- Existing solenoid type drains were replaced with zero-loss drains.

Pre-Retrofit Conditions

- The pre - retrofit compressor system consisted of one Sullair 150-hp screw compressor (700 cfm @ 125 psi) with a 40-hp Ingersoll-Rand (capacity not known) as backup. The 150-hp compressor operated under modulating control mode continuously to maintain the set point pressure.
- The compressor setpoint and distribution system pressure was 120 psi.
- System drains were solenoid valve type and were controlled to open to drain for a preset time at regular intervals.
- The pre-retrofit system did not include a refrigerated air dryer.

Post-Retrofit Conditions

The 150-hp Sullair compressor was removed. The 40-hp compressor was retained as emergency backup only. The items listed in Table 4-68 were added.

Table 4-68
Equipment Added
Project No. 47988

Added Equipment	Quantity	Specification, Description
50-hp air compressor	1	Gardner Denver 215 cfm @ 125 psi & 52 bhp
25-hp air compressor	1	Gardner Denver 92 cfm @ 125 psi & 26 bhp
Refrigerated air Dryer	1	300-HSE Zeks dryer; 300 cfm refrig. Cycling type
Air filter	1	300-LC Zeks , 300 cfm coalescing
receiver tank	1	400 gallon vertical
2" demand expander	1	DXS-2x3
large zero-loss drains	2	GD Evacuator
small zero-loss drains	4	UFM - T1
regenerative blower	1	Fuji VFC509A-7W 150 cfm @ 3psi & 2.5 bhp

- The compressor setpoint was increased to 120 psi, the storage pressure was set at 110 psi and the distribution pressure was controlled to be 87.5 psi downstream of the demand expander.
- The compressed air supply line was plugged and piping added. The blower is operated continuously to agitate tank contents.
- The new compressors, Zeks dryer and drains were all installed and appeared to be operating properly.

4.13.5 Ex Ante Load Impact Estimates

The *ex ante* load impact estimates were based on a site-specific study of the facility's compressed air system conducted by a compressed air system consultant provided by SDG&E's IEEI Program. The study comprised a detailed audit, including an inventory of air compressor system equipment, review of current operating practices with plant maintenance staff, spot and short term measurements of compressor operating power, evaluation of the plant compressed air requirements and performance (air-load balance), and recommendations that would reduce air compressor system operating costs, including energy savings.

Tables 4-69 and 4-70 show a summary of the load impact estimates, and the air balance and savings calculations, respectively. These tables show total *ex ante* load impacts of 555,388 kWh saved and 48.66 kW reduced. All entries entered in these tables were taken from tables in the project file. There were instances where errors were noted; these were part of the ex ante worksheets. These values were copied directly into Table 4-70.

Table 4-69
Ex Ante Energy Calculation Summary Table
Project No. 47988

Base Case Energy Usage

Summer Season

	kWh	kW
Peak	80,628	109.70
Semi-peak	103,665	
Off-peak	156,868	
Total	341,161	109.70

Winter Season

	kWh	kW
Peak	49,035	109.70
Semi-peak	212,485	
Off-peak	218,738	
Total	480,257	109.70

Annual energy usage = 821,418 kWh
Demand = 109.70 kW

Enhanced Case Energy Usage

Summer Season

	kWh	kW
Peak	26,113	61.04
Semi-peak	33,573	
Off-peak	50,804	
Total	110,491	61.04

Winter Season

	kWh	kW
Peak	15,881	61.04
Semi-peak	68,817	
Off-peak	70,842	
Total	155,539	61.04

Annual energy usage = 266,030 kWh
Demand = 61.04 kW

Annual Energy Savings = 821,418 kWh - 266,030 kWh

= 555,388 kWh

Annual Demand Savings = 109.70 kW - 61.04 kW

= 48.66 kW

Table 4-70
Ex Ante Load Impact Estimate Worksheet
Project No. 47988

Ex Ante Compressed Air Demand Estimates

	End Use	Constituent	CFM	Pres-sure	PDCF	PPM	PPH	Hrs of Op	PPY
Pre-retrofit	Tank Agitation	Blowing	40	40	0.2637	11	633	7,488	4,738,652
	Blow Guns	Blowing	90	85	0.4806	43	2,595	7,488	19,433,881
	Presses	Cylinders	140	85	0.4806	67	4,037	3,120	12,596,034
	EDM	Blowing	52.5	85	0.4806	25	1,514	3,120	4,723,513
	Leaks	Production	30	85	0.4806	14	865	7,488	6,477,960
	Filter Press/Water Jet	Production	45	85	0.4806	22	1,298	624	809,745
	Totals		**353**			**182**	**10,942**		**48,779,785**
Post-retrofit	Tank Agitation	Blowing	0	85	0.4806	0	0	7,488	0
	Blow Guns	Blowing	70	85	0.4806	34	2,019	7,488	15,115,241
	Presses	Cylinders	120	85	0.4806	58	3,460	3,120	10,796,600
	Leaks	Production	20	85	0.4806	10	577	7,488	4,318,640
	Filter Press /Water Jet	Production	45	85	0.4806	22	1,298	624	809,745
	Totals		**255**			**123**	**6,056**		**31,040,226**
Variance/Savings			**98**						**17,739,559**

Ex Ante Compressor Testing

Make & Model	HP	VAC Name Plt	VAC Actual	Amps HP	Amps Name Plt (FLA x 1.10)	Amps Actual	Mfg Flow	Mfg PSI	PDSCF @ Mfg PSI	Actual PSI	Actual PDCF	Adj Flow Power	Adj Flo Press	kW
Sullair 150-hp	150	460	480	180.0	198.0	145	700	125	0.7116	86	0.4943	513	353	109.7
	50	460	472	0.0	0.0	0	0	125	0.7116	0	0.0000	ERR	ERR	0
Proposed Dryer	0.75	460	480	0.8	0.8	1	0	125	0.7116	0	0.0000	0	0	0.6
Proposed 50-hp Screw	50	460	480	65.0	71.5	72	201	125	0.7116	125	0.6857	201	201	54.1
Proposed 25-hp Screw	25	460	480	34.0	37.4	37	92	125	0.7116	125	0.6857	92	92	28.3

Compressor Testing (continued)		Adj Flo Press.	Inlet PSIA	Adj Flow	Temp Cor-rected Inlet Temp	Cor-rection	Adjus-ted	PPM Actual	PPM Pro-posed	Differ ential
Sullair 150-hp		353	14.70	353	90	550	367	182	498	317
		ERR	14.40	ERR	101	561	ERR	ERR	0	ERR
Proposed Dryer		0				460	0	0	0	0
Proposed 50-hp Screw		201	14.70	201	90	550	209	144	143	-1
Proposed 25-hp Screw		92	14.40	94	90	550	98	67	67	0

Ex Ante Energy Savings

		PDCF	PD/YR	kW	Annu-al Hrs	kWh
Pre-retrofit	Sullair 150-hp	0.4943	113,836,642	109.7	7,488	821,418
	Total		**113,836,642**			**821,418**
Post-retrofit	Sullair 150-hp		0			0
	Dryer	0.0000		0.6	7,488	4,493
	50-hp Proposed	0.7116	21,565,440	43.6	3,120	135,907
	25-hp Proposed	0.7116	20,067,840	22.4	5,616	125,630
	Total		41,633,280			266,030
Energy Savings						**555,388**

4.13.6 Ex Post Load Impact Estimates

The ex post analysis was carried out using an engineering calculation methodology similar to the ex ante estimates. The operating power and operating hours of the pre-and post-retrofit compressor system were determined from short term monitoring, a review of operating logs, and interviews with operating staff. The pre- and post-retrofit kWh were calculated as the product of the average operating kW and the operating hours. The gross impact estimate is the difference between the pre- and post-retrofit kWh. The kW impact is based on the average kW for the summer on-peak period.

The ex post post-retrofit kWh estimates used:

- kW values calculated from monitoring over two weeks of operation.
- Post-retrofit compressor hours calculated from readings of the compressors' operating hour meters at the time of the post-retrofit site survey.
- Modified pre-retrofit operating hours based on ex post data obtained.
- Ex ante measured operating kW.

Ex Post Basecase

The basecase is the pre-retrofit equipment operating as described in the ex ante basecase. The ex post basecase operating hours were increased to 8,760 hours from the ex ante estimated 7,488 annual operating hours to reflect the operating schedule and production intensity at the time of the ex post evaluation site visit.

Ex Post Operating Schedule

- The facility operates 24 hours per day, seven days per week, 365 days per year.
- The compressors operate on demand as determined by their operating controls to maintain the system pressure continuously.
- First and second shift: 7 A.M. to 11 P.M. are full production shifts; the third shift is a partial production shift.

Ex Post Production Level Changes

Operating staff report that production activity and compressed air demand have increased since the measures were installed. The increase in activity is reflected in the increased basecase compressor run hours used in the ex post estimates. Although production has increased, it is clear from the information provided that the increase neither caused nor occurred as a result of the incentive project.

Data Collected Ex Post

Two site visits were carried out on November 19 and November 29, 1998. Data collected during the evaluation site visits included:

- Nameplate information and hour meter readings from the operating compressors, dryer and blower.
- All equipment was observed in operating and cycling duration observed.
- The post-retrofit compressor input power was monitored at 30 minute intervals from November 19, 1998 to November 29, 1998.
- The production and operating schedule was discussed with the customer.

Ex Post kWh Savings and TOU Impact

Annual Gross kWh Impact

The compressor post-retrofit average operating kW was calculated by the general formula:

$$\text{Average kW}_{\text{postcase,i}} \frac{\sum \text{kW}_{\text{monitoring,i}}}{\sum \text{Hours}_{\text{monitoring,i}}},$$

where:

$\text{kW}_{\text{monitoring,i}}$ = measured kW for each hour the compressor operated during the monitoring period for compressor i; and

$\text{Hours}_{\text{monitoring,i}}$ = operating hours (hours with non - zero measured kW values) during the monitoring period.

The compressor average pre-retrofit operating kW was calculated from ex ante measured power data.

The ex post equipment pre-retrofit annual energy use was calculated by:

$$\text{Annual kWh}_{\text{i,p}} = \text{kW}_{\text{i,p}} \times \text{AH}_{\text{i,p}},$$

where:

$\text{Annual kWh}_{\text{i,p}}$ = Annual kWh for compressor i at loading conditions for pre - or post - retrofit period, p, based on ex ante measurements that were adjusted ex post;

AH_{i} = Annual operating hours of compressor i at loading condictions (for pre - or post - retrofit period p) based on customer operating logs.

The gross ex post annual kWh impacts are estimated as:

$$\text{Annual kWh Savings} = \sum_{i=1}^{3} (\text{Annual kWh}_{\text{i,pre-retrofit}} - \text{Annual kWh}_{\text{i,post-retrofit}})$$

Table 4-71 shows the operating hours data derived from plant records that were used in the ex post impact calculations.

Table 4-71
Ex Post Compressor Operating Hours Data
Project No. 47988

	Date	Hours Meter	Elapsed Days	Compressor Operating Hours	Hours per Day	Average Hours Per Day	Annual Operating Hours
Sullair 150-hp Total							
Pre-retrofit				0	0	0	**0**
Post-retrofit	1/1/98	Not used					
	12/31/98	Not used	365	0	0	0	**0**
Compressor #1: GD 50-hp							
Pre-retrofit	Not Inst.	Not Inst.	0	0	0	0	**0**
Post-retrofit	7/27/97	0					
	11/19/98	11,453.0	479	11453	23.91	23.91	**8,727.2**
Compressor #2: GD 25-hp							
Pre-retrofit	Not Inst.	Not Inst.		0	0	0	**0**
Post-retrofit	9/12/97	0					
	11/19/98	2,459.9	433	2459.9	5.68	5.68	**2,073.6**

Table 4-72 shows the ex post kWh savings calculations.

Table 4-72
Ex Post kWh Savings Calculation
Project No. 47988

	Compressor	Average Operating kW	Source of kW Data	Total Annual Operating Hours	Source of Operating Hour Data	Annual kWh
Pre-retrofit	Sullair 150-hp	109.70	Ex Ante Measurement and Observations	8,760	Ex Post Operating Hours	960,972
	IR 40-hp		Standby Only	-		
	Total - Pre-retrofit					**960,972**
Post-retrofit	AC #1 50-hp	39.11	Ex Post Monitoring	8,727	Ex Post Monitoring	341,298
	AC #2 25-hp	12.25	Ex Post Monitoring	2,074	Ex Post Monitoring	25,398
	Sullair 150-hp	0	Site Observation/Cust. Interview	0	Site Observation /Cust. Interview	0
	1.5 -hp Blower	2.27	Ex Post kW Estimate 2.5 bhp @.82 Eff.	8,760	Customer Interview	19,924
	Zeks Dryer	2.00	Ex Post Estimate	6,570	Ex Post Observation: 0.75 cycle	13,140
	Total-Post-retrofit					**399,760**
Gross Ex Post Gross kWh Savings						**561,212**

Ex Post kWh Impacts by TOU Period

Gross kWh impacts for costing period *c* were determined by calculating a factor that represents the proportion of annual savings that occurs during each time-of-use period based on the ex post monitoring results. The ex post monitoring period was considered to be representative of typical operations at this facility as far as the proportion of energy impacts. The following steps were used:

1. The average post-retrofit kW (of all compressors) for each operating hour of each "Daytype" (Daytype 1 = Weekdays, Daytype 2 = Weekend/Holidays) was calculated from the monitoring data.
2. The total annual kWh for each hour of each Daytype was calculated by multiplying the average hourly kW by the 254 for weekdays (the number of full operating weekdays estimated for 1998) and 111 (to account for 104 weekend days per year and 7 weekday holidays
3. The kWh for the daily hours in each seasonal TOU period were summed.
4. The kWh sum for the hours that occur during each summer time-of-use period was multiplied by 5/12 to reflect TOU consumption during the five summer season months. The total kWh which occur during each winter TOU period were multiplied by 7/12 to calculate the total which applies to each TOU period during the winter season.

5. The kWh in each TOU period for the year were summed and divided by the total kWh to calculate a "TOU period kWh consumption weighting factor."
6. The ex post total annual kWh savings was multiplied by the TOU period weighting factor" to calculate the kWh savings for each TOU period.

The process for estimating the TOU factors and ex post load impacts by TOU period is shown in the following equations:

$$\left(\text{Total kWh Usage For Each Hour}_{\text{daytype}}\right) = \left(\text{Average Post - Retrofit kW For Each Hour}_{\text{daytype}}\right) \times \left(\text{No. Days}_{\text{daytype}}\right),$$

where:

$$\text{No. Days}_{\text{daytype}} = 254 \text{ days for weekdays}$$
$$= 111 \text{ days for weekends}$$

$$\left(\text{Sum of kWh Usage for Each TOU Period}\right) = \sum \begin{pmatrix} \text{Total kWH Usage For Each Hour}_{\text{daytype}} \text{ in} \\ \text{each summer and winter TOU period} \end{pmatrix}$$

$$\left(\text{Adjusted kWh Usage for Each TOU Period}\right) = \left(\text{Sum of kWh Usage for Each TOU Period}\right) \times \left(\text{Seasonal Adjustment Multiplier}\right)$$

where:

$$\text{Seasonal Adjustment Multiplier} = \left(\frac{5}{12}\right) \text{ for summer; and}$$
$$= \left(\frac{7}{12}\right) \text{ for winter.}$$

$$\left(\text{Total Annual kWh Usage}\right) = \sum_{p} \text{Adjusted kWh Usage for Each TOU Period},$$

where:

p = the six TOU periods.

$$\left(\text{TOU Adjustment Factor for Each TOU Period}\right) = \frac{\text{Adjusted kWh Usage for Each TOU Period}}{\text{Total Annual kWh Usage}}$$

$$\left(\text{Ex Post kWh Savings by TOU Period}\right) = \left(\text{Ex Post Gross kWh Savings}\right) \times \left(\text{TOU Adjustment Factor for Each TOU Period}\right).$$

The results are summarized in Table 4-73.

Ex Post Average Gross kW Impacts

Average gross kW impacts were calculated for each costing period by dividing the total kWh impacts for the costing period by the total number of hours in the TOU period:

$$\text{Average Ex Post kW Reduced}_c = \frac{\text{Ex Post kWh Savings}_c}{\text{Hours}_c}$$

These results are shown in Table 4-73.

Table 4-73
Ex Post Load Impacts By TOU Period
Project No. 47988

Season	Period	Total Hours	TOU Adjustment Factor	kWh Impact	Average kW
Col. A	Col. B	Col. C	Col. D	Col. E	Col. F
				Col. D x 561,212 kWh	Col. E/Col. C
Summer	On-peak	749	0.0899	50,438	67.3
	Semi-peak	963	0.1125	63,126	65.6
	Off-peak	1,960	0.2143	120,274	61.4
Winter	On-peak	441	0.0526	29,511	66.9
	Semi-peak	1,911	0.2307	129,478	67.8
	Off-peak	2,736	0.3000	168,384	61.5
Total				**561,212**	

Gross kW Impact Coincident with System Peak

The impact across the daytime hours is reasonable constant. The summer on-peak TOU period average kW impact is reported as the ex post peak coincident kW impact.

4.13.7 Summary of Gross Impacts

Table 4-74 summarizes the ex post gross kW and kWh Impacts and shows a comparison of the ex ante gross impact estimates with the ex post estimates.

Table 4-74
Load Impact Summary and Comparison with Ex Ante Estimate
Project No. 47988

	kWh	kW	Therms
Ex Ante	555,388	48.66	n/a
Ex Post	561,212	67.34	n/a
Realization Rate	101.0%	138.4%	n/a

The ex post gross annual energy impact was 561,212 kWh, 101% of the ex ante estimate of 555,388 kWh. The ex post gross demand impact was 67.34 kW, 138.4 % of the ex ante estimate of 48.65 kW.

The kWh savings discrepancy was small and somewhat coincidental. The ex ante analysis did not include the post-retrofit power of the blower or Zeks dryer that were added as part of the project. Additionally, the ex ante analysis used 7,488 hours of operation of the pre-project compressor. This was increased to 8,760 hours because the average operating power over the entire year was used as the ex ante pre-retrofit operating kW. The larger basecase kWh found in the ex post analysis was offset by the larger post-retrofit annual kWh estimated ex post based on the monitoring results.

There is a large discrepancy in the kW estimates. The primary reason for this discrepancy is the difference between the ex ante and ex post calculation methodology for estimating kW impacts. The *ex ante estimates* calculated the *peak operating kW* for the pre- and post-retrofit compressors at full load and took the difference. The *ex post estimates* used the *average kW* during the summer on-peak period as the basis for kW impacts. The peak operating kW will usually be greater than the average kW for these types of measures, since the peak operating kW does not account for the diversity of system operations that would be most likely to occur during the summer on-peak period.

4.13.8 Net-To-Gross Ratio

The net-to-gross ratio for this project was estimated to be 1.0. The SDG&E IEEI Program was the reason the measures were installed.

The site contact attended an SDG&E sponsored seminar on compressed air systems. He went back to his plant to review his compressed air system. He then contacted SDG&E and arranged to have an SDG&E-sponsored compressed air consultant prepare a study of the system. The recommendations presented in the study were implemented at the facility under this project. The consultant provided implementation assistance to the customer.

SDG&E staff (consultants) originated the project concept and provided all technical and engineering analysis.

4.14 PROJECT ID 48378 - COMPRESSED AIR SYSTEM MODIFICATION WITH AUTOMATION & CONTROLS

4.14.1 Summary of Findings

The savings for this site were based on the installation of two new 200-hp air compressors and one new 40-hp air compressor to replace seven air compressors of various sizes. The results of the ex post evaluation are different than those of the ex ante estimate due to differences in the ex post operation and basecase from the ex ante assumptions. Plant operations were reduced in the fourth quarter of 1998 to six shifts per week from 21 shifts per week, and production is approximately 25% of level used in the ex ante estimates.

Table 4-75
Summary of Ex Post Load Impacts
Project No. 48378

	kWh	kW	Therms
Ex Ante	1,777,021	182.28	n/a
Ex Post	1,743,798	199.83	n/a
Realization Rate	98.1%	109.6%	n/a

4.14.2 Facility Description

This site manufactures metal parts and assemblies for commercial jet liners and Department of Defense weapons. Manufacturing takes place in several large buildings across a large campus. Compressed air is used for operation of air tools such as grinders and wrenches, for grit blasting and spray painting, as a motive force in air cylinders on numerically controlled lathes and mills, and for blowing metal chips during and after machining operations.

4.14.3 Overview of Facility Schedule

This facility operates eight hours per day, six days per week, except during holiday periods when the plant is shut down. Hours of operation vary according to production levels on aerospace and defense contract work. Slow periods occur when contracts cannot be won for additional work. The plant is currently undergoing a permanent 40% reduction in capacity. Production levels are not expected to increase in the near future from present levels, and are never expected to return to ex ante levels. Therefore, the current facility schedule is expected to continue for the foreseeable future.

The current shift schedule is one eight-hour shift per day, six days per week for production workers, and one eight-hour shift per day, five days per week for office workers.

The ex post hours of operation are shown in Table 4-76.

Table 4-76
Ex Post Operating Schedule
Project No. 48378

Day of the Week	Start Time	End Time	Total Hours/Day
Monday	7:00 A.M.	3:00 P.M.	8
Tuesday	7:00 A.M.	3:00 P.M.	8
Wednesday	7:00 A.M.	3:00 P.M.	8
Thursday	7:00 A.M.	3:00 P.M.	8
Friday	7:00 A.M.	3:00 P.M.	8
Saturday	7:00 A.M.	3:00 P.M.	8
Sunday	Shut Down	Shut Down	-
Total Hours/Week			48
Holiday Hours/Year			192
Shutdown Hours/Year			-
Total Annual Hours			**2,439**

4.14.4 Measure Description

Piping, valves and controls were installed to tie the outputs of three new air compressors together to supply plant air demands from a central high pressure air receiver. A 30,000 propane tank was converted to high pressure air storage to provide surge capacity for the system. Also, two small blowers were installed to provide air for chemical tank agitation. Controls were set to fill the 30,000 gallon air receiver with 165 psig air from the new 40-hp compressor, and the 1,020 gallon receiver as necessary with 120 psig air from the two new 200-hp compressors. These reservoirs of high pressure air are then let down through two valves, called demand expanders, to feed the plant distribution system operating at 90 psig. This configuration provides surge capacity to supply high instantaneous loads while the compressors operate in a fairly steady mode to keep the high pressure receivers full. By separating the demand/distribution system from the supply/storage system in this manner, several energy efficiency improvements are realized.

- Lower parasitic losses in piping system due to reduced pressure drop.
- Lower leakage losses in distribution and end use systems since pressure is lower.
- Fewer compressors running to supply demand, since high pressure receivers absorb demand swings.
- Higher overall compressor efficiency since compressors are fully loaded most of the time rather than part loaded.

In addition, the seven existing compressors were isolated, and new nozzles were obtained to minimize chip blowing volumes.

Pre-Retrofit Conditions

- Seven existing air compressors of various sizes and types. Four compressors operate independently to supply 120 psig air to the plant distribution system. Three compressors are shut down and isolated from running.
- Compressed air being used for chemical tank agitation.
- Production facility operates 24 hours per day, seven days per week, except during eight holiday periods when the plant is shut down.
- Production workers work three eight-hour shifts per day, seven days per week, while office workers work one eight-hour shift per day, five days per week.
- The plant runs at capacity, and production levels are consistently high throughout the year.

Post-Retrofit Conditions

- Two new 200-hp Gardner-Denver, single stage, rotary screw, air-cooled, air compressors supply 120 psig air as necessary to maintain the pressure in a central air receiver for use in the plant distribution system. These compressors are controlled by a new PLC which loads and unloads them as necessary to maintain high pressure receiver pressure.
- One new 40-hp, Gardner-Denver, single stage, rotary screw, air-cooled, air compressor supplying 165 psig air to restore pressure in a 30,000 gallon tank. This air is let down as needed to the main plant distribution system through a demand expander butterfly valve at all times of the day.
- Seven pre-retrofit compressors of various sizes and types shut down and isolated to prevent running.
- Chemical agitation air provided by one 4.5-hp and one 2.5-hp Fuji fan blower. Compressed air connections for chemical tank agitation were removed.
- Production facility operates eight hours per day, six days per week, except during eight holiday periods when the plant is shut down.
- Production work accomplished during one eight hour shift per day, six days per week, while office work accomplished during one eight-hour shift per day, five days per week.
- The plant runs at low (25%) utilization. Abandonment of 40% of production area in progress.

4.14.5 Ex Ante Load Impact Estimates

The *ex ante* load impact estimates were based on a site-specific study of the facility's compressed air system conducted by a compressed air system consultant provided by SDG&E's IEEI Program. The study comprised a detailed audit, including an inventory of air compressor system equipment, current operating procedures, measurements of existing compressor operating performance, evaluation of the plant requirements and performance (air balance), and recommendations that would reduce air compressor system operating costs, including energy savings. Spot measurements were made to verify the current operating parameters of the system. The results of this monitoring revealed that the compressors operated to satisfy three main demand levels: high capacity, low capacity and leakage make-up.

Table 4-77 shows a summary of the load impact estimates, and the air balance and savings calculations, respectively. These tables show total *ex ante* load impacts of 1,777,021 kWh saved and 182.38 kW reduced.

Table 4-77
Summary of Ex Ante Load Impact Estimates
Project No. 48378

Compressor	Horsepower	Loading	kW	Peak kW	Annual Hours	Annual kWh
I-R XLE	200	Full	163.92	163.92	6,240	1,022,861
I-R XLE	200	Half	130.39	0	2,496	325,453
G-D 150	150	Full	136.35	136.35	6,240	850,824
G-D 150	150	Half	126.66	0	2,496	316,143
C-P 150	150	Full	117.72	117.72	3,380	397,894
C-P 150	150	Half	61.84	0	1,248	77,176
C-P 60	60	Full	48.65	48.65	2,080	101,192
Total Pre-Retrofit				**466.64**		**3,091,544**
G-D 200	200	Full	142.13	142.13	6,240	886,891
G-D 200	200	Full	142.13	142.23	2,548	362,147
G-D 40	40	Full	32.29	0	2,028	65,484
Total Post-Retrofit				**284.36**		**1,314,523**
Total Impact				**182.28**		**1,777,021**

Reductions in end use compressed air usage included repair of leaks. The leakage make up demand is the output of the compressor required to overcome leakage in the system to maintain the system pressure. Since these leaks are always present, this demand is always present as well. However, during the times when the production line is shut down, this is the only demand on the compressed air system. Repairs were made in an attempt to lower this by 90 to 160 scfm.

The pressure of the air distribution system was lowered to reduce artificial demand. Artificial demand is the demand created by the distribution system when air has to be supplied at a pressure greater than that required by the end use in order to provide sufficient volume to satisfy the demand. Parasitic pressure drop losses are increased when distribution piping pressure is raised and leakage losses are higher due to the increased pressure in the distribution system.

The ex ante analysis was carried out based on measured air flows and the kW demand of pre-retrofit equipment and engineering estimation of the effects of the post retrofit equipment and operation on kW consumption. The ex ante analysis assumed the post-retrofit equipment would operate on the pre-retrofit production schedule, and that post-retrofit process air demand would be the same as pre-retrofit air demand, except for the reductions in air demand caused by the energy efficiency measure modifications

Table 4-78 summarizes the nameplate and measured operating parameters of the pre- and post-retrofit compressors.

Table 4-78
Ex Ante Air Compressor Nameplate Data
Project No. 48378

Compressor	Manufacturer	Motor Horsepower	Voltage	kW	Rated Capacity scfm	Rated Operating Pressure, psig
I-R XLE	Ingersoll-Rand	200	480	163.92	1,000	
G-D 150	Gardner-Denver	150	480	136.35	750	
C-P 150	Chicago-Pneumatic	150	480	117.72	740	
C-P 60	Chicago-Pneumatic	60	480	48.65	200	
G-D 200	Gardner-Denver	200	480	142.13	752	125
G-D 200	Gardner-Denver	200	480	142.13	752	125
G-D 40	Gardner-Denver	40	480	32.29	115	175

All of the post-retrofit compressors are of the same type, single stage, air cooled, rotary screw, and the outputs of all are modulated using a common on-line/off-line control system. This control scheme is the most energy efficient means of operating rotary screw air compressors. These controls operate the compressors either fully loaded or totally unloaded. Thus a machine is either producing its maximum output when fully loaded, or producing no output when totally unloaded. There is, therefore, no partial loading mode when a compressor delivers some fraction of its maximum capacity. It's either all, or nothing at all. This does not mean, however, that energy consumption is zero when compressor output is zero. Even unloaded, this type of compressor consumes approximately 25% of what it consumes when fully loaded.

Ex Ante Basecase Definition

For the ex ante basecase (pre-retrofit), the four operating compressors run simultaneously, in various states of part to full loading. Each compressor in the system had its own control system that ran its machine to maintain the pressure in the distribution system. If equipment at the "end-of-the-line" was starved for air, the set points of each compressor were raised until the demand could be satisfied. Nominal distribution system pressure was 120 psig.

Ex Ante Postcase Definition

For the ex ante postcase (post-retrofit), the control system was to base load the two 200-hp Gardner-Denver compressors to maintain the central air receiver pressure. The 40-hp compressor was set to run during off-peak hours to re-pressurize and then maintain the 30,000 gallon receiver at 165 psig. High pressure air from the 165 psig receiver was delivered to the low pressure distribution system via a demand expander valve to satisfy high instantaneous air demands without starting a compressor during peak costing periods. Two small fan air blowers of 4.5-hp and 2.5-hp run continuously to provide agitation air for chemical baths.

Postcase compressor discharge pressure was to have been 125 psig into the 1,020 gallon air receiver, and 165 psig into the 30,000 gallon receiver. The demand expander valves were to have then regulated flow out of the receivers to maintain the distribution system at 90 psig.

Ex Ante Operating Schedule

The ex ante manufacturing operation runs 24 hours per day, seven days per week. Weekend production levels are lower than weekday production levels as only "must work" jobs are scheduled for weekend production.

Production workers work three eight hour shifts per day, seven days per week, while office workers work one eight hour shift per day, five days per week.

The compressors run 24 hours per day, every day, to maintain the system pressure. Therefore, compressor hours of operation are 8,760 hours per year. The plant runs at capacity, and production levels are consistently high throughout the year. Slow downs only occur between contracts.

Ex Ante Algorithms

Based on the measured pre-retrofit air demands, a post-retrofit air demand profile was developed. From this profile, the electrical power consumption was estimated based on the measured kW/cfm of the pre-retrofit machines at the various operating modes.

Hours of operation at the high and low demand modes were extrapolated from monitoring data. Annual kWh was obtained by multiplying kW at the low mode times hours of operation at the low mode, and adding that to the product of kW at the high mode time the hours of operation at the high mode. This is summarized in Table 4-77.

Annual energy savings is the difference between the pre-and post-retrofit kWh, or:

$$\text{Ex Ante Annual Energy Savings} = 3{,}091{,}544 \text{ kWh} - 1{,}314{,}523 \text{ kWh}$$

$$= 1{,}777{,}021 \text{ kWh}$$

The average demand reduction is the difference between the sum of the pre-retrofit demands at the high demand mode and the post-retrofit demands at the high demand mode (from Table 4-2), or:

$$\text{Ex Ante Average Demand Reduction} = 466.64 \text{ kW} - 284.36 \text{ kW}$$

$$= 182.28 \text{ kW}$$

Key Ex Ante Assumptions

- Assumed that pre- and post-retrofit air demand from production machinery is identical, except for reductions due to installation of energy efficiency measures.
- Assumed that pre- and post-retrofit production schedules would be the same.

Ex Ante Data Sources

- Compressor nameplate data and manufacturer's equipment data sheets.
- Spot measurements of equipment.
- Customer interviews.

4.14.6 Ex Post Load Impact Estimates

Monitoring data is analyzed to determine ex post power consumption patterns. These values are extrapolated to the 8,760 hour year assuming constant plant production levels, and accounting for planned production schedules.

Monitoring data for all three running compressors was obtained over a five week period in December 1998 and January 1999.

Ex Post Basecase

The ex post basecase is assumed to be the same as the ex ante basecase corrected for the current production level and schedule.

Ex Post Postcase

The ex post postcase is the three post-retrofit compressors loading as necessary to maintain the central air receiver pressure for the ex post production schedule. Controls were set to load the 200-hp compressors as necessary to maintain the 1,020 gallon air receiver pressure at 120 psig. The 40-hp compressor was set to run as necessary to maintain the 30,000 gallon receiver at 165 psig. Agitation air for chemical baths is provided by two small fan blowers of 4.5-hp and 2.5-hp that operate continuously.

Significant system leakage is present and the majority of compressor output goes to overcome system leakage to maintain the distribution system pressure.

Ex Post Operating Schedule

This facility operates eight hours per day, six days per week, except during holiday periods when the plant is shut down. Hours of operation vary according to production levels on aerospace and defense contract work. Slow periods occur when contracts cannot be won for additional work. The plant is currently undergoing a permanent 40% reduction in capacity. Production levels are not expected to increase in the near future from present levels, and are never expected to return to ex ante levels. Therefore, the current facility schedule is expected to continue for the foreseeable future.

The current shift schedule is one eight-hour shift per day, six days per week for production workers, and one eight-hour shift per day, five days per week for office workers. Currently, the plant is operating with minimal staffing due to lack of work.

Monitoring data and results of customer interviews show that the compressors operate continuously, even during off hours and holidays. Therefore, ex-post hours of operation for the compressed air system are 8,760 hours per year.

Ex Post Production Level Changes

Installation of the energy efficiency measures did not affect the production level of the plant. The overall ex post production levels are approximately 75% lower than the ex ante levels due to other factors. The plant is undergoing a permanent 40% reduction in capacity and staffing, and production levels are never expected to return to ex ante levels.

Data Collected Ex Post

The energy consumption of each of the three running compressors was measured using portable power monitoring equipment. Measurements were taken using a Pacific Science & Technology Energy Logger. This instrument measures true RMS kW. The following data were collected on-site:

- Runtime data for all three running compressors.
- Measured voltage, amperage, power factor and kW for the three compressors.
- Motor and compressor nameplate data.

Data was collected on one minute intervals over a five week period in December of 1998 and January of 1999. Thirty minute averages for each operating compressor were recorded for actual voltage, amperes, power factor and kW.

Ex Post Algorithms

Interviews with the customer indicated the existence of several existing large compressed air leaks in buried sections of the distribution system that had not been repaired. From the monitoring data it is evident that there is a significant demand for compressed air during periods when the production line is shut down which represents system leakage. Moreover, monthly compressor logs recorded by the plant maintenance department show a fairly constant utilization of compressors from month to month when average loaded run hours are compared. Given the recent lack of production, and the lack of variation between weekday production shifts and off hour shifts and Sundays, it must be concluded that nearly all of the output of the compressors is currently satisfying leakage demand. On the day of the ex post site visit, no compressed air uses were observed anywhere in the plant, yet one 200 hp compressor was running fully loaded.

The agitation air fans run continuously to maintain chemical tank circulation. Full load demand was estimated from the general equation:

$$\text{Full Load kW}_{\text{agitation air fans}} = (0.746 \text{ kW / hp}) \times \text{Motor hp / Motor Efficiency} \quad \textbf{Eqn. 2}$$

The following information was assumed for the motors:

Motor hp	5	3
Motor Efficiency	84.7%	82.7%

The baseline motor efficiencies are the average motor efficiencies for all motors of the type, speed range and horsepower cataloged in MotorMaster. Using these efficiencies and substituting into Equation 1 gives a Full Load kW of 4.40 kW for the 4.5 hp fan and 2.71 kW for the 2.5 hp fan. Since these blowers run continuously, it was assumed that the average hourly kW demand for the blowers was:

$$\text{Average Hourly kW}_{\text{Blowers}} = 4.40 \text{ kW} + 2.71 \text{ kW}$$

$$= 7.11 \text{ kW}$$

Average hourly kW for the compressors was calculated from the monitoring data for each hour of the day for each monitored compressor. A total average hourly kW was calculated for each hour of the day for each day of the monitoring period by summing the monitored kW's for each hour with the calculated hourly average kW for the fan blowers. The total average hourly kW for each hour of an average day was then found by averaging all the total average kW's for a specific hour of the day in the monitoring period. The average kW calculated for the monitoring period was 156.8 kW.

Annual ex post postcase energy use was then calculated by multiplying the average hourly kW times the annual hours of operation:

$$\text{Ex Post Annual kWh}_{\text{postcase}} = 153.9 \text{ kW} \times 8{,}760 \text{ hrs / yr}$$

$$= 1{,}347{,}745 \text{ kWh}$$

The annual ex post kWh impact was the difference between the annual basecase energy and the annual postcase energy:

$$\text{Ex Post Annual kWh Imapct} = 3{,}091{,}544 \text{ kWh} - 1{,}347{,}745 \text{ kWh}$$

$$= 1{,}743{,}798 \text{ kWh}$$

The maximum coincident kW was found from the differences between the average basecase kW and the average of the monitored kW's in the costing period hours. The average basecase kW was determined by dividing the basecase kWh by the annual operating hours:

$$\text{Ex Post Basecase kW} = 3{,}091{,}544\text{ kWh} / 8{,}760\text{ hours} / \text{yr}$$

$$= 352.92\text{ kW}$$

Table 4-79
Ex Post kW Impacts
Project No. 48378

	Winter On-Peak	Summer On-Peak
Average Basecase kW	352.92	352.92
Average Postcase kW	153.78	153.09
kW Impact	199.14	199.83

Ex Post Load Impacts By Time-Of-Use Period

The operating characteristics of the compressed air system for this facility was fairly consistent, with little variability. Thus, the allocation of kWh savings to the time-of-use (TOU) periods was based on the operating hours in each TOU period. The results are shown in Table 4-80.

The kW reduced coincident with system peak was calculated by subtracting the postcase average kW for the summer and winter on-peak periods from the basecase kW for the high demand operating mode.

$$\text{kW Reduced}_{\text{ex post,summer}} = \left(\text{kW}_{\text{basecase,high demand}}\right) - \left(\text{Average kW}_{\text{postcase,summer on-peak}}\right)$$

$$= 352.92\text{ kW} - 153.09\text{ kW}$$

$$= 199.83\text{ kW}$$

$$\text{kW Reduced}_{\text{ex post,winter}} = \left(\text{kW}_{\text{basecase,high demand}}\right) - \left(\text{Average kW}_{\text{postcase,winter on-peak}}\right)$$

$$= 352.92\text{ kW} - 153.78\text{ kW}$$

$$= 199.14\text{ kW}$$

Table 4-80
Ex Post kW and kWh Impacts by Time-of-Use Period
Project No. 48378

Time-of-Use Period	kWh Adjustment Factor	kWh Savings	Average kW Reduced	kW Reduced Coincident with System Peak Period
Summer On-peak	0.0855	115,235	199.06	199.83
Summer Semi-peak	0.1099	148,160	199.06	
Summer Off-peak	0.2237	301,550	199.06	
Winter On-peak	0.0503	67,849	199.06	199.14
Winter Semi-peak	0.2182	294,012	199.06	
Winter Off-peak	0.3123	420,940	199.06	

4.14.7 Net-To-Gross Ratio

The net-to-gross ratio for this project was estimated to be 1.0. The SDG&E IEEI Program was the reason the measures were installed.

SDG&E initiated the project by having its compressed air consultant conduct a study of the facility to improve the energy efficiency of the compressed air system. The financial incentives enabled the customer to implement the project by reducing the financial hurdles of the project.

SDG&E staff (consultants) originated the project concept and provided all technical and engineering analysis.

Motivation

Motivation for the project was inspired by the cost reduction opportunity and the promise of a more reliable compressed air supply system. The project was initiated by SDG&E, who apprised the customer of the potential for savings, provided the compressed air consultant who did the monitoring and performed the design engineering. According to the customer, this equipment would not have been installed without the assistance of SDG&E and the program rebate. Moreover, the project was only approved and built because the rebate was large enough to improve the project economics to meet the customer’s internal payback criteria.

Non-Energy Costs and Benefits

No non-energy costs or benefits resulted from the installation of the equipment.

Equipment Alternatives

The pre-retrofit compressor system would have been overhauled and remained in service had this project not been installed. No other alternatives other than the ex post equipment were considered.

4.15 PROJECT ID 48467 - CATALYTIC THERMAL OXIDIZER WITH HEAT EXCHANGER

4.15.1 Summary of Findings

A catalytic thermal oxidizer system was installed to remove volatile organic compounds from the exhaust of a commercial bakery. The system was installed rather than the lower cost afterburner direct oxidization emission control system used as the basecase

The ex post results are summarized in Table 4-81.

Table 4-81
Summary of Ex Post Load Impacts
Project No. 48467

	kWh	kW	Therms
Ex Ante	n/a	n/a	501,757
Ex Post	n/a	n/a	497,510
Realization Rate	n/a	n/a	99.2%

The ex post gross impacts are 497,510 therms per year, 99.2% of the 501,757 therm ex ante estimate.

The small discrepancy is somewhat coincidental. Several small differences between ex ante and ex post operating data combined to increase the ex post basecase and postcase gas consumption (by about 20,000 therms) and to decrease the difference between them. However, the slightly smaller difference in ex post average hourly savings was offset by a small increase in operating hours (6,485) found in the ex post study versus the ex ante estimated operating hours (6,258).

4.15.2 Facility Description

This facility is a commercial bakery. Dough is prepared, allowed to rise and sized. The dough blanks are the baked on continuous ovens. During the fermentation and baking process, the dough emits volatile organic compounds (VOC's), primarily ethanol. The San Diego Air Pollution Control District (APCD) required the facility to reduce the emission of these volatile organic compounds. The equipment installed under this project was installed in response to the APCD requirement. The catalytic thermal oxidizer was one of several options for controlling VOC's.

4.15.3 Overview of Facility Schedule

- The facility operates continuously with the exception of an (approximately) 24 hour shutdown during Tuesday/Wednesday and a second shutdown on Saturday/Sunday. The weekend shutdown is sometimes skipped if production requirements are high.

- The total annual operating hours for first year operation were 6,285 hours.

4.15.4 Measure Description

The equipment installed under this measure consists of a catalytic thermal oxidizer (CTO) system. The installed CTO equipment included:

1. A 60-hp fan (and associated ductwork and controls) which conveys exhaust gases from the ovens and dough production equipment; this fan is controlled by a variable speed drive that is the subject of a separate project with a separate savings claim (Project No. 49944);
2. The catalytic thermal oxidizer consisting of a gas burner /combustion chamber followed by a chamber with a series of beds in which the catalytic material is placed;
3. A crossflow air-to-air heat exchanger that transfers heat from the gases in the CTO exhaust to the entering oven exhaust gases, and serves to reduce the amount of supplemental heat that must be added by natural gas; and
4. Associated gas piping and combustion controls, and a complete control system connecting ductwork and exhaust stack; the CTO process breaks down volatile organic compounds contained in the oven and fermenter exhaust gases to water vapor, carbon dioxide and other harmless gases that are released to the atmosphere.

For the purposes of the impacts under this measure, the basecase technology equipment consists of an “afterburner” thermal oxidizer in which the VOC’s in the exhaust gases are destroyed by incineration i.e. by raising their temperature to the temperature at which the gases burn. The *afterburner thermal oxidation* requires the exhaust flow to be heated to the oxidation temperature of 1,400°F. Because the oven exhaust was vented directly to the atmosphere prior to this project, the basecase is a hypothetical lower initial cost, but more energy consuming, alternative.

The postcase equipment consists of the post-retrofit equipment which was actually installed: a catalytic thermal oxidizer. In the CTO, the VOC’s are oxidized at a much lower temperature (approximately 640°F) in the presence of the catalyst. The *catalytic thermal oxidation* process requires the exhaust flow to be heated to 640°F, since the catalyst facilitates the oxidation of the VOC’s. The lower temperature reduces the amount of natural gas used to heat the oven exhaust to the oxidation temperature.

4.15.5 Ex Ante Load Impact Estimates

A thermodynamic heat balance was carried out using accepted engineering algorithms to estimate the load impacts of the catalytic thermal oxidizer. Energy use for the basecase and postcase operating conditions was estimated using the heat balance figures. Table 4-82 shows the assumed temperatures of the exhaust stream used in the heat balance.

Table 4-82 shows flows, temperatures and conversion constants used in the estimation of the ex ante load impacts.

Table 4-82
Ex Ante Constant Values Used In Estimating Load Impacts
Project No. 48467

Solvent Heat Value, Ethanol C_2H_5OH (Hv)	12,800 Btu/lb
Density air @ 70 def-F (D)	0.075 Lbm/ft^3
Specific Heat Cp air @ 70 def-F 40 phi (Cp)	0.245 Btu/lbm F
Air Flow Quantity (Q)	7,880 CFM

The energy use for the basecase and postcase technologies were estimated using a spreadsheet similar to that shown in Table 4-83. The ex ante load impact was calculated as the difference in annual therm consumption between the basecase and postcase systems.

Table 4-83
3 Ex Ante Heat Balance and Load Impact Estimates
Project No. 48467

	Basecase Afterburner Thermal Oxidizers (GATO)	**Postcase Catalytic Thermal Oxidation (CTO)**	
Solvent air flow, SCFM F	7,880	7,880	
Inlet Temperature, (F) Ti	370	370	Site Data
Outlet Temperature, (F) To	1,400	475	Engineer Estimate
Temp Oxidization, (F) Tox	1,400	640	Engineer Estimate
Solvent Mass Rate, (lb/hour)M	45	45	Customer Measurement
Solvent Heat Rate, (Btu/hour) S	576,000	576,000	M x Hv
Total Energy Required, (Btu/hour) B	8,948,331	912,208.5	Fx(Tox-Ti)xDxCp
Energy Input, (Btu/hour) E	8,372,331	336,208.5	B - S
Run time, (Hour/year) R	6,258	6,258	Site Records
Total Annual Energy Use, Btu EA	52,394,047,398	2,104,000,000	E x R
Annual Energy, Therms	523,940	21,040	EA/100000
Energy Saved (running), (Therms) Es	0	502,901	Ga-Gcto
Start-up time, (Hours) S	0	0.5	Mfgr. Est.
Burner Rate (Btu/hour) BR	2,200,000	2,200,000	Eqpt. Specs.
Annual Starts, 2/week AS	104	104	52 weeks x 2 starts/week
Warm-up energy, (Therms) W	0	1,144	S x BR x AS
Net Energy Savings, Therms	**n/a**	**501,757**	**=(Energy Saved) - (Warm-up Energy)**

4.15.6 Ex Post Load Impact Estimates

The ex post load impact evaluation used a methodology similar to that used to calculate the ex ante load impacts. A thermodynamic heat balance was carried out using accepted engineering algorithms to estimate the load impacts of the catalytic thermal oxidizer. Energy use for the basecase and postcase operating conditions was estimated using the heat balance and the difference was the annual energy savings.

The ex post analysis used values for annual operating hours, inlet and outlet temperatures obtained from customer operating records and site observations. The ex post air flow rates were adjusted to match post retrofit fan power measurements and to match the actual post-retrofit annual natural gas consumption obtained from customer operating logs.

Ex Post Basecase

The basecase for the ex post analysis is the same as the ex ante basecase. Because the oven exhaust was vented directly to the atmosphere prior to this project, the basecase was a hypothetical, lower initial cost (but more energy consuming) alternative. For the purposes of the impacts under this measure, the basecase technology equipment consists of an "afterburner" thermal oxidizer in which the VOC's in the exhaust gases are destroyed by incineration, i.e., by raising the temperature to the level at which the gases burn. *Afterburner, or direct thermal oxidation* requires the exhaust flow to be heated to the oxidation temperature of 1,400°F.

Ex Post Operating Schedule

- The facility operates continuously with the exception of a 24 hour shutdown during Tuesday/Wednesday and a second shutdown on Saturday/Sunday. The weekend shutdown is sometimes skipped if production requirements are high.
- The total annual operating hours for first year operation used in the ex post analysis were 6,485 based on monitoring conducted ex post.

Ex Post Production Level Changes

The modifications to this equipment neither caused nor resulted in a change on bakery production.

Data Collected Ex Post

- The input power to the oven/CTO exhaust fan was monitored for one week to confirm fan operating flow rate and CTO system operating schedule. These data were also used to support the analysis of the fan VSD installed under Project No. 49944.
- Weekly inlet and outlet temperatures profile was provided by the customer. The profile verifies the CTO operating temperature and operating hours.
- Design flow and power of the exhaust fan for various operating speeds were obtained from the CTO system design documents. These were used to adjust the CTO / oven exhaust flow rate.
- Annual gas consumption for the CTO unit was obtained from customer records. These data were used to verify the post-installation thermal balance.

- Typical inlet and exhaust stack temperatures were obtained from the customer operating supervisor.

Ex Post kWh Savings and TOU Impact

The ex post analysis was carried out in similar fashion to the ex ante analysis, however, the values of key operating parameters were revised based on ex post measurements and other ex post data obtained.

The ex post operating hours were determined from two weeks logging the power of the exhaust fan motor input power combined with customer weekly operating logs for the CTO. The results are summarized in Table 4-84.

Table 4-84
CTO Annual Operating Hours (from Ex Post Monitoring Data)
Project No. 48467

	Operating Hours	Adj. Operating Hours	Proportion of Annual Operating Hours
Summer On-Peak	1,324.72	552.0	0.0851
Summer Semi-Peak	1,802.32	751.0	0.1158
Summer Off-Peak	3,358.25	1,399.3	0.2158
Winter On-Peak	564.75	329.4	0.0508
Winter Semi-Peak	2,562.29	1,494.7	0.2305
Winter Off -Peak	3,358.25	1,959.0	0.3021
Total		**6,485.3**	

The monthly gas consumed for the period April 3, 1998 through December 12, 1998 is summarized in Table 4-85.

Table 4-85
Natural Gas Consumption for CTO (from Customer Submeter)
Project No. 48467

Date	Elapsed Days	Gas Meter Reading (cf)	Gas Consumed (therms)	Average Therms per Day
4/3/98		36,36,000		
4/29/98	26	39,62,700	3,267	125.6538
6/2/98	34	43,89,000	4,263	125.3824
7/5/98	33	4,799100	4,101	124.2727
8/1/98	27	5,151,900	3,528	130.6667
9/4/98	34	5,577,700	4,258	125.2353
10/3/98	29	5,892,100	3,144	108.4138
11/6/98	34	6,295,800	4,037	118.7353
12/4/98	28	6,634,300	3,385	120.8929
Submetered	245		29,983	122.3796
Annual Projected Consumption	365		44,669	

The ex post analysis and results are summarized in Table 4-86.

Table 4-86
Ex Post Gross Annual Impact Calculation
Project No. 48467

Calculation of Fan Flow Rate				
Row	**Description**	**Value**		**Notes**
A1	Measured Average Operating Input kW with VSD	6.80 kW		Monitoring Data
B1	Calculated Average Fan bhp (Drive Eff. = .96;Motor Eff. = 0.925)	9.46 bhp		A1 x 0.96 / (0.746 kW/bhp x 0.925)
C1	Calculated Air Flow Rate (SCFM) (6" Pd; 75% Fan Eff. from design data)	7,499 scfm		B1 x 0.75 x 6,344 / 6"
Gas Consumption Calculation for Basecase and Postcase				
Row	**Description**	**Basecase Afterburner**	**Postcase Catalytic**	**Notes**
A	Exhaust Air Flow (scfm)	7,499	7,499	Calculated from Fan Power
B	Density of Air at 70F	0.075	0.075	Physical Constant
C	Specific Heat of Air (Btu/lb-DegF)	0.254	0.254	Physical Constant
D	Inlet Temperature (DegF)	370	370	Operating Data
E	Outlet Temperature (DegF)	1,400	475	Proj./ Actual Operating Data
F	Temp of Oxidization (Deg F)	1,400	610	Proj./ Actual Operating Data
G	VOC Mass Rate (lb/hr)	36.6	36.6	See Row Q
H	Solvent Heat Rate (Btu/lb)	12,800	12,800	Handbook Chemistry & Physics
I	Solvent Heat Input	468,161	468,161	G x H
J	Total Energy Required	8,828,498	1,157,133	(E-F) x A x B x C x 60
K	Net Energy Input Required	8,360,337	688,972	J-I
L	Annual Hours of Operation	6,485.29	6,485.29	Monitoring Data
M	Annual Energy Use (therms)	542,192	44,682	Kx L / 100,000 (Postcase = Actual Consumption)
N	**Annual Therm Savings**		**497,510**	**N(Basecase) - N (Postcase)**
Calculation of Average VOC Emission Rate				
Row	**Description**	**Value**		**Notes**
O	Average VOC Emission Rate Tons per Year	118.6	Tons/year	Emissions Test Data
P	Hours of Production	6,485.29	Hours/year	Monitoring Data
Q	Average VOC Rate lbs per hour	36.6	Lbs/hour	O x 2,000 /P

4.15.7 Summary of Gross Impacts

The results of the ex post impact analysis are shown in Table 4-87. This result is compared with the ex ante estimate.

Table 4-87
Summary of Ex Post Load Impacts
Project No. 48467

	kWh	kW	Therms
Ex Ante	n/a	n/a	501,757
Ex Post	n/a	n/a	497,510
Realization Rate	n/a	n/a	99.2%

The ex post gross impacts are 497,510 therms per year, 99.2% of the 501,757 therm ex ante estimate.

The small discrepancy is somewhat coincidental. Several small differences between ex ante and ex post operating data combined to increase the ex post basecase and post case gas consumption (by about 20,000 therms) and to decrease the difference between them. However, the slightly smaller difference in ex post average hourly savings was offset by a small increase in operating hours (6,485) found in the ex post study versus the ex ante estimated operating hours (6,258).

4.15.8 Net-To-Gross Ratio

The net-to-gross ratio for this project was estimated to be 0.40. The customer had two choices in implementing this project: filter or incinerate the VOC's. The customer had most of the conceptual and engineering work performed on the incineration options after discussions with SDG&E staff. The incentives helped to reduce first cost of the CTO measure and make it competitive with the Afterburner Thermal Oxidation process.

With a low level of involvement by SDG&E and the incentives influencing the decision to install the measure the net-to-gross ratio is 0.40.

4.16 PROJECT ID 48562 - COMPRESSED AIR SYSTEM MODIFICATION: NEW COMPRESSORS WITH ADDED STORAGE & CONTROLS

4.16.1 Summary of Findings

This project involved substantial improvements to the compressed air system serving this large facility with widely dispersed air loads. Three new air compressors (200, 50 and 10 horsepower), a valve called a *demand expander*, an additional 1,500 gallon storage receiver, and low-leakage drains were installed. A leakage reduction and system consolidation project was carried out for the compressed air system serving this ship-building facility. The project was initiated by SDG&E through a consultant that conducted a study and identified the savings opportunities.

The ex ante and ex post load impact estimates are summarized in Table 4-88.

Table 4-88
Summary of Ex Post Load Impacts
Project No. 48562

	kWh	kW	Therms
Ex Ante	855,249	150.3	n/a
Ex Post	1,254,460	253.3	n/a
Realization Rate	146.7%	168.6%	n/a

The ex post gross annual kWh impact was 1,254,460 kWh 46.7% greater than the ex ante estimate of 855,249 kWh. The primary reasons for the discrepancy were:

1. The customer described a concerted effort at reducing the consumption of compressed air as a part of the air compressor improvement program. Fittings and drains are checked. The system is “walked” during off-hours to listen for leaks.
2. From the data it appears that prior to the retrofit, the compressors were operating very inefficiently and they operated many hours at low or no load to satisfy relatively small air demands. The data show that the compressed air load, except for sand blasting, is now handled by the “new” 200 hp and 50 hp compressors installed as a part of this project. As a result, the larger, older, less efficient compressors operate fewer hours than anticipated and the “new” smaller compressors operate longer hours than anticipated.

The ex post gross kW impact was 253.3 kW, 68.6 % greater than the ex ante 150.3 kW estimate. The primary reasons is a result of a difference in methodology between the ex ante and ex post kW calculation. The ex ante estimate calculated the difference in compressor kW at a projected peak air demand condition. The ex post estimate calculation is the average of the summer TOU period on peak kWh impact. The reasons cited for the kWh discrepancy also apply to the kW impact discrepancy.

4.16.2 Facility Description

The facility is a large shipbuilding facility. Compressed air is used as motive power for large and small hand tools, for blow-off, sand-blasting, painting and miscellaneous uses. The compressed air plant is located at a central location in the yard. Compressed air is distributed through large diameter metal header and branch pipes out to the docks where it is conveyed to the work areas by flexible rubber hoses.

4.16.3 Overview of Facility Schedule

- The facility schedule varies with the amount of activity and the type of construction or maintenance being carried out in the yard.
- At the time of the evaluation site visits, the prevailing schedule was two shifts, five days per week.
- The compressor system which is the subject of this report operates as required to maintain the distribution pressure continuously.

4.16.4 Measure Description

- An existing 300-hp screw compressor was removed and dismantled for parts.
- Three new compressors were installed as described below.
- Storage and demand expander were added as described below.

Pre-Retrofit Conditions

Prior to the retrofit project there were air compressors three operating compressors at two locations. The pre-retrofit compressors are shown in Table 4-89.

Table 4-89
Pre-Retrofit Compressors and Capacity
Project No. 48562

Pre-Retrofit Compressor Plant					
Compressor Plant	**Quantity**	**Nominal hp**	**Cooler Fan hp**	**Capacity**	**Operating Notes**
PAC-Air 300	2	350	20	1345 ICFM@125 psi	Lead On Demand: On 110 psi; off 120 psi
IR SSR 2000 (also referred to as SSR 100 in ex ante report)	1	100	5	380 cfm @ 140 psi	On 100 psi; off 110 psi: 117 bhp on nameplate

- The compressors were sequenced to operate in stages as necessary to meet air flow demand as indicated by the distribution system pressure.
- Distribution system pressure was maintained at 110-115 psi.
- Compressors were sequenced to operate as described in Table 4-89.

Post-Retrofit Conditions

Table 4-90 lists the compressors in place after the retrofit project:

Table 4-90
Post-Retrofit Compressors and Capacity
Project No. 48562

Post-Retrofit Compressor Plant					
Compressor Plant	**Quantity**	**Nominal hp**	**Cooler Fan hp**	**Nominal Capacity**	**Operating Notes**
PAC-Air 300	1	350	20	1345 ICFM@125 psi	1 PA300 removed. Remaining unit now operates for standby and high-peak events (sand blasting) only
IR SSR 2000	1	100	5	380 cfm @ 140 psi	#3 on demand: On 100 psi; off 110 psi
Gardner Denver 200	1	200	5	755 cfm @ 130 psi	Lead on demand: On 110 psi; off 120 psi
Gardner Denver 50	1	50	1	180 cfm @ 125 psi (Ex Post Estimate)	#2 on demand;On 105 psi; off 115 psi
GD 10 hp Recip.	1	10	0	unknown	Not Used

The added equipment is described in Table 4-91.

Table 4-91
Installed Equipment
Project 48562

Qty	Item	Specification
1	Gardner - Denver Air Compressor	200 hp; 752 cfm @ 125 psi & 186 bhp
1	Gardner - Denver Air Compressor	50 hp; 215 cfm@ 125 psi & 52 bhp
1	Gardner - Denver Air Compressor	10 hp; 32 cfm@ 175 psi & 10.5 bhp
1	Vertical Receiver Tank	1,500 gallon
1	demand expander	3-inch; "AVP-1500"
1	Air Pressure Regulator	Master Pneumatic 180-12 high flow, pilot operated
5	Gardner Denver Evacuator	zero loss drains

- Compressor output pressure and storage tank pressure was maintained at 110-120 psi.
- Distribution system pressure was set at 97 psi.
- A concerted effort to reduce system leaks had been carried out.
- Compressors were controlled to operate in sequence in stages as indicated in Table 4-91.

4.16.5 Ex Ante Load Impact Estimates

The *ex ante* load impact estimates were based on a site-specific study of the facility's compressed air system conducted by a compressed air system consultant provided by SDG&E's IEEI Program. The study comprised a detailed audit, including an inventory of air compressor system equipment, current operating procedures, measurements of existing compressor operating performance, evaluation of the plant requirements and performance (air balance), and recommendations that would reduce air compressor system operating costs, including energy savings. Spot measurements were made to verify the current operating parameters of the system. The hours of operation under various operating scenarios for the compressed air system were multiplied by the estimated power required to meet the compressed air loads under the basecase and postcase scenarios.

Tables 4-92 shows a summary of the load impact estimates by season. Tables 4-93 through 4-98 shows the air balance and energy savings calculation worksheets for the first and second shifts. Table 4-99 shows a summary of the energy use and savings for the first and second shifts. These tables show total *ex ante* load impacts of 855,249 kWh saved and 150.3 kW reduced.

Table 4-92
Ex Ante Load Impact Summary
Project No. 48562

Base Case Energy Usage

Summer Season

	kWh	kW
Peak	181,834	419.00
Semi-peak	228,198	
Off-peak	440,216	
Total	850,248	419.00

Winter Season

	kWh	kW
Peak	109,149	419.00
Semi-peak	467,745	
Off-peak	604,181	
Total	1,181,074	419.00

Annual energy usage = 2,031,322 kWh
Demand = 419.00 kW

Enhanced Case Energy Usage

Summer Season

	kWh	kW
Peak	105,276	268.70
Semi-peak	132,119	
Off-peak	254,872	
Total	492,267	268.70

Winter Season

	kWh	kW
Peak	63,194	268.70
Semi-peak	270,810	
Off-peak	349,802	
Total	683,806	268.70

Annual energy usage = 1,176,073 kWh
Demand = 268.70 kW

Annual Energy Savings = 2,031,322 kWh - 1,176,073 kWh
= 855,249 kWh

Annual Energy Savings = 419.0 kW - 268.70 kW
= 150.3 kW

Table 4-93
Ex Ante Air Balance Worksheet
First Shift
Project No. 48562

BASECASE								
First Shift	**Application**	**Pressure**	**PCF**	**CFM**	**PPM**	**Hrs/Shift**	**Months**	**Hrs/Yr**
Shipboard	Blowing	104	0.605	530	320.4	14	9	3,780
Sand Blast	Blowing	104	0.605	254	153.6	6	9	1,620
Machine Shop	Blowing	104	0.605	45	27.2	8	9	2,160
Leaks	Leaks	104	0.605	60	36.3	24	9	6,480
Artificial Demand		104	0.605	100	60.5	24	9	6,480
			0 .075		0.0			0
Total				**989**	**597.97**			
First Shift/Peak	**Application**	**Pressure**	**PCF**	**CFM**	**PPM**	**Hrs/Shift**	**Months**	**Hrs/Yr**
Shipboard	Blowing	104.2	0.606	1,060	642.0	14	3	1,260
Sand Blast	Blowing	104.2	0.606	762	461.5	6	3	540
Machine Shop	Blowing	104.2	0.606	75	45.4	10	3	900
Leaks	Leaks	104.2	0.606	60	36.3	24	3	2,160
Artificial Demand		104.2	0.606	78	47.2	24	3	2,160
Total				**1,957**	**1185.24**			
POSTCASE								
First Shift	**Application**	**Pressure**	**PCF**	**CFM**	**PPM**	**Hrs/Shift**	**Hrs/Yr**	
Shipboard	Blowing	95	0.559	530	296.2	14	5,110	
Sand Blast	Blowing	95	0.559	254	141.9	6	2,190	
Machine Shop	Blowing	95	0.559	45	25.1	8	2,920	
Leaks	Leaks	95	0.559	60	33.5	24	8,760	
Artificial Demand		95	0.559	0	0.0	24	8,760	
Total				**889**	**496.75**			
Differential - PPM					**101.22**			
First Shift/Peak	**Application**	**Pressure**	**PCF**	**CFM**	**PPM**	**Hrs/Shift**	**Hrs/Yr**	
Shipboard	Blowing	95	0.559	1,060	592.3	14	5,110	
Sand Blast	Blowing	95	0.559	762	425.8	6	2,190	
Machine Shop	Blowing	95	0.559	75	41.9	10	3,650	
Leaks	Leaks	95	0.559	60	33.5	24	8,760	
Artificial Demand		95	0.559	0	0.0	24	8,760	
Total				**1,957**	**1093.53**			
Differential - PPM					**91.71**			

Table 4-94
Ex Ante Air Compressor Test Worksheet
First Shift
Project No. 48562

Compressor	HP	VAC Name Plate	VAC Actual	HP Amps	Amp Name Plt (FLA x 1.10)	FLA Actual	Mfg Flow	Mfg PSI	PDSCF @Mfg PSI
Pacair 300	300	460	470	360	426	278	1,310	125	0.7120
Pacair 300	300	460	470	360	426	289	1,310	125	0.7120
SSR 100H	100	100	478	120	141	102	380	140	0.7880
Compressor	**Adj Flo Pres**	**Inlet PSIA**	**Adj Flow**	**Temp Corrected Inlet Temp**	**Correction**	**Adjusted**	**PPM Actual**	**PPM Proposed**	**Differential**
Pacair 300	670	14.40	684	101	561	727	417	952	534
Pacair 300	725	14.40	740	101	561	787	468	952	484
SSR 100H	202	14.70	202	96	556	213	128	299	172

Table 4-95
Ex Ante Energy Use Worksheet
First Shift
Project No. 48562

Basecase			
Make and Model	**Power**	**Hours On**	**Total kWh**
Pacair 300	205	4,368	895,440.0
Pacair 300	214	1,080	231,120.0
SSR 100H	76.85	4,032	309,859.2
Total			**1,436,419**
Postcase			
Make and Model	**Power**	**Hours On**	**Total kWh**
Pacair 300	268.7	1,080	290,196.0
Pacair 300		0	0.0
SSR 100H		0	0.0
New 181 bhp a/c	145.2	4,380	635,976.0
Total			**926,172**
Energy Savings - First Shift			**510,247**

Table 4-96
Ex Ante Air Balance Worksheet
Second Shift
Project No. 48562

Basecase							
Second Shift	**Application**	**Pressure**	**PCF**	**CFM**	**PPM**	**Hrs/Shift**	**Months**
Shipboard	Blowing	110	0.635	210	133.4	10	9
Sand Blast	Blowing	110	0.635	0	0.0	0	9
Machine Shop	Blowing	110	0.635	0	0.0	0	9
Leaks	Leaks	110	0.635	30	19.1	24	9
Artificial Demand		110	0.635	50	31.8	24	9
Total				**290**	**184.2**		
Second Shift/Peak	**Application**	**Pressure**	**PCF**	**CFM**	**PPM**	**Hrs/Shift**	**Months**
Shipboard	Blowing	110	0.635	460	304.9	14	3
Sand Blast	Blowing	110	0.635	0	0.0	6	3
Machine Shop	Blowing	110	0.635	0	0.0	10	3
Leaks	Leaks	110	0.635	60	38.1	24	3
Artificial Demand		110	0.635	78	49.5	24	3
Total				**540**	**343.0**		
Postcase							
Second Shift	**Application**	**Pressure**	**PCF**	**CFM**	**PPM**	**Hrs/Shift**	**Hrs/Yr**
Shipboard	Blowing	95	0.559	210	117.3	10	3,650
Sand Blast	Blowing	95	0.559	0	0.0	0	0
Machine Shop	Blowing	95	0.559	45	25.1	0	0
Leaks	Leaks	95	0.559	60	33.5	24	8,760
Artificial Demand		95	0.559	0	0.0	24	8,760
Total				**315**	**176.01**		
Differential - PPM					**8.19**		
Second Shift/Peak	**Application**	**Pressure**	**PCF**	**CFM**	**PPM**	**Hrs/Shift**	**Hrs/Yr**
Shipboard	Blowing	95	0.559	480	268.2	10	3,650
Sand Blast	Blowing	95	0.559	0	0.0	0	0
Machine Shop	Blowing	95	0.559	0	0.0	0	0
Leaks	Leaks	95	0.559	60	33.5	24	8,760
Artificial Demand		95	0.559	0	0.0	24	8,760
Total				**540**	**301.74**		
Differential - PPM					**41.26**		

Table 4-97
Ex Ante Air Compressor Test Worksheet
Second Shift
Project No. 48562

Compressor	HP	VAC Name Plate	VAC Actual	HP Amps	Amp Name Plt (FLA x 1.10)	FLA Actual	Mfg Flow	Mfg PSI	PDSCF @ Mfg PSI	PSI Actual	PDCF Actual	Adj Flo Pwr
Pacair 300	300	460	470	360	426	278	1,310	125	0.7120	98	0.574	855
Pacair 300	300	460	470	360	426	289	1,310	125	0.7120	102	0.594	889
SSR 100H	100	100	478	120	141	102	380	140	0.7880	103	0.600	275

Compressor	Adj Flo Pres	kW	Adj Flo Pres	Inlet PSIA	Adj Flow	Temp Corrected Inlet Temp	Correc-tion	Adjusted	PPM Actual	PPM Pro-posed	Differ-ential
Pacair 300	670	205.94	670	14.40	684	101	561	727	417	952	534
Pacair 300	725	214.08	725	14.40	740	101	561	787	468	952	484
SSR 100H	202	76.85	202	14.70	202	96	556	213	128	299	172

Table 4-98
Ex Ante Energy Use Worksheet
Second Shift
Project No. 48562

Basecase			
Make and Model	**Power**	**Hours On**	**Total kWh**
Pacair 300	205	1,260	258,300
Pacair 300	214	0	0
SSR 100H	76.85	4,380	336,603
Total			**594,903**
Postcase			
Make and Model	**Power**	**Hours On**	**Total kWh**
Pacair 300	268.7	0	0.0
Pacair 300		0	0.0
SSR 100H	52.93	3,240	171,490.2
New 181 bhp a/c	87.17	900	78,406.0
Total			**249,901**
Energy Savings - Second Shift			**345,002**

Table 4-99
Ex Ante Energy Savings Estimate
Project No. 48562

	1st Shift	2nd Shift	Total
Basecase, kWh	1,436,419	594,903	2,031,322
Postcase, kWh	926,172	249,901	1,176,073
kWh Savings	510,247	345,002	855,249

4.16.6 Ex Post Load Impact Estimates

The ex post analysis was carried out using an engineering calculation methodology similar to the method used in the ex ante estimates. The operating power and operating hours of the pre-and post retrofit compressor system were determined from data gathered through short term monitoring, a review of operating logs, and interviews with operating staff. The pre- and post kWh were calculated as the product of the average operating kW and the operating hours. The gross impact estimate is the difference between the pre- and post-retrofit kWh. The kW impact is based on the average kW reduced during the summer on-peak TOU period.

The ex post post-retrofit kWh estimates used:

- The kW values calculated from monitoring during the period November 17, 1998 through December 3, 1998: two weeks of operation.
- Post-retrofit compressor hours calculated from readings of the compressors' operating hour meters and from computerized compressor operating logs at the time of the post retrofit site survey.
- Modified pre-retrofit operating hours based on ex post data obtained and
- Ex ante measured operating kW.

Ex Post Basecase

The pre-retrofit compressors are shown in Table 4-89.

The ex ante basecase consisted of the pre-retrofit compressor system operating at the pre-retrofit operating pressure (approximately 110-120 psi - both distribution and storage). The pre-retrofit air balance indicated extensive leaks and inefficient end use equipment. Leaks comprised a large part of the air demand. Storage was limited. The large compressors operated at higher than necessary discharge pressures under modulating control and as a result operated many hours in unloaded condition consuming electrical power for little or no compressed air production.

Ex Post Operating Schedule

The facility operating schedule varies with activity in the shipyard. The typical schedule is a full first shift, approximately 6 A.M. until 2 P.M., and a smaller swing shift from 2 P.M. until about 10 P.M. The compressors operate as, and when, necessary to maintain the distribution system pressure at 97 psi (post-retrofit) at all times.

Ex Post Production Level Changes

No change in production was caused by or occurred as a result of this measure.

Data Collected Ex Post

- In put power to all four compressors was measured at 30 minute intervals for two weeks.

- Annual operating hours for all compressors (both pre- and post-retrofit) since their installation was calculated from data contained in the compressor maintenance logs
- Seasonal operating differences and annual modifications in compressor operations were obtained from interviews with management and operating personnel.
- Verified equipment installation.

Ex Post kWh Savings and TOU Impact

Annual Gross kWh Impact

The *post-retrofit average operating kW* was calculated by the general formula:

$$\text{Average kW}_{\text{postcase,i}} \frac{\sum \text{kW}_{\text{monitoring,i}}}{\sum \text{Hours}_{\text{monitoring,i}}},$$

where:

$\text{kW}_{\text{monitoring,i}}$ = measured kW for each hour the compressor operated during the monitoring period for compressor i; and

$\text{Hours}_{\text{monitoring,i}}$ = operating hours (hours with non - zero measured kW values) during the monitoring period.

The *average pre-retrofit operating kW* was calculated from ex ante measured power data.

The ex post equipment *pre-retrofit annual energy use* was calculated by:

$$\text{Annual kWh}_{\text{i,p}} = \text{kW}_{\text{i,p}} \times \text{AH}_{\text{i,p}},$$

where:

$\text{Annual kWh}_{\text{i,p}}$ = Annual kWh for compressor i at loading conditions for pre - or post - retrofit period, p, based on ex ante measurements that were adjusted ex post;

AH_{i} = Annual operating hours of compressor i at loading condictions (for pre - or post - retrofit period p) based on customer operating logs.

The *gross ex post annual kWh savings* were estimated as:

$$\text{Annual kWh Savings} = \sum_{i=1}^{3} (\text{Annual kWh}_{\text{i,pre-retrofit}} - \text{Annual kWh}_{\text{i,post-retrofit}})$$

Table 4-100 shows the operating hours data derived from plant records that were used in the ex post impact calculations.

Table 4-100
Ex Post Compressor Operating Hours Data
Project No. 48562

	Compressor	Status	Period	Date	Hour Meter Reading	No. Days	Annual Hours
Existing Compressors	SSR2000	(Retained)	Pre-Retrofit	12/13/93	722		
				6/23/97	9,100	1,288	**2,374**
			Post-Retrofit	12/14/97	2,879		
				11/9/98	4,372	330	**1,651**
	Pac Air 300 -#2	(Retained)	Pre-Retrofit	11/10/93	18,192		
				9/24/97	31,418	1,415	**3,412**
			Post-Retrofit	12/14/97	32,377		
				11/9/98	32,625	330	**275**
	Pac Air 300 -#1	(Removed)	Pre-Retrofit	11/3/93	21,807		
				12/30/96	33,000	1,036	**3,943**
		Removed	Post-Retrofit	11/7/97			
		Gone		11/9/98			**0**

	Compressor	Status	Period	Date	Total Hours	Loaded Hours	No. Days	Annual Hours Total	Annual Hours Loaded
New Compressors	GD 200 hp	Not Installed	Pre-Retrofit					0	**0**
			Post-Retrofit	12/05/97	0	0	0		
				11/09/98	2,291.9	2,052.0	339	2,467.7	**2,209.4**
	GD50 hp	Not Installed	Pre-Retrofit					0	**0**
			Post-Retrofit	12/08/97	0	0	0		
				11/09/98	4,349.9	2,597.6	336	4,725.3	**2,821.8**
	GD 10 hp	Not Installed	Pre-Retrofit					0	
		Installed, Not Used	Post-Retrofit	12/15/97	0				
				11/09/98	0			0	

Table 4-101 shows the ex post kWh savings calculations. The data supporting this table are included as an Attachment in electronic format.

Table 4-101
Ex Post kWh Savings Calculation
Project No. 48562

	Compressor	**Average Operating kW**	**Source of kW Data**	**Annual Hours**	**Source of Operating Hour Data**	**Annual kWh (Col. B x Col. D)**
	Column A	Column B	Column C	Column D	Column E	Column F
Pre-Retrofit	SSR 2000	**76.7**	Ex Ante Spot Meas. & Interview	**2,374**	Maint. Operating Log Obtained Ex Post	**181,982**
	Pac Air #1	**205**	Ex Ante Spot Meas. & Interview	**3,943**	Maint. Operating Log Obtained Ex Post	**808,413**
	Pac Air #2	**214**	Ex Ante Spot Meas. & Interview	**3,412**	Maint. Operating Log Obtained Ex Post	**730,094**
	Total					**1,720,490**
Post-Retrofit	SSR 2000	**79.5**	Ex Post Monitoring	**1,651**	Maint. Operating Log Obtained Ex Post	**131,250**
	Pac Air #2	**195.5**	Ex Post Monitoring	**275**	Maint. Operating Log Obtained Ex Post	**53,710**
	GD200	**78.2**	Ex Post Monitoring	**2,468**	Maint. Operating Log Obtained Ex Post	**192,993**
	GD50	**18.6**	Ex Post Monitoring	**4,725.3**	Maint. Operating Log Obtained Ex Post	**88,076**
	GD10	**0**	Customer Interview	**0**	Customer Interview	**0**
	Total					**466,029**
Ex Post Gross Annual kWh Savings						**1,254,460**
Ex Post Gross kW Reduced						**143.2**

TOU Period kWh Impacts

Gross kWh impacts for costing period *c* were determined by calculating a factor that represents the proportion of annual savings that occurs during each time-of-use period based on the ex post monitoring results. The ex post monitoring period was considered to be representative of typical operations at this facility as far as the proportion of energy impacts. The following steps were used:

1. The average post-retrofit kW (of all compressors) for each operating hour of each "Daytype" (Daytype 1 = Weekdays, Daytype 2 = Weekend/Holidays) was calculated from the monitoring data.
2. The total annual kWh for each hour of each Daytype was calculated by multiplying the average hourly kW by the 254 for weekdays (the number of full operating weekdays estimated for 1998) and 111 (to account for 104 weekend days per year and 7 weekday holidays
3. The kWh for the daily hours in each seasonal TOU period were summed.
4. The kWh sum for the hours that occur during each summer time-of-use period was multiplied by 5/12 to reflect TOU consumption during the five summer season months.

The total kWh which occur during each winter TOU period were multiplied by 7/12 to calculate the total which applies to each TOU period during the winter season.

5. The kWh in each TOU period for the year were summed and divided by the total kWh to calculate a "TOU period kWh consumption weighting factor."
6. The ex post total annual kWh savings was multiplied by the TOU period weighting factor" to calculate the kWh savings for each TOU period.

The process for estimating the TOU factors and ex post load impacts by TOU period is shown in the following equations:

$$\left(\text{Total kWh usage for each hour}_{\text{daytype}}\right) = \left(\text{Average post - retrofit kW for each hour}_{\text{daytype}}\right) \times \left(\text{No. Days}_{\text{daytype}}\right),$$

where:

$$\text{No. Days}_{\text{daytype}} = 254 \text{ days for weekdays}$$
$$= 111 \text{ days for weekends}$$

$$\left(\text{Sum of kWh usage for each TOU period}\right) = \sum \begin{pmatrix} \text{Total kWH usage for each hour}_{\text{daytype}} \text{ in} \\ \text{each summer and winter TOU period} \end{pmatrix}$$

$$\left(\text{Adjusted kWh Usage for Each TOU period}\right) = \left(\text{Sum of kWh Usage for Each TOU period}\right) \times \left(\text{Seasonal Adjustment Multiplier}\right)$$

where:

$$\text{Seasonal Adjustment Multiplier} = \left(\frac{5}{12}\right) \text{ for summer; and}$$

$$= \left(\frac{7}{12}\right) \text{ for winter.}$$

$$\left(\text{Total Annual kWh Usage}\right) = \sum_{p} \text{Adjusted kWh Usage for Each TOU period},$$

where:

p = the six TOU periods.

$$\left(\text{TOU Adjustment Factor for Each TOU Period}\right) = \frac{\text{Adjusted kWh Usage for Each TOU Period}}{\text{Total Annual kWh Usage}}$$

$$(\text{Ex Post kWh Savings by TOU Period}) = (\text{Ex Post Gross kWh Savings}) \times (\text{TOU Adjustment Factor for Each TOU Period}).$$

The results are summarized in Table 4-102.

Table 4-102
Ex Post Load Impacts By TOU Period
Project No. 48562

Season	Period	TOU Adjustment Factor	kWh Impact	Total Hours	Average kW
Column A	Column B	Column C	Column D	Column E	Column F
			Col. C X (1,254,460 kWh)		Column D ÷ Column E
Summer	**On-peak**	0.1513	189,752	749	253.3
	Semi-peak	0.1826	229,014	963	237.8
	Off-peak	0.0828	103,925	1960	53.0
Winter	**On-peak**	0.0255	32,024	441	72.6
	Semi-peak	0.4418	554,250	1911	290.0
	Off-peak	0.1160	145,495	2736	53.2
Total			**1,254,460**		

Average Gross kW Impacts

Average gross kW impacts were calculated for each costing period by dividing the total kWh impacts for the costing period by the total number of hours in the TOU period:

$$\text{Average Ex Post kW Reduced}_c = \frac{\text{Ex Post kWh Savings}_c}{\text{Hours}_c}$$

These results are shown in Table 4-102.

Gross kW Impact Coincident with System Peak

The impact across the daytime hours is reasonable constant. The summer on-peak TOU period average kW impact is reported as the ex post peak coincident kW impact.

4.16.7 Summary of Gross Impacts

Table 4-103 summarizes the ex post gross kW and kWh Impacts and shows a comparison of the ex ante gross impact estimates with the ex post estimates.

Table 4-103
Results and Comparison with Ex Ante Estimate
Project No. 48562

	kWh	kW	Therms
Ex Ante	855,249	150.3	n/a
Ex Post	1,254,460	253.3	n/a
Realization Rate	146.7%	168.6%	n/a

The ex post gross annual kWh impact was 1,254,460 kWh 46.7% greater than the ex ante estimate of 855,249 kWh. The primary reasons for the discrepancy were

1. The customer described a concerted effort at reducing the consumption of compressed air as a part of the air compressor improvement program. Fittings and drains are checked. The system is “walked” during off-hours to listen for leaks.
2. From the data it appears that prior to the retrofit, the compressors were operating very inefficiently and they operated many hours at low or no load to satisfy relatively small air demands. The data show that the compressed air load (except for sand blasting) is now handled by the “new” 200 hp and 50 hp compressors installed as a part of this project. As a result, the larger, older, less efficient compressors operate fewer hours than anticipated and the “new” smaller compressors operate longer hours than anticipated.

The ex post gross kW impact was 253.3 kW, 68.6 % greater than the ex ante 150.3 kW estimate. The primary reasons is a result of a difference in methodology between the ex ante and ex post kW calculation. The ex ante estimate calculated the difference in compressor kW at a projected peak air demand condition. The ex post estimate calculation is the average of the summer TOU period on peak kWh impact. The reasons cited for the kWh discrepancy also apply to the kW impact discrepancy.

4.16.8 Net-To-Gross Ratio

The net-to-gross ratio for this project is 1.0. The customer conceptualized the project, but management considered the project in its prior state to be non-cost effective. SDG&E sponsored a study that provided verified load impact and cost estimates and added enhancements that expanded the scope of the project. The improved project scope provided through the study, coupled with the lessened financial impact attributed to the program incentives offered through the program “put the project over the edge.”

SDG&E had a high level of involvement in ushering the project from an initial concept developed by the customer, but rejected by management, to one that provided greater energy savings and was approved by management through a combination of improved operating economics and improved cost effectiveness.

4.17 PROJECT ID 48605 - COMPRESSED AIR SYSTEM MODIFICATION WITH CONTROLS & STORAGE

4.17.1 Summary of Findings

This report documents a large number of improvements that were made to this compressed air system including the following: storage was added; two new compressors were installed; and *demand expander*“ pressure regulating devices were installed. The specific items are detailed in the project description section below.

Table 4-104 summarizes the results of this ex post impact study.

Table 4-104
Comparison with Ex Ante Estimates
Project No. 48605

	kWh	kW	Therms
Ex Ante	3,444,389	540.96	n/a
Ex Post	1,496,568	176.7	n/a
Realization Rate	43.4%	32.7%	n/a

The ex post annual kWh impact estimates are 43.4 % of the ex ante gross kWh impact. The evaluation kW impact estimate of 176.7 kW is 32.7% of the ex ante estimate.

The primary reason for the kWh discrepancy is that the verified, ex post basecase compressor kWh were about 1.65 million kWh *lower* that the ex ante basecase estimate and the ex post postcase kWh were about 700 kWh *higher* than the ex ante projected post retrofit kWh. These differences occurred as a result of differences in the interpretation of ex ante data and differences in ex post postcase system consumption calculated from the ex post monitoring data. The specific differences are discussed further in Section 4.17.7.

4.17.2 Facility Description

This manufacturing facility occupies several buildings in the SDG&E service territory. The principal processes at the plant involve metal working for manufacture of air frame, jet and rocket engine components. Processes include casting, precision machining, milling, grinding, pressing, stamping, polishing, brazing, heat treating, small scale batch foundry operations, forging, welding and drilling. Compressed air is used for motive power of some floor and hand tools, for bead and sand blasting, air driven pumps, vacuum eductors, blow-off and control air pressure.

There were three separate compressed air plants at the site, in Buildings 1 and 5, and the Maintenance Building in the basecase configuration. Currently, three compressors located in

Building 1 serve Buildings 1 and 2, and four compressors adjacent to Building 5 serve Buildings 5 and 6 and several other nearby buildings including the Maintenance Building which formerly had its own dedicated compressors. The two systems are not interconnected. As part of the project the system in the Maintenance Building were removed and a interconnecting pipe from Building 5 was installed.

4.17.3 Overview of Facility Schedule

The facility is in operation continuously, year round. The compressors operate to maintain system pressure at all times. Compressed air demand depends on production activity. Production activity depends on the amount of product orders and the specific process taking place at any given time. In general, activity is greatest during the first shift, is slightly reduced during second shift and is significantly lower during third shift, seven days per week.

4.17.4 Measure Description

The actions at this facility included a number of actions and addition of equipment intended to stabilize air supply quantity and pressure, optimize system operation and minimize energy consumption per unit of air delivered.

Pre-Retrofit Conditions

- The facility where this project was implemented is a large multi-building industrial campus. The primary buildings that were affected by this project are Buildings 1, 2, 5, 6, and the Maintenance Building (Building 8).
- Prior to the retrofit project there were three separate compressed air systems with a total of eight rotary screw air compressors. One system served Buildings 1 and 2, another served Buildings 5 and 6, and the third system served the Maintenance Building (Building 8). Table 4-105 lists the pre-retrofit compressor equipment.

Table 4-105
Pre-Retrofit Compressors and Capacity
Project No. 48605

Building	Compressor	Horse power	Rated Capacity	Auxiliary	Measured Power
1,2	Atlas Copco ZT60	60	221scfm@115psi	2 hp AC dryer; est. 2 hp refrig. Cooler HG400	65.9A@480
1,2	Sullair 32-300H	300	1,187@115 psi	10hpAC; 7.5 hp refrig. Dryer	347A@480
1,2	Quincy QSI1500	300	1,439 scfm @110psi	10hpAC; 7.5 hp refrig. Dryer	347A@480
5,6	Rollair	60	275cfm @110 psi	2-1 hp ac;1-7.5 hp refrig. (total Bldg. 5,6)	69A@480
5,6	Rollair	60	275cfm @110 psi		69A@480
5,6	QuincyQMA31D	60	272cfm @100 psi		68A@480
MB	Atlas Copco ZT60	60	221scfm @115psi	1 hp AC dryer	65.9A@480
MB	Atlas Copco ZT60	60	221scfm @115psi	1 hp AC dryer	65.9A@480

Post-Retrofit Conditions

Table 4-106 lists the equipment installed under this project.

- A connecting pipe was installed to extend the compressed air system serving Buildings 5 and 6 to the Maintenance Building. The compressors in the Maintenance Building were removed.
- Storage capacity and the demand expanders were installed at Buildings 1 and 5. Compressor supply and storage pressure was set at 125 to 130 psi and distribution system pressure was set at 95 psi.
- A PLC control system was installed and programmed to control and optimize compressor operation.

Table 4-106
Compressed Air System Equipment Installed
Project No. 48605

Equipment Recommended	Quantity	Condition
Precision Drains	12	Installed and in operation
New 4" pipe from building #5 to Maintenance Building	1	Installed and in operation
60 gal tank at plasma spray.	1	Installed (per Cust. Interview)
5,000 gallon receiver	1	Installed Bldg. 5
3" Demand Expander	1	Installed Bldg. 5
3,200 cfm dryer - Bldg. 1	1	Installed
6" Demand Expander	1	Installed Building 1
PLC Control System	1	Building 1 Control Room: In Operation

Table 4-107 lists the post-retrofit compressors and associated specifications and ratings.

Table 4-107
Postcase Compressors Specifications and Ratings
Project No. 48605

Building	Compressor	Horsepower	Rated Capacity	Auxiliary	Measured Power
1,2	Atlas Copco ZT60	60	221scfm@115psi	2-10 hp refrig. Dryer (all 3 compr.)	65.9A@480
1,2	Sullair 32-300H	300	1187@115 psi	(backup only)	347A@480
1,2	Quincy QSI1500	300	1439 scfm@110psi	10hpAC;	347A@480
5,6	Rollair	60	275cfm@110 psi	2-1hp ac;1-7.5 hp refrig. (total Bldg. 5,6)	69A@480
5,6	Rollair	60	275cfm@110 psi	1 hp AC dryer	69A@480
5,6	QuincyQMA31D	60	272cfm@100 psi	1 hp AC dryer	68A@480
5,6	Atlas Copco ZT60	60	221scfm@115psi		Relocated
5,6	Atlas Copco ZT60	60	221scfm@115psi		Relocated

4.17.5 Ex Ante Load Impact Estimates

The *ex ante* load impact estimates were based on a site-specific study of the facility's compressed air system conducted by a compressed air system consultant provided by SDG&E's IEEI Program. The study comprised a detailed audit, including an inventory of air compressor system equipment, current operating procedures, measurements of existing compressor operating performance, evaluation of the plant requirements and performance (air balance), and recommendations that would reduce air compressor system operating costs, including energy savings.

The input electric power for each compressor and the supply system air pressure at several locations, were monitored for several days. Normal operations and peak events were observed. The amperage and pressure in pounds per square inch (psi) were monitored. Spot measurements were also taken to verify the load and unloaded conditions for major compressors.

The annual hours of operation for each compressor were estimated based on the monitoring data, observations during the ex ante site visit, and interviews with operating personnel. The average operating power for each compressor was calculated from the pre-retrofit amperage monitoring data. Some compressor operating power was adjusted for expected changes.

The post-retrofit operating power and operating hours for each compressor was estimated by the consultant assuming full implementation of the compressed air study.

The product of the operating hours and the average operating power for each compressor in the pre- and post-retrofit operating scenarios was summed to calculate the total kWh. The difference between the total pre- and post-retrofit kWh was reported as the ex ante gross kWh estimate.

The ex ante demand impact was calculated by summing the power of the compressors that were expected to be in operation during the "peak event" under the pre- and post-retrofit operating scenarios. The difference between the total pre-retrofit compressor power and post-retrofit compressor power during the peak event operation is the ex ante demand kW impact.

Tables 4-5 through 4-7 show the air balance and energy savings calculation worksheets for the project. These tables show total ex ante load impacts of 3,444,389 kWh saved and 540.96 kW reduced.

Table 4-108
Ex Ante Air Balance
Project No. 48605

Scenario	Building	Compressor	Base Load HP	Base Load Scfm	Peak Load HP	Peak Load Scfm
BASECASE	**Bldg 1 & 2**	Sullair 32-300H	307	644	339	1,187
		Quincy 1500-110	286	795	319	1,439
		Atlas Copco 60	18	3	20	49
		Dryers	15	-	15	-
		Total	**626**	**1,442**	**693**	**2,675**
		Annual Hours	**7,010**		**1,750**	
	Bldg 5 & 6	Rollair 60	3	5	42	91
		Rollair 60	55	99	61	275
		Quincy QMA 60	68	272	68	272
		Kaesar/Quincy	11	40	15	48
		Dryers	8	-	8	-
		Total	**145**		**194**	**686**
		Annual Hours	**7,510**		**1,250**	
	Maintenance Building	Atlas Copco 60	13	13	14	27
		Atlas Copco 60	64	221	64	221
		Total	**77**	**234**	**78**	**248**
		Annual Hours	**8,260**		**500**	
POSTCASE	**Bldg 1 & 2**	Sullair 32-300H	0	0	0	0
		Quincy 1500-110	285	833	339	1,439
		Atlas Copco 60	0	0	64	221
		Dryers	5	-	9	-
		Total	**290**	**833**	**412**	**1,660**
		Annual Hours	**7,010**		**1,750**	
	Bldg 5 & 6	Rollair 60	0	0	0	0
		Rollair 60	37	142	66	275
		Quincy QMA 60	68	272	68	272
		Kaesar/Quincy	11	40	15	48
		Dryers	8	-	8	-
		Total	**124**	**454**	**157**	**595**
		Annual Hours	**7,510**		**1,250**	
	Maintenance Building	Atlas Copco 60	0	0	0	0
		Atlas Copco 60	0	0	0	0
		Total	**0**	**0**	**0**	**0**
		Annual Hours	**0**		**0**	

Table 4-109
Ex Ante Load Impact Estimate
Project No. 48605

		Base Load				Peak Load			
BASECASE		**BHp**	**Annual Hours**	**kW**	**kWh**	**BHp**	**Annual Hours**	**kW**	**kWh**
Bldg 1 & 2	Sullair 32-300H	307	7,010	246.26	1,726,284	339	1,750	271.93	475,876
	Quincy 1500-110	286	7,010	229.42	1,608,200	319	1,750	255.89	447,801
	Quincy 1500-110	0	0	0.00	0	275	1,750	220.59	386,035
	Atlas Copco 60	18	7,010	15.81	110,794	20	1,750	16.99	29,741
	Dryers	15	7,010	12.94	90,684	15	1,750	12.03	21,056
	Total			**504.43**	**3,535,962**			**777.43**	**1,360,509**
Bldg 5 & 6	Rollair 60	3	7,510	5.37	40,334	42	1,250	34.81	43,517
	Rollair 60	55	7,510	45.59	342,373	61	1,250	50.56	63,203
	Quincy QMA 60	68	7,510	56.36	423,297	68	1,250	54.55	68,183
	Kaesar/Quincy	11	7,510	9.49	71,245	15	1,250	12.79	15,986
	Dryers	8	7,510	7.00	52,729	8	1,250	7.00	8,776
	Total			**123.81**	**929,978**			**159.71**	**199,665**
Maintenance Building	Atlas Copco 60	13	8,260	12.39	102,306	14	500	13.34	6,669
	Atlas Copco 60	64	8,260	53.05	438,184	64	500	53.05	26,524
	Total			**65.44**	**540,490**			**66.39**	**33,193**
Total Basecase				**1,003.53**	**6,599,797**				
POSTCASE									
Bldg 1 & 2	Sullair 32-300H	0	0	0.00	0	0	0	0.00	0
	Quincy 1500-110	286	7,010	228.61	1,602,576	339	1,750	271.93	475,876
	Atlas Copco 60	0	0	0.00	0	64	1,750	54.38	95,170
	Dryers	5	7,010	4.31	30,228	9	1,750	7.22	12,634
	Total			**232.92**	**1,632,804**			**333.53**	**583,680**
Bldg 5 & 6	Rollair 60	0	0	0.00	0	0	0	0.00	0
	Rollair 60	37	7,510	30.67	230,323	66	1,250	54.71	68,383
	Quincy QMA 60	68	7,510	56.36	423,297	68	1,250	54.55	68,183
	Kaesar/Quincy	11	7,510	9.49	71,245	15	1,250	12.79	15,986
	Dryers	8	7,510	7.00	52,729	8	1,250	7.00	8,776
	Total			**103.52**	**777,594**			**129.05**	**161,328**
Maintenance Building	Atlas Copco 60	0	0	0.00	0	0	0	0.00	0
	Atlas Copco 60	0	0	0.00	0	0	0	0.00	0
	Total			**0.00**	**0**			**0.00**	**0**
Total Postcase				**462.58**	**3,155,406**				
Ex Ante Gross Load Impacts				**540.95**	**6,599,797**				

4.17.6 Ex Post Load Impact Estimates

The ex post analysis was carried out using an engineering calculation methodology similar to the ex ante estimation method. The operating power and operating hours of the pre-and post retrofit compressors were determined from short term monitoring, a review of operating logs, and interviews with operating staff. The pre- and post kWh for each compressor were calculated as the product of the average operating kW from the ex post monitoring and the annual operating hours calculated from the hour meter readings. The kWh for each pre- and post compressor were summed. The gross kWh impact estimate is the difference between the total compressors' pre- and post-retrofit kWh. The kW impact is based on the average kW for the summer on-peak period..

The ex post post-retrofit kWh estimates used:

- kW values calculated from monitoring from November 19, 1998 to December 1, 1998.
- Post-retrofit compressor hours calculated from readings of the compressors' operating hour meters at the time of the post retrofit site survey.
- Modified pre-retrofit operating hours based on ex post data obtained.
- Pre-retrofit operating kW based on measurements carried out by the consultant preparing the ex ante load impact estimates as a part of the ex ante site study.

Ex Post Basecase

The ex post basecase consisted of the pre-retrofit compressor plant and operating conditions as described in the ex ante basecase. The baseline kW and operating hours were based on ex ante monitoring carried out prior to the system modifications. Operating hours were increased by 20% to reflect customer statements that air demand had increased by 20% since the ex ante site survey.

Ex Post Postcase

The ex post postcase consists of the as built equipment configuration and operating parameters described in the ex ante postcase description.

Ex Post Operating Schedule

The compressors are on line continuously. The compressor control setpoints are set such that the compressors are staged to come on line and drop off line sequentially as the pressure varies due to air demand. All areas of the plant operate 3-shifts per day, year-round. Compressor air demand is highest during the first shift and decreases to a lower level during second and third shift.

Ex Post Production Level Changes

No data was available regarding production at the plant. The plant fabricates components and sub assemblies for the defense industry, including rockets and jet engines. Many of the processes are small quantity batch operations or one-of-a-kind. During discussions with plant staff it was reported that there was a fairly even amount of work from year to year.

Data Collected Ex Post

The compressor power was monitored before and after the project was implemented by SDG&E staff. SDG&E engineering staff monitored compressor power at one minute intervals for several days during the initial site study. Graphs are included in the project file.

The power to all compressors was monitored for a period of two weeks from November 19 to December 1, 1998.

Ex Post kWh Savings and TOU Impact

Annual Gross kWh Impact

The compressor post-retrofit average operating kW was calculated by the general formula:

$$\text{Average kW}_{\text{postcase,i}} \frac{\sum \text{kW}_{\text{monitoring,i}}}{\sum \text{Hours}_{\text{monitoring,i}}},$$

where:

$\text{kW}_{\text{monitoring,i}}$ = measured kW for each hour the compressor operated during the monitoring period for compressor i; and

$\text{Hours}_{\text{monitoring,i}}$ = operating hours (hours with non - zero measured kW values) during the monitoring period.

The compressor average pre-retrofit operating kW was calculated from ex ante measured power data. However, the power of Compressor #2 and operating hour data for Compressors #1 and #3 was modified to reflect operating data gathered ex post.

The ex post equipment pre-retrofit annual energy use was calculated by:

$$\text{Annual kWh}_{\text{i,p}} = \text{kW}_{\text{i,p}} \times \text{AH}_{\text{i,p}},$$

where:

$\text{Annual kWh}_{\text{i,p}}$ = Annual kWh for compressor i at loading conditions for pre - or post - retrofit period, p, based on ex ante measurements that were adjusted ex post;

AH_{i} = Annual operating hours of compressor i at loading condictions (for pre - or post - retrofit period p) based on customer operating logs.

The gross ex post annual kWh impacts are estimated as:

$$\text{Annual kWh Savings} = \sum_{i=1}^{3} (\text{Annual kWh}_{\text{i,pre-retrofit}} - \text{Annual kWh}_{\text{i,post-retrofit}})$$

Table 4-110 and 4-111 show the operating hours data derived from plant records that were used in the ex post impact calculations.

Table 4-110
Ex Post Compressor Operating Hours Data Buildings 5 & 6
Project No. 48605

	Date	Hours Meter	Elapsed Days	Compressor Oper. Hours	Hours/Day	Average Hours Per Day	Annual Operating Hours
GF 005 - Worthington #1 Compressor							
Pre-retrofit	2/21/97	33,796.1					
	4/15/97	34,580.2	53	784.1	14.79		
	6/7/97	34,996.8	53	416.6	7.86		
	8/27/97	35,200.0	81	203.2	2.51		
	11/4/97	35,706.5	69	506.5	7.34	7.46	**2,723.8**
Post-retrofit	2/18/98	36,012.0	106	305.5	2.88		
	5/15/98	36,872.0	86	860	10.00		
	11/19/98	36,940.0	249	68	0.27	2.77	**1,011.1**
GF 005 - Worthington #2 Compressor							
Pre-retrofit	2/24/97	5,577.8					
	4/17/97	6,017.8	52	440	8.46		
	6/7/97	7,163.0	51	1145.2	22.45		
	10/27/97	10,004.1	142	2841.1	20.01		
	12/4/97	10,394.7	38	390.6	10.28	17.02	**6,212.6**
Post-retrofit	2/17/98	10,902.5	75	507.8	6.77		
	5/15/98	11,957.0	87	1054.5	12.12		
	12/9/98	12,634.5	249	677.5	2.72	5.45	**1,989.1**
GE 031 - GD Compressor Logger 80976							
Pre-retrofit	2/25/97	43,367.5					
	4/30/97	44,926.5	63	1559	24.75		
	11/10/97	49,486.9	194	4560.4	23.51	23.81	**8,691.0**
Post-retrofit	2/28/98	51,787.0	110	2300.1	20.91		
	4/13/98	52,320.0	44	533	12.11		
	6/8/98	53,068.5	56	748.5	13.37		
	9/28/98	53,664.0	112	595.5	5.32		
	11/19/98	53,944.8	52	876.3	16.85		
	12/3/98	54,004.5	15	340.5	22.70	11.09	**4,047.4**
GE 184 - GD Compressor Logger 8096A (NEW)							
Post-retrofit	4/15/98	7.6					
	5/6/98	508.0	21	500.37	23.83		
	6/15/98	1,404.0	40	896	22.40		
	7/18/98	2,161.0	33	757	22.94		
	9/28/98	3,883.0	72	1722	23.92		
	11/19/98	5,051.5	52	1168.5	22.47		
	12/3/98	5,384.2	14	332.7	23.76	23.17	**8,458.8**

Table 4-111
Ex Post Compressor Operating Hours Data Buildings 1 & 2
Project No. 48605

	Date	Hours Meter	Elapsed Hours	Compressor Oper. Hours	Hours/Day	Average Hours Per Day	Annual Operating Hours
Large Quincy 300 hp Compressor							
No Data, The ex ante value was used in the ex post estimates							
Post-retrofit	11/19/98	35,040.8					
	12/3/98	35,351.3	332	310.5	22.45	22.45	**8,192.7**
Sullair Compressor: 300 hp							
Pre-Retrofit	3/23/97	4,291.1					
	5/8/97	4,826.2	46	535.0	11.63		
	7/20/97	5,784.0	73	957.8	13.12	12.5	**4,578.9**
Post Retrofit	10/8/98	12,480.0	445	6,696.0	15.05		
	11/16/98	13,120.0	39	640.0	16.41		
	11/19/98	13,166.8	3	46.8	15.60	16.352	**5,968.6**
Quincy API Air Touch Compressor: 50 hp							
New Compressor No Pre-Rertrofit hours							
Post Retrofit	12/19/97	-					
	11/19/98	1,899.4					
	12/3/98	2231.7	349	2231.7	6.39	6.39	**2,334.0**

The ex post load impacts are shown in Table 4-112.

Table 4-112
Ex Post Gross Annual Impact Calculation
Buildings 1 & 5, and the Maintenance Building
Project No. 48605

Bldg.	Compressor	Operating Priority / Status	Nominal Hp	Avg. Amps @ 480 V PF =0.86	Avg. Operating kW	Source of kW Data	Total Annual Operating Hours	Source of Operating Hour	Annual kWh
Pre-Retrofit									
1	Sullair 32-300H	Primary	300	320.00	228.79	Ex Ante Monitoring	4,579	Cust. Maint. Log	1,047,608
	Quincy 1500-110	Primary	300	351.90	251.60	Ex Ante Monitoring	8,664	Ex Ante Monitoring	2,179,843
	Atlas Copco 60	Peaking	60	22.42	16.03	Ex Ante Monitoring	8,664	Ex Ante Monitoring	138,881
	Dryers	As. Req.	20	na	12.94	Ex Ante Est.	8,664	Ex Ante Est.	112,081
	Total-Bldg 1				**509.35**				**3,478,413**
5	Worthington (Rollair) 60	Primary	60	48.88	34.95	Ex Ante Monitoring	2,724	Cust. Maint. Log	40,334
	Worthington (Rollair) 60	Primary	60	70.54	50.43	Ex Ante Monitoring	6,213	Cust. Maint. Log	313,326
	Quincy QMA 60	Primary	60	76.62	54.78	Ex Ante Monitoring	8,691	Cust. Maint. Log	476,100
	Dryers	As. Req.	10	na	7.00	Ex Ante Est.	8,760	Ex A. Est.	61,320
	Total-Bldg 5				**147.16**				**891,081**
M	AC 60	Shop Use	60	0.00	0.00	Ex Ante Monitoring	0	Ex Ante Mon.	0
	AC60	Shop Use	60	26.42	18.67	Ex Ante Monitoring	3,893	Ex Ante Mon.	72,679
	Total-Bldg M				**18.67**				**72,679**
	Total-Unadjusted				**675.18**				**4,442,172**
	Total-Pre-Retrofit-Adjusted for Production			**Customer Estimate 10% Load Increase: Multiplied Total Unadjusted by 1.20**					**5,330,607**

(Continued)

Table 4-112 (continued)
Ex Post Gross Annual Impact Calculation
Buildings 1 & 5, and the Maintenance Building
Project No. 48605

Bldg.	Compressor	Operating Priority / Status	Nominal Hp	Avg. Amps @ 480 V PF =0.86	Avg. Operating kW	Source of kW Data	Total Annual Operating Hours	Source of Operating Hour	Annual kWh
Post Retrofit									
1	Sullair 32-300H	Primary	300		228.79	Ex Ante Monitoring	5,969	Cust. Maint. Log	1,365,562
	Quincy 1500-110	Primary	300		233.90	Ex Post Monitoring	8,193	Cust. Maint. Log	1,916,277
	AC 60	Peaking	60		32.26	Ex Post Monitoring	2,334	Cust. Maint. Log	75,284
	Dryers	As. Req.	5		4.31	Ex Post Est.	6,570	Ex Post Est.	28,317
	Total-Bldg 1				**499.26**				**3,385,439**
5	Worthington (Rollair) 60	Peaking	60		34.95	Ex a. Monitoring	1,011	Cust. Maint. Log	35,336
	Worthington (Rollair) 60	Peaking	60		50.43	Ex a. Monitoring	1,989	Cust. Maint. Log	100,319
	Quincy QMA 60	Primary	60		9.91	Ex Post Monitoring	4,047	Cust. Maint. Log	40,105
	Kaeser/Qncy	Primary	125		32.26	Ex Post Monitoring	8,459	Cust. Maint. Log	272,840
	Dryers	Continuou s	10		7.00	Ex Post Spot Meas.	6,570	Ex Post Est.	45,990
	Total-Bldg 5				**127.55**				**448,600**
M	AC 60	Removed	0		0.00		0		0
	AC60	Removed	0		0.00		0		0
	Total-Bldg M				**0.00**				**0**
	Total-Post-Retrofit				**626.80**				**3,834,039**
Ex Post kWh Savings									**1,496,568**

kWh Impacts by TOU Period

Gross kWh impacts for costing period *c* were determined by calculating a *TOU Adjustment Factor* that represents the proportion of annual savings that occurs during each time-of-use period based on the ex post monitoring results. The ex post monitoring period was considered to be representative of typical operations at this facility. The following steps were used:

1. The average post-retrofit kW (of all compressors) for each operating hour of each "Daytype" (Daytype 1 = Weekdays, Daytype 2 = Weekend/Holidays) was calculated from the monitoring data.
2. The total annual kWh for each hour of each Daytype was calculated by multiplying the average hourly kW by the 254 for weekdays (the number of full operating weekdays

estimated for 1998) and 111 (to account for 104 weekend days per year and seven weekdays for either holidays, either part-production or maintenance shutdown).

3. The kWh for the daily hours in each seasonal TOU period were summed.
4. The kWh sum for the hours that occur during each summer time-of-use period was multiplied by 5/12 to reflect TOU consumption during the five summer season months. The total kWh which occur during each winter TOU period were multiplied by 7/12 to calculate the total which applies to each TOU period during the winter season.
5. The kWh in each TOU period for the year were summed and divided by the total kWh to calculate a “TOU period kWh consumption weighting factor.”
6. The ex post total annual kWh savings was multiplied by the TOU period weighting factor” to calculate the kWh savings for each TOU period.

The process for estimating the TOU factors and ex post load impacts by TOU period is shown in the following equations:

$$\left(\text{Total kWh Usage for Each Hour}_{\text{daytype}}\right) = \left(\text{Average Post - Retrofit kW for Each Hour}_{\text{daytype}}\right) \times \left(\text{No. Days}_{\text{daytype}}\right),$$

where:

$$\text{No. Days}_{\text{daytype}} = 254 \text{ days for weekdays}$$
$$= 111 \text{ days for weekends}$$

$$\left(\text{Sum of kWh Usage for Each TOU Period}\right) = \sum \left(\begin{array}{c} \text{Total kWH usage for each hour}_{\text{daytype}} \text{ in} \\ \text{each summer and winter TOU period} \end{array} \right)$$

$$\left(\text{Adjusted kWh Usage for Each TOU Period}\right) = \left(\text{Sum of kWh Usage For Each TOU Period}\right) \times \left(\text{Seasonal Adjustment Multiplier}\right)$$

where:

$$\text{Seasonal Adjustment Multiplier} = \left(\frac{5}{12}\right) \text{ for summer; and}$$
$$= \left(\frac{7}{12}\right) \text{ for winter.}$$

$$\left(\text{Total Annual kWh Usage}\right) = \sum_{p} \left(\text{Adjusted kWh Usage for Each TOU Period}\right),$$

where:

p = the six TOU periods.

$$(\text{TOU Adjustment Factor for Each TOU Period}) = \frac{\text{Adjusted kWh Usage for Each TOU Period}}{\text{Total Annual kWh Usage}}$$

$$(\text{Ex Post kWh Savings by TOU Period}) = (\text{Ex Post Gross kWh Savings}) \times (\text{TOU Adjustment Factor for Each TOU } P\text{period}).$$

The results are of the TOU estimates are summarized in Table 4-113.

Average Gross kW Impacts

Average gross kW impacts were calculated for each costing period by dividing the total kWh impacts for the costing period by the total number of hours in the TOU period:

$$\text{Average ex post kW reduced}_c = \frac{\text{Ex post kWh savings}_c}{\text{Hours}_c}$$

These results are shown in Table 4-113.

Table 4-113
Ex Post Load Impacts By TOU Period
Project No. 48605

Season	**Period**	**Total Hours**	**TOU Adjustment Factor**	**kWh Savings**	**Average kW**
Col. A	Col. B	Col. C	Col. D	Col. E	Col. F
				Col. D x 1,496,568	Col. E/Col. C
Summer	On-peak	749	0.0884	132,324	176.7
	Semi-peak	963	0.1145	171,297	177.9
	Off-peak	1,960	0.2138	319,949	163.2
Winter	On-peak	441	0.0512	76,580	173.7
	Semi-peak	1,911	0.2329	348,489	182.4
	Off-peak	2,736	0.2993	447,929	163.7
Total		**8,760**		**1,496,568**	

Gross kW Impact Coincident with System Peak

The impact across the daytime hours is reasonable constant. The summer on-peak TOU period average kW impact is reported as the ex post peak coincident kW impact.

4.17.7 Ex Post Load Impact Summary

Table 4-114 summarizes the ex post gross impact estimates, and shows a comparison of the ex post estimates to the ex ante estimates.

Table 4-114
Comparison of Ex Post Load Impact Estimates with Ex Ante Estimates
Project No. 48605

	kWh	kW	Therms
Ex Ante	3,444,389	540.96	n/a
Ex Post	1,496,568	176.7	n/a
Realization Rate	43.4%	32.7%	n/a

The ex post annual kWh impact estimate is 43.4 % of the ex ante gross kWh impact. The ex post kW impact estimate of 176.7 kW is about 32.7% of the ex ante estimate.

The primary reason for the kWh discrepancy is that the verified pre-retrofit compressor kWh was *lower* than the ex ante basecase estimate and the ex post postcase kWh was *higher* than the ex ante projected postcase kWh. These differences occurred as a result of differences in the interpretation of ex ante data and differences in ex post postcase system consumption calculated from the ex post monitoring data.

The principal reasons for the difference between the ex ante and ex post estimates of basecase kWh are:

- The operating hour data obtained during the ex post site visit suggests that the Sullair 32-300H compressor operated only (the annual equivalent of) 4,579 hours in the year prior to the retrofit project. This value was used to calculate the ex post basecase annual consumption. The ex ante estimates assumed that the compressor operated 8,760 hours per year. The ex ante estimates also assumed that the compressor would operate 1,750 hours at 339 kW and 7,010 hours at 246 kW. The ex post calculation used 229 kW as the average operating kW for this compressor based on the ex ante monitoring data. These differences account for about 1.15 million kWh difference between the ex ante and ex post basecase kWh. **These findings suggest a reduction in the basecase of 1.15 million kWh.**
- It appears that the ex ante basecase calculation erroneously “double-counted” the operating kW and kWh of the Quincy 1500 compressor operating in the peak load condition. This accounts for 386,000 kWh discrepancy. About half of this discrepancy is offset by ex post added kWh for the dryer, and AC 60 hp compressor in Building 1. **This finding suggest a “net” reduction in the basecase of approximately 195,000 kWh.**
- The ex post operating data obtained for the #2 Worthington compressor in Building 5 operated only 6,213 hours /year prior to the project rather than 8,760 hours used in the

ex ante estimates. **This finding suggests a reduction of about 100,000 kWh of the postcase kWh**.

- The ex post interpretation of the operating data for the shop (Building 8) differed substantially from the ex ante interpretation of the operating power data and a much lower pre-retrofit kWh was calculated for the shop compressors. **This accounts for approximately a 700,000 kWh decrease in the ex post basecase kWh.**

The difference in the ex post postcase kWh results from a difference in methodology between the ex ante and ex post calculations. The ex ante estimates were based on expected compressor operating power and operating hours. The ex post postcase kWh were based on measured postcase kW and operating hours obtained from hour meter readings.

The difference in the kW impact is primarily explained by a difference in methodology. The ex ante estimate method calculated the pre- and post compressor operating kW for a peak scenario lasting 1,710 hours in the Building 1 system and 1,250 hours for the Building 5 & 6 system. The ex post analysis distributed the impacts in proportion to the consumption during each of the seasonal time-of-use hours. The total kWh during seasonal TOU period was divided by the total operating hours during the that period to calculate the average kW demand during that period. The impact during the summer on-peak period was selected as representative of the system peak impact. The most appropriate method to estimate kW impacts for this measure is the use of the average kW, since the approach allows for diversity of system use. The alternate methodology assumes there is no diversity in the operation of the compressors.

4.17.8 Net-To-Gross Ratio

The net-to-gross ratio for this project was estimated to be 1.0. The SDG&E IEEI Program was the reason the measures were installed. SDG&E arranged to have a program-sponsored compressed air consultant prepare a study of the system. The recommendations presented in the study were implemented at the facility under this project. The consultant provided implementation assistance to the customer.

SDG&E staff (consultants) originated the project concept and provided all technical and engineering analysis.

4.18 PROJECT ID 48652 - COMPRESSED AIR SYSTEM MODIFICATIONS WITH CONTROLS & STORAGE

4.18.1 Summary of Findings

The compressed air system at this site was modified by the addition of air demand reduction equipment including a 275 cfm supplemental blower, and efficient blow guns and nozzles; and equipment to reduce system losses including a 1,500 gallon receiver and a demand expander to allow distribution system pressure reduction, low-loss drains, and improved pressure controls.

Table 4-115 provides a comparison of the ex ante gross impact estimates with the ex post load impact estimates.

Table 4-115
Summary of Ex Post Load Impacts
Project No. 48652

	kWh	kW	Therms
Ex Ante	988,222	238.15	n/a
Ex Post	673,165	111.2	n/a
Realization Rate	68.1%	46.7%	n/a

The ex post gross annual energy impact was 673,165 kWh, 68.1% of the ex ante estimate, 988,222 kWh. The ex post gross peak demand impact was 111.2 kW, 46.7 % of the ex ante estimate of 238.15 kW.

The primary reason for the large discrepancy was the overly optimistic expectation of the impacts of the measures installed at the site in reducing the demand for compressed air. The ex ante projection assumed that three of the compressors that operated at least part of the time prior to the retrofit could be shut down entirely. The ex post evaluation showed that the three compressors' hours of operation was reduced, but not nearly to the degree projected in the ex ante estimates. The blower which was intended to reduce the demand for compressed air by more than 250 cfm was never fully implemented due to production staff concerns with production quality.

4.18.2 Facility Description

This is a manufacturing facility that produces small extruded and injection molded plastic parts and plastic foam products. Compressed air is used for motive power for machine tools and hand tools, blow-off for trimming and shaping machinery, and blow guns for production of expanded plastic materials.

4.18.3 Overview of Facility Schedule

The plant operates 24 hours per day, five days per week, for 223 equivalent full-production days, year-round. The plant is shut down and the compressors are not operated on 104 weekend days and 10 annual weekday holidays, including the 7 SDGE holidays. Compressor energy consumption and hour log data indicate that the system is shut down partially or for full shifts or full days for retooling, maintenance or production interruptions an additional 28 (equivalent) weekdays per year. Compressed air loads are very consistent across the operating day when the plant is in full production. Third shift air demands are only slightly lower than first and second shift air demands.

4.18.4 Measure Description

Equipment was installed and a number of actions were taken to reduce compressed air consumption and to reduce compressed air waste and losses. The specific equipment is listed in Table 4-116.

Table 4-116
Installed Equipment Inventory
Project No. 48652

Installed Equipment	Quantity	Specification
4012 MD blower	1	275cfm@5 psi & 13 bhp
Receiver	1	1,500 gallon, vertical
2-inch demand expander	1	AVP-0750
Large, zero loss drains	5	GD Evacuator
Small, zero loss drains	2	GD UFM T1
Various size blow guns & nozzles	39	Silvent

- The blower is intended to replace low-pressure air used for blow off in certain equipment, thereby reducing demand for compressed air by about 250 cfm.
- The receiver/demand expander was installed to allow storage of air at higher pressure than the distribution pressure, thereby stabilizing supply at a lower pressure, which in turn will reduce leak losses (which increase with pressure).
- The drains and precision blow guns and nozzles are intended to perform their function with lower air consumption than the pre-retrofit non-precision guns and nozzles, thereby reducing compressed air demand.

4.18.5 Ex Ante Load Impact Estimates

The *ex ante* load impact estimates were based on a site-specific study of the facility's compressed air system conducted by a compressed air system consultant provided by SDG&E's IEEI Program. The study comprised a detailed audit, including an inventory of air compressor system equipment, current operating procedures, measurements of existing compressor operating performance, evaluation of the plant requirements and performance (air balance), and recommendations that would reduce air compressor system operating costs, including energy savings. Spot measurements were made to verify the pre-retrofit compressor operating power. The compressor hours of operation were projected based on observed cycling during all shifts and interviews with the customer then projected to calculate annual operating hours. The hours of operation under various operating scenarios for the compressed air system were multiplied by the estimated power required to meet the compressed air loads under the basecase and postcase scenarios.

The compressors installed at the time of the ex ante site visit and analysis were three Atlas Copco GA75, 100-hp screw type compressors and one LeRoi 100-hp screw type compressor operating in modulating control mode to maintain a pressure setpoint of 120 psi, but the observed pressure ranged from 105 to 120 psi. The ex ante analysis assumed that the compressors would remain in place, but that the modifications described previously would be made to reduce system pressure and the demand for air and would significantly reduce the hours of operation of the compressors.

Tables 4-3 and 4-4 show a summary of the ex ante load impact estimates, and the air balance and savings calculations, respectively. These tables show total *ex ante* load impacts of 988,222 kWh saved and 238.15 kW reduced.

Table 4-117
Ex Ante Energy Calculation Summary
Project No. 48652

Base Case Energy Usage

Summer

	kWh	kW
Peak	253,388	331.98
Semi-peak	317,997	
Off-peak	68,647	
Total	640,033	331.98

Winter

	kWh	kW
Peak	152,100	331.98
Semi-peak	651,810	
Off-peak	95,904	
Total	899,814	331.98

Annual energy usage = 1,539,847 kWh
Demand = 331.98 kW

Enhanced Case Energy Usage

Summer

	kWh	kW
Peak	90,772	93.93
Semi-peak	113,917	
Off-peak	24,592	
Total	229,281	93.93

Winter

	kWh	kW
Peak	54,487	93.83
Semi-peak	233,500	
Off-peak	34,356	
Total	322,344	93.83

Annual energy usage = 551,625 kWh
Demand = 93.83 kW

Annual Energy Savings = 1,539,847 kWh - 551,625 kWh
= 988,222 kWh

Annual Demand Savings = 331.98 kW - 93.83 kW
= 238.15 kW

Table 4-118
Ex Ante Load Impact Estimate Calculation Worksheet
Project No. 48652

Compressor	Rated Capacity	Adj for Press	Adj for Power	Adj for Differential
Atlas Copco #1	439 @ 421 cfm	421 cfm	413 cfm	393 cfm
Atlas Copco #2	439 @ 421 cfm	421 cfm	421 cfm	406 cfm
Atlas Copco #3	439 @ 421 cfm	418 cfm	418 cfm	411 cfm
Le Roi 100-hp	439 @ 445 cfm	379 cfm	379 cfm	369.5 cfm
1st and 2nd Shift				
Energy - Current				
Compressor	**Power**	**Hours On**	**Total kWh**	
Atlas Copco #1	85.50	4,576	391,248	
Atlas Copco #2	91.90	4,576	420,534	
Atlas Copco #3	79.78	4,576	365,073	
Le Roi 100-hp	74.80	832	62,234	
Totals	**331.98**		**1,239,089**	
Energy - Proposed				
Compressor	**Power**	**Hours On**	**Total kWh**	
Atlas Copco #1	85.5	4,576	391,248	
Atlas Copco #2	91.9	0	0	
New Blower	8.33	4,576	38,118	
Totals	**93.83**		**429,366**	
Savings			**809,723**	
3rd Shift				
Energy - Current				
Compressor	**Power**	**Hours On**	**Total kWh**	
Atlas Copco #1	85.5	2,288	195,624	
Atlas Copco #2	91.9	1,144	105,134	
Atlas Copco #3	79.78	0	0	
Le Roi 100-hp	74.8	0	0	
Totals			**300,758**	
Energy - Proposed				
Compressor	**Power**	**Hours On**	**Total kWh**	
Atlas Copco #1	85.5	1,144	97,812	
Atlas Copco Unloaded	21.37	1,144	24,447	
New Blower	8.33	0	0	
Totals			**122,259**	
Savings			**178,499**	
Total Saving - All Shifts			**988,222**	

4.18.6 Ex Post Load Impact Estimates

The ex post analysis was carried out using an engineering calculation methodology similar to the ex ante estimate calculations. The ex post analysis, however used direct measurements of post-retrofit compressor operating power and operating hour data from customer operating logs, where available, as the basis for equipment pre- and post retrofit compressor energy use. The operating power of the post-retrofit compressors was based on monitoring at half hour intervals carried out over a typical nine day operating period as the basis for the daily and weekly post-retrofit compressor average power and both the pre- and post-retrofit compressor load profile.

Ex Post Basecase

The ex post basecase system consisted of four 100-hp screw-type air compressors as described for the ex ante basecase. Three were Atlas Copco (AC) GA 75 with 100-hp motors. The fourth was a LeRoi 100-hp. The three AC compressors were connected and staged to maintain a distribution pressure of 120 psi but system pressure varied from 105 to 120 psi depending on demand.

The ex post basecase operating kW for the compressors was the ex ante values documented in the notes obtained from the consultant who performed the ex ante site study and analysis. The compressor kW used in the ex post analysis were close to the values used in the ex ante analysis with the exception of the kW of Compressor #3 whose values were changed to the average of Compressors #1 and #2. The ex post basecase operating hours for Compressors #1 and #3 were based on operating hour logs obtained during the ex post evaluation site visit. The basecase operating hours for Compressors #2 and #4 used the ex ante basecase operating hour estimates derived from the ex ante consultant study.

Ex Post Postcase

Table 4-119 shows the equipment installed under the project.

Table 4-119
Ex Post Postcase Installed Equipment
Project No. 48652

Quantity	Equipment	Description
1	4012 MD blower (not used)	PD blower 275 cfm @ 5 psi & 13. Bhp
1	1,500 gallon vertical receiver	
1	AVP-0750	2" demand expander
5	GD Evacuator	large zero-loss drains
2	UFM-T1	small zero-loss drains
39	Silvent various size blow guns and nozzles	
Source: Pneumatic Systems, Inc. Fax, Nov. 2, 1998		

The ex post postcase consisted of the same Compressors #1, #3 and #4, however, Compressor #3 had been changed. A 40-hp Atlas Copco screw compressor had been brought in from another customer site to replace one of the AC GA75 100-hp compressors. This work was shortly after the SDG&E project. It was done without incentive funds.

The post-retrofit system operates with at the same compressor output pressure and storage pressure of 110 to 120 psi. The distribution pressure has been reduced to 91 psi. The customer believes that the reduced-loss drains and lower-flow end use nozzles and blow-guns listed in Table 4-119 have been very effective in reducing losses.

The ex post process air demand has remained nearly constant since the AC system improvements according to maintenance personnel at the plant. The blower shown in Table 4-119 had been installed but the equipment had not been put into operation due to technical concerns of production staff, however, its implementation is anticipated during 1999.

The ex post postcase operating kW for Compressors #1, #2 , and #3 were calculated from direct power measurements taken at the site from December 12, 1998 to December 21, 1998. The kW for Compressors #2 and #3 used in the ex post postcase analysis were generally much lower than the operating kW found in the ex ante survey. Compressor #4 had not operated except for emergencies and repairs since the retrofit project according to the operator. The ex post post-retrofit operating hours for Compressors #1, #2 and #3 were based on operating hour logs from the compressors' operating hour meter that were obtained during the ex post evaluation site visit.

Ex Post Production Level Changes

No changes in production or compressed air demand occurred as a result of or were caused by the installation of the equipment in this project.

Data Collected Ex Post

- Post-retrofit compressor power was measured at one minute intervals and reported at 30 minute intervals for nine days from December 10, 1998 to December 21, 1998.
- Compressor nameplate and rating data and spot observations of power and pressures were obtained by direct observation during site visits on December 10, 1998 and December 21, 1998.
- Compressor operating hours for July 1997 through December 1998 was obtained for most equipment from the customer via maintenance records.

Ex Post kWh Savings and TOU Impact

The post-retrofit average compressor operating kW was calculated by the general formula:

$$\text{Ex Post Average kW}_{\text{postcase,i}} \frac{\sum \text{Ex Post kW}_{\text{monitoring,i}}}{\sum \text{Ex Post Hours}_{\text{monitoring,i}}},$$

where:

$$\text{Ex Post kW}_{\text{monitoring,i}} = \text{measured kW for each hour the compressor operated during the monitoring period for compressor i; and}$$

$$\text{Ex Post Hours}_{\text{monitoring,i}} = \text{operating hours (hours with non-zero measured kW values) during the monitoring period.}$$

The pre-retrofit average compressor operating kW was calculated from ex ante measured power data. However, the power of Compressor #2 and operating hour data for Compressors #1 and #3 was modified to reflect operating data gathered ex post.

The ex post equipment pre-retrofit annual energy use was calculated by:

$$\text{Ex Post Annual kWh}_{\text{i,p}} = \text{Ex Post kW}_{\text{i,p}} \times \text{Ex Post AH}_{\text{i,p}},$$

where:

$$\text{Ex Post Annual kWh}_{\text{i,p}} = \text{Annual kWh for compressor i at loading conditions for pre- or post-retrofit period, p, based on ex ante measurements that were adjusted ex post;}$$

$$\text{Ex Post AH}_{\text{i}} = \text{Annual operating hours of compressor i at loading condictions (for pre- or post-retrofit period p) based on customer operating logs.}$$

The gross ex post annual kWh impacts are estimated as:

$$\text{Ex Post Annual kWh Savings} = \sum_{i=1}^{3} (\text{Ex Post Annual kWh}_{\text{i,pre-retrofit}} - \text{Ex Post Annual kWh}_{\text{i,post-retrofit}})$$

Table 4-120 shows the operating hours data derived from plant records that were used in the ex post impact calculations.

Table 4-120
Ex Post Compressor Operating Hours Data
Project No. 48652

Date	Hours Meter Reading	Elapsed Days	Compressor Operating Hours	Average Hours Per Day	Ex Post Annual Operating Hours
Compressor #1					
Pre-retrofit					
7/31/97	5,460.0				
10/7/97	6,793.0	68	1,333.0	19.60	7,155.1
Post retrofit					
1/21/98	8,097.0				
12/9/98	13,651.0	322	5,554	17.25	6,295.7
Compressor #2					
Pre-retrofit					
	No Pre-Retrofit Log Data Available-Consultant Estimate from Short Term Observation Used.				
Post retrofit					
1/13/98	20,442.0				
6/11/98	21,228.0	149	786.0	5.275	1,925.4
Compressor #3					
Pre-retrofit					
7/31/97	11,340.0				
10/7/97	12,311.0	68	971.0	14.28	5,212.0
Post retrofit					
1/13/98	12,731				
12/9/98	18,063	330	5,332	16.16	5,897.5
Compressor #4	(Installation not Completed)				Operating Hours =0 Blower Hours = 0

Table 4-121 shows the ex post kWh savings calculations. The data supporting this table are included as an Attachment in electronic format.

Table 4-121
Ex Post kWh Savings Calculation
Project No. 48652

Compressor	Average Operating kW	Source of Data on kW	Total Annual Operating Hours	Source of Operating Hour Data	Annual kWh
Pre-Retrofit Operation					
Atlas Copco #1	78.4	Consultant Notes from Ex Ante Spot Measurements.	7,155	Compressor Operating Log Obtained Ex Post.	560,958
Atlas Copco #2	81.7	Consultant Notes from Ex Ante Spot Measurements.	4,576	Ex Ante Consultant Estimate based on Site Observation and Customer Interview	373,859
Atlas Copco #3	85.0	Average of AC #1 and AC#2 Ex Ante Spot Obs. from Consultant Notes (Compressor being repaired at time of ex ante site survey so no reading was available.)	5,212	Compressor Operating Log Obtained Ex Post.	443,019
LeRoi 100-hp	79.6	Consultant Notes from Ex Ante Spot Measurements	832	Ex Ante Consultant Estimate from Customer Interview	66,227
Total - Pre-retrofit					**1,444,063**
Post Retrofit Operation					
Atlas Copco #1	86.65	Ex Post Monitoring	6,296	Cust. Maint. Log	545,500
Atlas Copco #2	25.43	Ex Post Monitoring	1,925	Cust. Maint. Log	48,966
Atlas Copco #3	29.9	Ex Post Monitoring	5,898	Cust. Maint. Log	176,432
LeRoi 100-hp	0	Not in Use	0	Not in Use	0
Blower	0	Use not Implemented	0	Use not Implemented	0
Total - Post-retrofit					**770,898**
Gross kWh Savings					**673,165**

Ex Post TOU Period kWh Impacts

Gross kWh impacts for costing period *c* were determined by calculating a factor that represents the proportion of annual savings that occurs during each time-of-use period based on the ex post monitoring results. The ex post monitoring period was considered to be representative of typical operations at this facility. The following steps were used:

1. The average post-retrofit kW (of all compressors) for each operating hour of each "Daytype" (Daytype 1 = Weekdays, Daytype 2 = Weekend/Holidays) was calculated from the monitoring data.
2. The total annual kWh for each hour of each Daytype was calculated by multiplying the average hourly kW by the 223 for weekdays (the number of full operating weekdays estimated for 1998) and 142 (to account for 104 weekend days per year and 38 weekdays of either part-production or maintenance shutdown).

3. The kWh for the daily hours in each seasonal TOU period were summed.
4. The kWh sum for the hours that occur during each summer time-of-use period was multiplied by 5/12 to reflect TOU consumption during the five summer season months. The total kWh which occur during each winter TOU period were multiplied by 7/12 to calculate the total which applies to each TOU period during the winter season.
5. The kWh in each TOU period for the year were summed and divided by the total kWh to calculate a "TOU period kWh consumption weighting factor."
6. The ex post total annual kWh savings was multiplied by the TOU period weighting factor" to calculate the kWh savings for each TOU period.

The process for estimating the TOU factors and ex post load impacts by TOU period is shown in the following equations:

$$\left(\text{Total kWh usage for each hour}_{\text{daytype}}\right) = \left(\text{Average post - retrofit kW for each hour}_{\text{daytype}}\right) \times \left(\text{No. Days}_{\text{daytype}}\right),$$

where:

$$\text{No. Days}_{\text{daytype}} = 223 \text{ days for weekdays}$$
$$= 142 \text{ days for weekends}$$

$$\left(\text{Sum of kWh usage for each TOU period}\right) = \sum \begin{pmatrix} \text{Total kWH usage for each hour}_{\text{daytype}} \text{ in} \\ \text{each summer and winter TOU period} \end{pmatrix}$$

$$\left(\text{Adjusted kWh usage for each TOU period}\right) = \left(\text{Sum of kWh usage for each TOU period}\right) \times \left(\text{Seasonal Adjustment Multiplier}\right)$$

where:

$$(\text{Seasonal Adjustment Multiplier}) = \left(\frac{5}{12}\right) \text{ for summer; and}$$

$$= \left(\frac{7}{12}\right) \text{ for winter.}$$

$$\left(\text{Total Annual kWh Usage}\right) = \sum_{p} \text{Adjusted kWh usage for Each TOU period},$$

where:

p = the six TOU periods.

$$\left(\text{TOU Adjustment Factor for Each TOU period}\right) = \frac{\text{Adjusted kWh Usage for Each TOU period}}{\text{Total Annual kWh Usage}}$$

$$(\text{Ex Post kWh Savings by TOU period}) = (\text{Ex Post Gross kWh Savings}) \times (\text{TOU Adjustment Factor for Each TOU period}).$$

The results of these calculations are summarized in Table 4-122.

Table 4-122
Ex Post Load Impacts By TOU Period
Project No. 48652

Season	TOU Period	TOU Adjustment Factor	kWh Savings	Total Hours	Average kW
Column A	Column B	Column C	Column D	Column E	Column F
			from "Ex. Post"		D/E
Summer	On-peak	0.1237	83,260	749	111.2
	Semi-peak	0.1602	107,847	963	112.0
	Off-peak	0.1328	89,379	1,960	45.6
Winter	On-peak	0.0753	50,708	441	115.0
	Semi-peak	0.3221	216,841	1,911	113.5
	Off-peak	0.1859	125,131	2,736	45.7
Total			**673,165**		

Average Gross kW Impacts

Average gross kW impacts were calculated for each costing period by dividing the total kWh impacts for the costing period by the total number of hours in the TOU period:

$$\text{Average Ex Post kW Reduced}_c = \frac{\text{Ex Post kWh Savings}_c}{\text{Hours}_c}$$

These results are shown in Table 4-122.

Gross kW Impact Coincident with System Peak

The load impacts from this measure occur during weekday daytime hours, and is reasonably constant. The summer on-peak TOU period average kW impact is reported as the ex post peak coincident kW impact.

Summary of Gross Impacts

Table 4-123 summarizes the ex post gross kW and kWh Impacts and shows a comparison of the ex ante gross impact estimates with the ex post estimates.

Table 4-123
Results and Comparison with Ex Ante Estimate
Project No. 48652

	kWh	kW	Therms
Ex Ante	988,222	238.15	n/a
Ex Post	673,165	111.2	n/a
Realization Rate	68.1%	46.7%	n/a

The ex post gross annual energy impact was 673,165 kWh, 68.1% of the ex ante estimate, 988,222 kWh. The ex post gross peak demand impact was 111.2 kW, 46.7 % of the ex ante estimate of 238.15 kW.

The primary reason for the large discrepancy was the overly optimistic expectation of the impacts of the measures installed at the site in reducing the demand for compressed air. The ex ante estimate assumed that three of the compressors that operated at least part of the time prior to the retrofit could be shut down entirely. The ex post study showed that the three compressors' hours of operation was reduced, but not nearly to the degree projected in the ex ante estimates. The blower which was intended to replace the air of nearly one 100-hp compressor was not fully implemented.

4.18.7 Net-To-Gross Ratio

The net-to-gross ratio for this project was estimated to be 1.0. SDG&E had a high level of involvement in identifying the opportunity and implementing this project.

SDG&E arranged to have an SDG&E-sponsored compressed air consultant prepare a study of the system. The recommendations presented in the study were implemented at the facility under this project. The consultant provided implementation assistance to the customer.

SDG&E staff (consultants) had a high level of involvement in this project, having originated the project concept and provided all technical and engineering analysis.

4.19 PROJECT ID 48698 - VACUUM PUMP GENERATION SYSTEM MODIFICATION

4.19.1 Summary of Findings

The savings for this site were based on the installation of two 20-hp vacuum pumps to replace vacuum generated in vacuum ejector devices by high pressure compressed air. This compressed air was supplied by 135-hp rotary screw air compressors. The results of the ex post evaluation were different than those of the ex ante estimate due to differences in the ex post operation and basecase from the ex ante assumptions.

Table 4-124
Summary of Ex Post Load Impacts
Project No. 48698

	kWh	kW	Therms
Ex Ante	935,480	106.79	n/a
Ex Post	707,527	83.99	n/a
Realization Rate	75.6%	78.6%	n/a

4.19.2 Facility Description

This site manufactures plastic components used for 3-1/2" floppy disk cartridges, audio cassette housings, and plastic audio cassette cases. There are forty Nigata and Sumitomo injection molding machines that produce the various components. Assembly of floppy disks is also performed at this site using the cartridge halves and shutters manufactured onsite. Vacuum systems generate the suction needed for the "pick and place" mechanisms at the injection molding machines and in the floppy disk assembly room. Each "pick and place" mechanism has a series of suction cups on the end of an articulating arm which draw the parts and hold them until they are placed in a new location by the arm where the vacuum is broken and the parts are released.

4.19.3 Overview of Facility Schedule

This facility operates 24 hours per day, seven days per week, except during 14 holiday periods when the plant is shut down. The plant runs at capacity, utilizing four floppy disk assembly lines and production levels are consistently high throughout the year. Slow downs occur only when injection molding equipment is taken down for repair.

The current shift schedule is two twelve-hour shifts per day, seven days per week for production workers, and one eight-hour shift per day, five days per week for office workers. Currently, the plant is operating forty injection molding machines and four floppy disk assembly lines.

The ex post hours of machine operation are therefore:

$$\text{Ex Post Hours of Machine Operation} = (\text{Hours in a Year}) - (\text{Holidays})$$

$$= (8{,}760 \text{ hrs/yr}) - (14 \text{ Holidays/yr} \times 24 \text{ hrs/Holiday})$$

$$= 8{,}424 \text{ hrs/yr}$$

4.19.4 Measure Description

Two 20-hp Quincy air-cooled, rotary screw, vacuum pumps were installed along with necessary piping, valves and controls to generate a 26" Hg vacuum to be used to operate the "pick and carry" mechanisms for the injection molding machines. This system replaced a series of 176 vacuum ejectors that were generating a vacuum using high pressure compressed air from the central compressed air system for 32 injection molding machines installed as of October 1998. All of the vacuum ejectors were removed from the compressed air system in the injection molding room and their piping connections capped.

The efficiency of the central compressed air system was concurrently upgraded in a separate project rebated under Project No. 46697.

Pre-Retrofit Conditions

- Compressed air from the plant central compressed air system at 125 psig is used to generate vacuum for the "pick and place" mechanisms for 32 injection molding machines in the injection molding room.
- Central compressed air system included four 125-hp rotary screw compressors and two 200-hp reciprocating compressors.
- Production facility operates 24 hours per day, seven days per week, except during 14 holiday periods when the plant is shut down.
- Production workers work two twelve-hour shifts per day, seven days per week, while office workers work one eight-hour shift per day, five days per week.
- The plant runs at capacity, utilizing six floppy disk assembly lines, and production levels are consistently high throughout the year. Slow downs only occur when injection molding equipment is taken down for repair.

Post-Retrofit Conditions

- Vacuum for the "pick and place" mechanisms for 40 injection molding machines in the injection molding room is supplied by two 20-hp Quincy air-cooled, rotary screw, vacuum pumps.
- Central compressed air system provides 80 psig air to the plant from two 125-hp rotary screw and one 75-hp rotary screw compressors.
- Production facility operates 24 hours per day, seven days per week, except during 14 holiday periods when the plant is shut down.
- Production work accomplished during two 12-hour shifts per day, seven days per week, while office work accomplished during one eight-hour shift per day, five days per week.
- The plant runs at capacity, utilizing four floppy disk assembly lines, and production levels are consistently high throughout the year. Slow downs only occur when injection molding equipment is taken down for repair.

4.19.5 Ex Ante Load Impact Estimates

The *ex ante* load impact estimates were based on a site-specific study of the facility's compressed air system conducted by a compressed air system consultant provided by SDG&E's IEEI Program. The study comprised a detailed audit, including an inventory of air compressor system equipment, current operating procedures, measurements of existing compressor operating performance, evaluation of the plant requirements and performance (air balance), and recommendations that would reduce air compressor system operating costs, including energy savings. Spot measurements were made to verify the current operating parameters of the system. The results of this monitoring revealed that vacuum pumps could provide the necessary vacuum to the plant with lower power consumption than the existing system that used high pressure compressed air to create the vacuum.

Testing of the ejectors was performed to determine the compressed air demand for vacuum generation. It was determined that each ejector was consuming 5.5 scfm of 100 psig compressed air. Based on customer input, a diversity factor of 60% was applied and a total demand of:

$$\text{Ejector Air Demand} = (5.5\text{scfm} / \text{ejector}) \times (176 \text{ ejectors}) \times (0.60)$$

$$= 580.8 \text{ scfm}$$

Since one of the 125-hp compressors produced 624 scfm of air, the installation of the vacuum pumps would result in a significant unloading of one compressor. It was also determined that *two cfm of 100 psig compressed air* was needed by the pre-retrofit equipment *for every one cfm evacuated* to generate the vacuum. New vacuum pumps were sized based on the need for approximately 289 acfm of air evacuation to satisfy plant vacuum demand.

Table 4-125 shows a summary of the ex ante load impact estimates, and the air balance and savings calculations, respectively. These tables show total *ex ante* load impacts of 935,480 kWh saved and 106.79 kW reduced.

Table 4-125
Summary of Ex Ante Load Impacts
Project No. 48698

	Demand (kW)	Annual Hours	Energy (kWh)
Pre-Retrofit Compressed Air	124.00	8,760	1,086,240
Post-Retrofit Vacuum	17.21	8,760	150,760
Savings	106.79		935,480

Table 4-126 summarizes the nameplate and measured operating parameters of the vacuum pumps.

Table 4-126
Ex Ante Vacuum Pump Nameplate Data
Project No. 48698

	Vacuum Pump Data	Source of Data
Manufacturer	Quincy	Manufacturer
Type of Compressor	Rotary Screw	Manufacturer
Model Number	QSVB-20	Manufacturer
Capacity at 29.9" HgV, ACFM	319	Manufacturer
Nominal Horsepower	20	Manufacturer
Voltage	480	Measured
Full Load Amps	27	Manufacturer
Nominal Motor Efficiency	0.93	Manufacturer
Power Factor	0.93	Measured
Motor Service Factor	1.15	Manufacturer
Type of Cooling	Air	Manufacturer
Number of Stages	1	Manufacturer

All of the post-retrofit compressors are of the same type, single stage, air cooled, rotary screw, and the outputs of all are modulated using a common on-line/off-line control system. This control scheme is the most energy efficient means of operating rotary screw air compressors. These controls operate the compressors either fully loaded or totally unloaded. Thus, a machine is either producing its maximum output when fully loaded, or producing no output when totally unloaded. There is, therefore, no partial loading mode when a compressor delivers some fraction of its maximum capacity. It's either all, or nothing at all. This does not mean, however, that energy consumption is zero when compressor output is zero. Even unloaded, this type of compressor consumes approximately 25% of what it consumes when fully loaded.

Only one of the Quincy vacuum pumps runs at a time, with the other pump configured as a backup maintenance spare. These pumps are rotated into and out of service every six months to balance run time on each machine.

Ex Ante Basecase Definition

For the ex ante basecase (pre-retrofit), the four 125-hp Sullair compressors run simultaneously, in various states of part to full loading. Each compressor in the system had its own control system that ran its machine to maintain the pressure in the distribution system. If equipment at the "end-of-the-line" was starved for air, the set points of each compressor were raised until the demand could be satisfied. Nominal distribution system pressure was 125 psig.

Approximately 580 scfm of 100 psig compressed air is consumed in the generation of vacuum in the vacuum ejectors for 32 injection molding machines.

Ex Ante Postcase Definition

For the ex ante postcase (post-retrofit), the compressed air system is disconnected from the vacuum system and the vacuum ejectors are removed. One 20-hp vacuum pump runs at all times to generate the vacuum necessary to satisfy the demands of 32 injection molding machines. The second vacuum pump is connected as a maintenance standby unit.

Ex Ante Operating Schedule

Manufacturing and assembly operations occur 24 hours per day, seven days per week. Production workers work three eight-hour shifts per day, seven days per week, while office workers work one eight-hour shift per day, five days per week. The plant runs at capacity, utilizing six assembly lines, and production levels are consistently high throughout the year. Slow downs only occur when injection molding equipment is taken down for repair. Ex ante hours of operation were therefore 8,760 hours per year.

Key Ex Ante Assumptions

- Post-retrofit vacuum demand is the same as pre-retrofit vacuum demands since output of 32 injection molding machines is the same.
- Vacuum ejector diversity factor is 60%.

Ex Ante Algorithms

The post-retrofit vacuum demand was developed based on the measured pre-retrofit vacuum demand and a 60% diversity factor. Basecase (pre-retrofit) electrical power demand was estimated based on the measured kW/cfm of the pre-retrofit machines at the various operating modes.

For the ex ante basecase, the hours of compressor operation at the loaded and unloaded demand modes were extrapolated from monitoring data. Annual kWh was obtained by multiplying kW at the unloaded mode times hours of unloaded operation, and adding that to the product of kW at the loaded mode time the hours of loaded operation. From this analysis, it was determined that pre-retrofit demand was 124.0 kW for compressed air. The ex ante basecase hours of operation were 8,760 hours per year.

For the ex ante postcase, it was assumed that the vacuum pumps would operate 8,760 hours per year at 17.21 kW.

Annual energy savings is the difference between the pre-and post-retrofit kWh, or:

$$\begin{aligned}\text{Ex Ante Annual Energy Savings} &= 124.0\ \text{kW} \times 8{,}760\ \text{hrs/yr} - 17.21\ \text{kW} \times 8{,}760\ \text{hrs/yr} \\ &= 1{,}086{,}240\ \text{kWh} - 150{,}760\ \text{kWh} \\ &= 935{,}480\ \text{kWh}\end{aligned}$$

The average demand reduction is the average kW of the pre-retrofit compressors minus the average kW of the vacuum pumps:

$$\begin{aligned}\text{Ex Ante Average Demand Reduction} &= 124\ \text{kW} - 17.21\ \text{kW} \\ &= 106.79\ \text{kW}\end{aligned}$$

Ex Ante Data Sources

- Equipment manufacturer's data sheets.
- Spot measurements of equipment performance.
- Customer interviews.

4.19.6 Ex Post Load Impact Estimates

Ex post monitoring data was analyzed to determine ex post power consumption patterns of the vacuum pump system supplying the 40 injection molding machines using the ex post operating schedule. Calculated values were extrapolated to the annual level assuming constant plant production levels and the ex post operating schedule. Based on ex post vacuum pump power consumption, actual vacuum demand was calculated, and ex ante demands for the 32 ex ante injection molding machines were derived.

The customer's compressed air system was concurrently upgraded and rebated by the utility. An evaluation of the load impacts of the compressed air system was completed and reported separately as Project No. 46697. Concurrent monitoring of both systems was performed and did establish a significant decrease in the total combined horsepower required to operate the compressed air system and the vacuum system.

Ex Post Basecase Definition

The ex post basecase (pre-retrofit) is the four 125-hp Sullair compressors running simultaneously to suppy air for vacuum generation for 32 injection molding machines. The Sullair compressors load and unload as necessary to satisfy demand,. Each compressor in the system had its own control system that ran its machine to maintain the pressure in the distribution system. If equipment at the "end-of-the-line" was starved for air, the set points of each compressor were raised until the demand could be satisfied. Nominal distribution system pressure was 125 psig.

Ex Post Postcase Definition

For the ex post postcase (post-retrofit), the compressed air system was disconnected from the vacuum system and the vacuum ejectors were removed. One 20-hp vacuum pump runs at all times to generate the vacuum necessary to satisfy the vacuum needs of 32 injection molding machines. The second vacuum pump is connected as a maintenance standby unit.

Monitoring data establishes that observed postcase vacuum pump demand averages 15.33 kW.

Ex Post Operating Schedule

Manufacturing and assembly operations occur 24 hours per day, seven days per week, except during 14 holiday periods when the plant is shut down. The plant runs at capacity, utilizing four assembly lines and production levels are consistently high throughout the year. Slow downs only occur when injection molding equipment is taken down for repair.

The current shift schedule is two twelve-hour shifts per day, seven days per week for production workers, and one eight-hour shift per day, five days per week for office workers. Currently, the plant is operating forty injection molding machines and four floppy disk assembly lines.

The ex post hours of machine operation are therefore:

$$\text{Ex Post Hours of Operation} = (8{,}760 \text{ hrs / yr}) - (14 \text{ Holidays / yr} \times 24 \text{ hrs / Holiday})$$

$$= 8{,}424 \text{ hrs / yr}$$

Ex Post Production Level Changes

Installation of the energy efficiency measure did not affect the production level of the plant. However, the overall ex post vacuum consumption levels are higher than the ex ante levels due to the installation of additional injection molding equipment on the plant production line. The addition of eight injection molding machines increased vacuum demand by 25% over ex ante demands.

Data Collected Ex Post

The energy consumption of the running vacuum pump was measured using portable power monitoring equipment. Measurements were taken using a Pacific Science & Technology Energy Logger. This instrument measures true RMS kW. The following data were collected on-site:

- Runtime data for the vacuum pump, and the three running compressors;
- Measured voltage, amperage, power factor and kW for the vacuum pump and the 3 running compressors; and
- Motor and vacuum pump nameplate data.

Data was collected on one minute intervals over a three week period in November and December of 1998. Thirty minute averages for the vacuum pump and each operating compressor were recorded for actual voltage, amperes, power factor, and kW.

Ex ante test data of vacuum generation demand was performed in December, 1995. It is used as the basis for the compressor kW savings.

Ex Post Algorithms

Basecase specific power demand (kW/scfm) for compressed air is determined from data developed in the evaluation of Project 46697. Table 4-127 summarizes measured pre-retrofit data from the compressed air system consultant provided by SDG&E's IEEI Program for Project No. 46697.

Table 4-127
Ex Post Basecase Air and kW Demands
Project No. 48698

	kW	scfm	kW/scfm	Hours
High Demand	344	1,696	0.2028	6,000
Low Demand	225	1,079	0.2085	2,400
Avg. Specific Power Demand			0.2045	8,400

Where the average specific power demand to make compressed air was determined as follows:

$$\text{Avg. Specfic Power Demand} = \frac{\left(\left(344\text{ kW}/1{,}696\text{ scfm}\right)\times 6{,}000\text{ hrs}\right)+\left(\left(225\text{ kW}/1{,}079\text{ scfm}\right)\times 2{,}400\text{ hrs}\right)}{8{,}400\text{ hours}}$$

$$= 0.2045\text{ kW}/\text{scfm}$$

Based on ex post monitoring data, observed *average vacuum pump demand* is 15.33 kW and the measured power factor is 0.93.

Full Load kW Demand for the vacuum pump was calculated from the following:

$$\text{Full Load kW Demand}_{\text{post-retrofit}} = \frac{\left[(\text{Volts})\times(\text{Full Load Amps})\times(1.73)\times(\text{Power Factor})\right]}{1{,}000\ \text{watts / kW}}$$

$$= \frac{(480\ \text{volts})\times(27\ \text{amps})\times(1.73)\times(\text{Power Factor})}{1{,}000\ \text{watts / kW}}$$

$$= 20.88\ \text{kW}$$

Since measured *average vacuum pump demand* is 15.33 kW, observed vacuum demand is:

$$\text{Vacuum Demand}_{\text{observed}} = \frac{15.33\ \text{kW}}{20.88\ \text{kW}} \times 319\ \text{acfm}$$

$$= 234.2\ \text{acfm}$$

Based on ex ante test data, basecase compressed air demand required to generate 234.2 acfm of vacuum would have been:

$$\text{Air Demand}_{\text{basecase}} = \frac{234.2\ \text{acfm}}{289\ \text{acfm}} \times 580.8\ \text{scfm}$$

$$= 470.7\ \text{scfm}$$

Basecase compressor power consumption was 0.2045 kW/scfm, therefore, ex post basecase kW demand is:

$$\text{Ex Post kW}_{\text{basecase}} = 470.7\ \text{scfm} \times 0.2045\ \text{kW / scfm}$$

$$= 96.25\ \text{kW}$$

Ex post average demand was measured to be 15.33 kW. Since basecase vacuum demand was lower than observed vacuum demand by the ratio of $\left(\frac{32}{40}\right)$, ex post postcase demand is therefore:

$$\text{Ex Post Average kW}_{\text{postcase}} = 15.33\ \text{kW} \times \left(\frac{32}{40}\right)$$

$$= 12.26\ \text{kW}$$

Therefore, the average demand reduction is found by subtracting average postcase demand from average basecase demand.

$$\text{Ex Post Average } \Delta\text{kW} = \text{kW}_{\text{basecase}} - \text{kW}_{\text{postcase}}$$

$$= 96.25 \text{ kW} - 12.26 \text{ kW}$$

$$= 83.99 \text{ kW}$$

Ex post basecase energy consumption is the product of the basecase kW and the ex post hours of operation:

$$\text{Ex Post kWh}_{\text{basecase}} = 96.25 \text{ kW} \times 8{,}424 \text{ hours / year}$$

$$= 810{,}839 \text{ kWh}$$

Similarly, ex post postcase energy consumption is:

$$\text{Ex Post kWh}_{\text{postcase}} = 12.26 \text{ kW} \times 8{,}424 \text{ hours / year}$$

$$= 103{,}312 \text{ kWh}$$

Ex post annual energy savings is simply the difference between the basecase and postcase kWh consumption:

$$\text{Ex Post kWh Savings} = (810{,}839 \text{ kWh}) - (103{,}321 \text{ kWh})$$

$$= 707{,}527 \text{ kWh}$$

The results of ex post analysis are summarized in Table 4-128.

Table 4-128
Ex Post Load Impact Summary
Project No. 48698

	Ex Post Evaluation Basecase	Ex Post Evaluation Postcase	Ex Post Evaluation Impact
Annual Hours of Operation	8,424	8,424	
Average Demand, kW	96.25	12.26	83.99
Annual Energy Usage, kWh	810,839	103,312	707,527

Ex Post Load Impacts By Time-Of-Use Period

The operating characteristics of the vacuum system for this facility was fairly consistent, with little variability. Thus, the allocation of kWh savings to the time-of-use (TOU) periods was based on the operating hours in each TOU period, where:

$$\text{kWh Adjustment Factor for Each TOU Period} = \frac{\text{Annual Hours for the Period}}{\text{Total Annual Hours}}.$$

The results are shown in Table 4-129.

Table 4-129
Ex Post kW and kWh Impacts by Time-of-Use Period
Project No. 46698

Time-of-Use Period	Annual Hours	kWh Adjustment Factor	kWh Savings	Average kW Reduced	kW Reduced Coincident with System Peak Period
Summer On-peak	749	0.0889	62,908	83.99	83.99
Summer Semi-peak	963	0.1143	80,882	83.99	
Summer Off-peak	1,912	0.2270	160,588	83.99	
Winter On-peak	420	0.0499	35,276	83.99	83.99
Winter Semi-peak	1,820	0.2160	152,861	83.99	
Winter Off-peak	2,560	0.3039	215,013	83.99	
Total	**8,424**	**1.0000**	**707,527**		

4.19.7 Net-To-Gross Ratio

The net-to-gross ratio for this project is 1.0. SDG&E's IEEI Program had a high level of involvement, from hiring the compressed air consultant to providing implementation assistance, as well as providing the financial incentive.

Motivation

The motivation for the project was inspired by the cost reduction opportunity. The project was initiated by SDG&E, who apprised the customer of the potential for savings, provided the compressed air consultant who did the monitoring and performed the design engineering. According to the customer, this equipment would not have been installed without the assistance of SDG&E and the program rebate. Moreover, the project was only approved and built because the rebate was large enough to improve the project economics to meet the customer's internal payback criteria.

Non-Energy Costs and Benefits

No non-energy costs or benefits resulted from the installation of the equipment.

Equipment Alternatives

The pre-retrofit vacuum generators would have remained in service had this project not been installed. No other alternatives other than the ex post equipment were considered.

4.20 PROJECT ID 49180 - IPA COLUMN #3 WITH HEAT RECOVERY

4.20.1 Summary of Findings

The savings for this site were based on the installation of a shell and tube heat exchanger to recover heat from the overhead stream of distillation column to generate hot water for process uses. The recovered heat allowed reductions in production of 125 psig saturated steam. Ex post savings are higher than ex ante savings due to the lower efficiency of the ex post steam generation source.

Table 4-130
Summary of Ex Post Load Impacts
Project No. 49180

	kWh	kW	Therms
Ex Ante	n/a	n/a	695,647
Ex Post	n/a	n/a	757,049
Realization Rate	n/a	n/a	108.8%

4.20.2 Facility Description

This site manufactures food additives. Part of the process involves a solvent extraction process for purification of one product feed stream. The prepared feedstock is mixed with isopropyl alcohol (IPA) which preferentially dissolves one component from the feed stream. The saturated liquid IPA is then separated from the solid feed stock and enters distillation columns. The distillation process separates the IPA from the now purified food additive, and the purified IPA is used to treat additional feedstock. Hot water is used for feed dilution in another part of the plant. This water is heated through waste heat recovery exchangers and then steam is added as necessary from the 125 psig steam system to the hot water tank to raise the temperature to the desired level. Steam is produced in three cogeneration exhaust Heat Recovery Steam Generators (HRSG's) and three package boilers. In addition to generating hot water, steam is used in the plant for product drying, distillation heat, and sterilizing equipment.

4.20.3 Overview of Facility Schedule

This facility operates 24 hours per day, seven days per week, year round except for one 12-hour period when high voltage switch gear is serviced and cleaned. There is a 15 day maintenance shut down for each gas turbine each year. The plant runs at capacity, and production levels are consistently high throughout the year.

The current shift schedule is three eight-hour shifts per day, seven days per week for production workers, and one eight-hour shift per day, five days per week for office workers.

The distillation column is on stream 95% of the time. The ex post hours of operation are therefore:

$$\text{Ex Post Hours of Operation} = (0.95) \times (8{,}760 \text{ hrs/yr} - 12 \text{ hrs/yr})$$

$$= 8{,}311 \text{ hrs/yr}$$

4.20.4 Measure Description

One new *shell and tube heat exchanger* was installed to cool the overhead stream of IPA distillation column #3 with water. The heated water is used for diluting feedstock in another part of the plant. Cooling of the IPA column #3 overhead stream in the pre-retrofit configuration was accomplished exclusively in an *air-fan heat exchanger* cooled by three 40-hp fans. Installation of the measure reduces the duty on the *air-fan cooler* enough that on cool days, one or more of the fan motors shuts down. However, because this customer site generates all of its own power and purchases no electrical power from the utility, electrical impacts are not included in the program impacts.

Hot feedstock dilution water is generated in overhead shell and tube heat exchangers on two other distillation columns. The total volume of hot water required varies between 400 and 600 gallons per minute. Existing pre-retrofit process water heaters were not large enough, however, to make all of the hot water required. The remaining heat necessary to satisfy plant hot water demand is supplied by *make-up steam* into the hot water storage tank from the 125 psig saturated steam system. This steam is normally produced by the cogeneration turbine exhaust heat recovery steam generators (HRSG's), and package boilers provide replacement steam when one of the cogeneration units is off line. By generating additional hot water in the new shell and tube heat exchanger, *make-up steam* use is reduced.

The capacity of the HRSG's was concurrently upgraded in a separate project rebated under Project No. 14201. There are no interactive effects from Project No.14201 on Project No. 49180.

Pre-Retrofit Conditions

- Hot IPA distillation column #3 overhead stream cooled by an air-fan heat exchanger only.
- Hot overhead streams from IPA distillation columns #1 and #2 used to drive absorbtion chillers with the remaining heat recovered in shell and tube heat exchangers or rejected by air-fan heat exchangers.
- Some plant process dilution water heated in IPA distillation column #1 and #2 overhead condenser heat recovery heat exchangers.

- 125 psig saturated steam added to a hot water storage tank to make-up hot water shortfall coming from the IPA distillation column #1 and #2 overhead condenser heat recovery heat exchangers.
- Three 8-MW gas turbine/generator sets with HRSG's equipped with 2-inch duct burners producing all of the plant power demands and 160,000 lb/hr of saturated 125 psig steam.
- Four package boilers in standby service capable of producing 140,000 lb/hr saturated 125 psig steam when a cogeneration unit is off line.
- Production facility operates 24 hours per day, seven days per week, except during 12 hour maintenance period for high voltage switch gear servicing periods when the plant is shut down.
- Annual HRSG maintenance shutdown duration of 15 days per unit.
- Annual maintenance shutdown of 36 days each for IPA column #1and #2 overhead shell and tube condensers.
- Production workers work three eight-hour shifts per day, seven days per week, while office workers work one eight-hour shift per day, five days per week.
- The plant runs at capacity, and production levels are consistently high throughout the year.

Post-Retrofit Conditions

- IPA distillation column #3 overhead cooled by a new shell and tube heat exchanger with the balance of unrecovered heat rejected by the pre-retrofit air-fan heat exchanger.
- All process dilution water heated in heat recovery heat exchangers when all three IPA columns operate. Make-up 125 psig saturated steam added to a hot water storage tank when one or more IPA columns are off line.
- Three 8-MW gas turbine/generator sets with HRSG's equipped with 3-inch duct burners producing all of the plant power demands and 160,000 lb/hr of saturated 125 psig steam.
- Four package boilers in standby capable of producing 140,000 lb/hr saturated 125 psig steam when a cogeneration unit is off line.
- Production facility operates 24 hours per day, seven days per week, except during 12 hour maintenance period for high voltage switch gear servicing periods when the plant is shut down.
- Annual HRSG maintenance shutdown duration of 15 days per unit.
- Annual maintenance shutdown of 36 days each for IPA column #1and #2 overhead shell and tube condensers.
- Annual maintenance shutdown duration of 18 days for IPA distillation column #3.
- Production workers work three eight-hour shifts per day, seven days per week, while office workers work one eight-hour shift per day, five days per week.

- The plant runs at capacity, and production levels are consistently high throughout the year.

4.20.5 Ex Ante Load Impact Estimates

The ex ante impact estimates were based on a site-specific study of the facility's steam system conducted by a process industry consultant provided by SDG&E's IEEI Program. The plant "pinch" study comprised a detailed audit, including an inventory of steam production system equipment, current operating procedures, measurements of existing system operating performance, evaluation of the plant requirements and performance (steam balance), and recommendations that would reduce steam system operating costs, including energy savings. Spot measurements were made to verify the current operating parameters of the system. The results of this monitoring revealed the opportunity to improve the system efficiency by generating hot process water from waste heat recovery and reducing use of make-up steam for hot water heating.

The total ex ante load impact was 695,647 therms saved per year based on 8,760 hours per year of operation and a 90% *annual capacity factor*.

Electrical impacts from the shut down of air cooler fans were not included in the program impacts because there is relatively little electricity is purchased from the utility grid. The cogeneration units provide the majority of the power onsite.

Ex Ante Basecase

For the ex ante basecase (pre-retrofit), 150 gpm of 165°F hot process water is produced by adding make-up steam to the hot water tank from the 125 psig saturated steam system. This steam is normally produced in the plant cogeneration turbine exhaust HRSG, which has an operating efficiency of 85%. When a cogeneration unit is off line, package boilers provide replacement steam. Overhead cooling for the IPA distillation column is accomplished with an air-fan cooled heat exchanger.

Three 8-MW gas turbine HRSG's run simultaneously, producing 160,000 lb/hr of 125 psig saturated steam from the hot turbine exhaust supplemented by the heat from firing six 2-inch diameter duct burners. Additional steam is produced by three package boilers as necessary to satisfy plant steam needs when a cogeneration unit is off line.

Ex Ante Postcase Definition

For the ex ante postcase (post-retrofit), 150 gpm of 165°F hot process water is produced by recovering heat from the IPA distillation column #3 overhead stream to the process water system. Make-up steam is added to the hot water tank from the 125 psig saturated steam system when the exchanger is off line. The make-up steam is produced in the plant cogeneration turbine exhaust HRSG, which has an operating efficiency of 85%. Overhead cooling for the IPA distillation column is accomplished with the new *shell and tube heat recovery exchanger* and the pre-retrofit *air-fan cooled heat exchanger*.

Three 8-MW gas turbine HRSG's run simultaneously, producing 160,000 lb/hr of 125 psig saturated steam from the hot turbine exhaust supplemented by the heat from firing six 3-inch diameter duct burners. Additional steam is produced by three package boilers as necessary to satisfy plant steam needs.

Ex Ante Operating Schedule

This facility operates 24 hours per day, seven days per week, year round. There is a 15 day maintenance shut down for each gas turbine each year. The plant runs at capacity, and production levels are consistently high throughout the year.

The IPA distillation column is on line 90% of the time. It is shut down periodically for cleaning and planned maintenance. The hot dilution water facility runs continuously and never shuts down in a normal year.

The current shift schedule is three eight-hour shifts per day, seven days per week for production workers, and one eight-hour shift per day, five days per week for office workers.

The ex ante hours of operation are therefore:

$$\text{Ex Ante Hours of Operation} = 8{,}760 \text{ hours / year} \times 0.9$$

$$= 7{,}884 \text{ hours / year}$$

Key Ex Ante Assumptions

- Post-retrofit process hot water demand is the same as pre-retrofit demand.
- Reduced steam production comes from reduced firing of HRSG's.
- Pre- and post-retrofit production schedules would be the same.
- Did not include electric load impacts of fan motor shutdowns on air-fan cooler because customer self generates virtually all of its power and buys little utility power.

Ex Ante Algorithms

The following operating parameters for hot water production shown in Table 4-131 were obtained from pre-retrofit monitoring.

Table 4-131
Ex -Ante Operating Data
Project No. 49180

Average Flow Rate,	150 gpm
Conversion Factor	500 lb/hr/gpm
Make-up Water Temp.	65 °F
Water Outlet Temp	165 °F
Heat Capacity	1.0 Btu/lb-°F

The average hourly heat recovery wasis calculated as follows:

$$\text{Ex Ante Average Heat Recovery} = (150\text{ gpm}) \times (500\text{ lb / gpm}) \times (165°\text{F} - 65°\text{F}) \times (1.0\text{ Btu / lb}\cdot°\text{F})$$

$$= 7.5\text{ MMBtu / hr}$$

$$= 75\text{ therms / hr}$$

The efficiency of the HRSG was assumed to be 0.85. The annual hours of operation are the annual capacity factor times the number of hours in an average year. The annual energy saved is the average hourly heat recovery times the annual hours of operation divided by the efficiency of the HRSG.

$$\text{Ex Ante Annual Energy Saved} = \frac{(75\text{ therms / hr}) \times (0.9 \times 8{,}760\text{ hrs / yr})}{0.85}$$

$$= 695{,}647\text{ therms / yr}$$

Ex Ante Data Sources

- Customer DCS system and customer meters.
- Customer supplied operating and maintenance schedule.

4.20.6 Ex Post Load Impact Estimates

Monitoring data was used to determine the customer's production rate of hot water from the new *shell and tube heat recovery exchanger*. The make-up steam rate to the hot water tank was tracked and found to be zero in the post-retrofit operation, while total hot water use was found to be the same as the ex ante consumption. The efficiency of the HRSG duct burners was used in the calculation of annual energy savings. This was determined to be 87.5% at full load and 82.5% at ¼ loading in the analysis completed for Project No. 14201. Since the steam savings from the postcase equipment causes the duct burners to fire at less than 100% capacity, an average operating efficiency of 85% was used to determine the gas savings using a methodology similar to the ex ante calculation. Likewise, the full load efficiency of Boiler 6, which provides makeup steam when one of the cogeneration units is down was found to be 66.9% in the analysis completed for Project No. 14201. Since there are three 15 day periods when one cogeneration unit is down, the efficiency of the steam generation system producing the make-up steam to the hot water tank is:

$$\text{Steam System Efficiency} = \left(\frac{320 \text{ Running Days}}{365 \text{ Days / yr}} \times 0.85\right) + \left(\frac{45 \text{ Running Days}}{365 \text{ Days / yr}} \times 0.669\right)$$

$$= 82.8\%$$

Ex Post Basecase Definition

For the ex post basecase (pre-retrofit), 160°F hot process water was produced by adding make-up steam to the hot water tank from the 125 psig saturated steam system to supplement the output of the heat recovery exchangers on overhead streams of IPA distillation columns #1 and #2. This steam was produced by the HRSG duct burners, that have an average operating efficiency of 85%, and, when one of the cogeneration units is down for maintenance, by Boiler 6, which has a measured efficiency of 66.9%,. The combined efficiency of the make-up steam system was found to be 82.5%. Overhead cooling for the IPA distillation column is accomplished with an *air-fan cooled heat exchanger*.

Three 8-MW gas turbine HRSG's run simultaneously, producing 160,000 lb/hr of 125 psig saturated steam from the hot turbine exhaust supplemented by the heat from firing six 2-inch diameter duct burners. Additional steam is produced in four package boilers, as necessary, to satisfy plant steam needs when a cogeneration unit is off line.

Ex Post Postcase Definition

For the ex ante postcase (post-retrofit), all of the plant 160°F hot process water is produced by recovering heat from the three IPA distillation column overhead streams into the process water system. Make-up steam is added to the hot water tank from the 125 psig saturated steam system when any distillation column is off line. This steam was produced by the HRSG duct burners, which have an average operating efficiency of 85%, and, when one of the cogeneration units is down for maintenance, by Boiler 6, which has a measured efficiency of 66.9%. The combined efficiency of the make-up steam system was found to be 82.8%. Overhead cooling for IPA distillation column #3 is accomplished with the new *shell and tube heat recovery exchanger* and the pre-retrofit air-fan cooled heat exchanger.

Three 8-MW gas turbine HRSG's run simultaneously, producing 160,000 lb/hr of 125 psig saturated steam from the hot turbine exhaust supplemented by the heat from firing six 3-inch diameter duct burners. Additional steam is produced in three package boilers as necessary to satisfy plant steam needs.

Ex Post Operating Schedule

This facility operates 24 hours per day seven, days per week, year round except for one 12-hour period when high voltage switch gear is serviced and cleaned. There is a 15 day maintenance shut down for each gas turbine each year. The plant runs at capacity, and production levels are consistently high throughout the year.

The new IPA overhead exchanger is on line 95% of the time. It is shut down periodically for cleaning and planned maintenance. The hot dilution water facility runs continuously and never shuts down in a normal year.

The current shift schedule is three eight-hour shifts per day, seven days per week for production workers, and one eight-hour shift per day, five days per week for office workers.

The ex post hours of operation of the post-retrofit equipment are therefore:

$$\text{Ex Post Hours of Operation} = (0.95) \times (8{,}760 \text{ hrs/yr} - 12 \text{ hrs/yr})$$

$$= 8{,}311 \text{ hrs/yr}$$

Ex Post Production Level Changes

Installation of the energy efficiency measures did not affect the production level of the plant. Plant steam demand is lower in the ex post operation due to other conservation initiatives. This lower level of demand is still high enough to require firing of all of the HRSG duct burners and one or more of the package boilers.

Data Collected Ex Post

Operating data was collected from the customer's DCS system over a two week period during which the post-retrofit exchanger was on line and off line. The make-up steam rate to the hot water tank was tracked and found to be zero when the post-retrofit exchanger was on line and to average 7,500 lb/hr when it was off line. The customer's post-retrofit usage rate of hot water from the hot water tank was the same as the pre-retrofit rates.

Ex Post Algorithms

The pre-retrofit make-up steam rate to the hot water tank was compared to post-retrofit rates and an average reduction of 7,500 lb/hr was observed. The change in enthalpy per pound of the heated fluid, ΔEnthalpy/lb, is the difference between the enthalpy of the boiler feed water and the enthalpy steam produced. From the evaluation for Project No. 14201, ΔEnthalpy/lb for Boiler #6 water to steam was 1,005.3 Btu/lb. Based on a make-up steam efficiency rate of 82.5%, the reduction in gas use is found from the general equation:

$$\text{Ex Post Annual Gas Savings} = \left(\frac{\text{lb of Steam / hr} \times \Delta\text{Enthalpy / lb}}{\text{Make up Steam System Efficiency}}\right) \times (\text{Annual Operating Hours / yr})$$

$$= \frac{(7{,}500 \text{ lb / hr}) \times (1{,}005.3 \text{ Btu / lb})}{(0.828) \times (100{,}000 \text{ Btu / therm})} \times 8{,}311 \text{ hrs / yr}$$

$$= 757{,}049 \text{ therms / yr}$$

Annualization of Results

The average basecase and postcase therm savings were extended to the 8,760-hour annual period using the schedule discussed above in the ex post Operating Schedule section. According to customer staff, this facility operates a nearly identical schedule year-round.

4.20.7 Summary of Gross Impacts

The gross annual savings is 757,049 therms/year in natural gas use. This is higher than ex ante estimates because the average efficiency of the makeup steam system is 82.8% versus the ex ante estimate of 85%, and the ex post hours of operation are 8,311 versus ex ante estimates of 7,884 hours/year.

4.20.8 Net-To-Gross Ratio

The net-to-gross ratio for this project was estimated to be 1.0. The SDG&E IEEI Program was the reason the measure were installed. SDG&E arranged to have a program-sponsored process engineering consultant prepare a study of the IPA system. The heat recovery system implemented under this project was among the recommendations presented in the study.

SDG&E staff (consultants) had a high level of involvement in originating the project concept and providing the technical and engineering analysis necessary to gain approval to implement the project.

Motivation

Motivation for the project was inspired by the cost reduction opportunity. The project was initiated by SDG&E, who apprised the customer of the potential for savings. SDG&E provided the process consultant who did the monitoring and performed the engineering analysis. The customer performed all design, procurement and installation activities. According to the customer, this equipment would not have been installed without the assistance of SDG&E.

Non-Energy Costs and Benefits

No non-energy costs or benefits resulted from the installation of the equipment.

Equipment Alternatives

No other alternatives other than the ex post equipment were considered

4.21 PROJECT ID 49944 - INSTALL VARIABLE FREQUENCY DRIVE TO CONTROL THE SPEED OF 60-HP PROCESS OVEN EXHAUST FAN MOTOR

4.21.1 Summary of Findings

A catalytic thermal oxidizer system was installed to remove volatile organic compounds from the exhaust of a commercial bakery. A centrifugal fan was installed to convey the baking oven exhaust to the CTO unit and out through the stack. The variable frequency drive was installed to control the fan volumetric flow rate by means of adjusting the fan speed in response to a control signal. The VFD was installed rather than a basecase control technology which controlled exhaust air flow by mechanically-inducing a pressure drop in the exhaust air stream near the fan by restricting the exhaust air passage.

The ex post results are summarized in Table 4-132.

Table 4-132
Summary of Ex Post Load Impacts
Project No. 49944

	kWh	kW	Therms
Ex Ante	161,302	22.0	n/a
Ex Post	139,836	15.9	n/a
Realization Rate	86.7%	72.2%	n/a

The ex post gross kWh savings is 139,836 kWh per year, 86.7 % of the ex ante estimate, 161,302 kWh. The ex post gross kW impact was 15.9 kW, 72.2% of the ex ante estimate, 22 kW.

The discrepancy is primarily a result of differences in the base case equipment selected for the ex ante and ex post impact analysis. The ex ante estimates assumed that discharge damper flow controls would have been installed. The ex post analysis rejected the ex ante assumption and based the impact calculation on inlet vortex damper control. The discharge damper control device and strategy requires greater fan power for a given exhaust flow rate.

The difference in ex post average kW savings was offset slightly by a small increase in operating hours (6,487) found in the ex post study versus the estimated operating hours (6,285) in the ex ante kWh calculation.

4.21.2 Facility Description

This facility is a commercial bakery. Dough is prepared, allowed to rise and sized. The dough blanks are the baked on continuous ovens. During the fermentation and baking process, the dough emits volatile organic compounds (VOC's), primarily ethanol. The San Diego Air Pollution Control District (APCD) required the facility to reduce the emission of these volatile organic compounds. The equipment installed under this project was installed in response to the APCD requirement. The VFD was one of several options for fan air flow and pressure control in the CTO unit.

4.21.3 Overview of Facility Schedule

- The facility operates continuously with the exception of a (approximately) 24 hour shutdown during Tuesdays and Wednesdays and a second shutdown on Saturdays and Sundays. The weekend shutdown is sometimes skipped if production requirements are high.
- The total annual operating hours for first year operation were projected ex ante to be 6,264 and found to be 6,487 hours per year, ex post.

4.21.4 Measure Description

The equipment installed under this measure consists of a catalytic thermal oxidizer (CTO) system. The CTO system is the subject of a separate 1997 IEEI project with a separate savings claim for natural gas impacts, Project No. 48467.

The installed CTO equipment included

1. A 60-hp fan with a variable frequency drive (VFD) capacity control (and associated ductwork and controls) that conveys exhaust gases to the CTO from the ovens and dough production equipment.
2. The catalytic thermal oxidizer consisting of a gas burner/combustion chamber followed by a chamber with a series of beds in which the catalytic material is placed, and
3. A crossflow air-to-air heat exchanger which transfers heat from the gases in the CTO exhaust to the entering oven exhaust gases (and serves to reduce the amount of supplemental heat which must be added by natural gas), and
4. Associated gas piping and combustion controls, and a complete control system connecting ductwork and exhaust stack. The CTO process breaks down volatile organic compounds contained in the oven and fermenter exhaust gases to water vapor, carbon dioxide and other harmless gases which are then released to the atmosphere.

Pre-Retrofit Conditions

- This project was installed as a new system that was required by environmental regulations. Prior to the installation of this system, the exhaust gases were conveyed directly to the atmosphere through the stack. The fan was installed to convey oven exhaust to the CTO emission control equipment
- The *basecase* equipment for the purposes of the *ex ante* impact estimate consisted of the 60-hp centrifugal fan with an outlet discharge throttling damper that would control air flow by causing a restriction downstream of the fan discharge. Airflow controlled by this

means essentially trades the energy of moving air with pressure drop. The fan power at a given air flow rate follows the fan's performance curve.

- The *basecase* equipment for the purposes of the *ex post* impact estimate consisted of the 60-hp centrifugal fan with inlet vane throttling that controls air flow by closing the fan inlet with radial vanes which provide rotation to the entering air. This flow control technique also trades some of the air flow energy by pressure drop, but the energy penalty is less than the outlet discharge throttling damper. The inlet vane volume control strategy has a lower power requirement for a given air flow that the discharge damper control strategy.

Post-Retrofit Conditions

- The postcase equipment consists of the fan installed by the equipment with variable frequency drive control. This technology controls the volume flow rate of the fan by changing the speed of the fan rather than inducing a pressure drop. It, therefore, results in lower power for a given flow rate than either of the means which induce a pressure drop.
- The fan speed is controlled to maintain a constant static pressure through the CTO unit.

4.21.5 Ex Ante Load Impact Estimates

The ex ante impact estimate was performed by the equipment vendor using the Allen-Bradley (A-B) savings estimating software. The algorithms used in the software were not described in the model results. The ex ante analysis is summarized in Table 4-133.

Table 4-133
Ex Ante Load Impact Analysis
Annual Energy Use Impact: VFD versus Outlet Damper
Project No. 49944

System (Full Flow Design) Pressure (inches)	21	inches wg	design data
Maximum Flow	11,500	cfm	design data
Static head (inches)	20	inches wg	design data
Fan Efficiency (%)	70	%	design data
motor Efficiency (%)	91	%	design data
Drive Efficiency (%)	96	%	design data
Annual Operating Hours	6,264	hours	oper. data
Calculated bhp	53	bhp	design data
Nominal Motor hp	60	hp	design data
Operating Profile(Load Segment)	1	2	
Percent Full Flow	68	34	vendor est.
Operating Hours	4,134	2,129	vendor est.
Cfm	7,820	3,910	design data
Annual Energy Impact:			
Basecase Annual Energy Use	226,379	kWh/yr	A-B Calculation
Postcase Annual Energy Use	65,077	kWh/yr	A-B Calculation
Annual Energy Savings	161,302	kWh/yr	A-B Calculation
Demand Impact (Calculated assuming all 6,264 operating hours at 68% airflow)			
Annual Operating kWh (discharge damper)	226,379	kWh	A-B Calculation
Annual Operating Hours	6,264	hours	Oper. Data
Average operating kW	36.1	= kW1	SDGE Calc.
Annual operating kWh (discharge damper-for 68% flow)	88,305	kWh	A-B Calculation
Annual Operating Hours	6,264	hours	Oper. Data
Average operating kW (VFD-for 68% flow)	14.1	=kW2	SDGE Calc.
Average operating Demand Impact	22.0	kW1-kW2	SDGE Calc.

Ex Ante Basecase

The ex ante basecase consisted of the pre-retrofit oven exhaust/CTO fan powered by a 60-hp motor at constant speed and operating 4,134 hours/year at 7,820 cfm and 2,129 hours/year at 3,910 cfm with flow controlled by outlet damper throttling with a static pressure of 20 inches. Other key fan and motor performance parameters are shown in Table 4-133.

Ex Ante Basecase

The ex ante postcase consisted of the pre-retrofit oven exhaust/CTO fan powered by a 60-hp motor at constant speed and operating 4,134 hours/year at 7,820 cfm and 2,129 hours/year at 3,910 cfm with the fan output airflow controlled by varying the motor speed via an adjustable frequency drive to maintain a pressure drop of about 6 inches. Other key fan and motor performance parameters are shown in Table 4-133.

Ex Ante Operating Schedule

This facility operates 24 hour per day, five days per week for a total of 6,264 hours per year.

Ex Ante Key Assumptions

- Basecase discharge damper technology.
- Allen Bradley fan power multiplier for VFD and outlet damper flow control equipment.
- Annual fan operating time: 24 hours per day 261 days per year : 6264 hours/year.
- Fan airflow profile: 2/3 of operating hours at 68% full flow; 1/3 of operating hours at 34% full flow.
- Outlet damper throttling from full flow to operating flow (no fan speed control via constant speed reduction such as sheave sizing).

Ex Ante Data Sources

- CTO system engineering design data.
- Manufacturer's (Allen Bradley) software.
- Customer operating schedule, emissions test data.

4.21.6 Ex Post Load Impact Estimates

The ex post load impact estimation methodology consisted of an engineering analysis that compared the fan power and annual energy use the between the basecase and postcase flow control equipment. The method consisted of the following steps:

- Monitor the power of the post retrofit (as-built) CTO system for 2 weeks.
- Review the ex ante basecase control technology and select the appropriate basecase technology for the ex post analysis. Inlet vane control was selected as the appropriate basecase control technology because the existing equipment accommodated the inlet vane capacity control equipment.
- The percentage of full load power (fan motor load factor) for the inlet vane capacity control that corresponded to the measured percent of full load kW with the VFD was extracted from the California Compliance Supplement: 1994. The operating power of the basecase fan with inlet vane control was calculated by multiplying the load factor by the motor full load power.
- The difference between the calculated basecase fan power and the measured postcase fan motor input power is the ex post kW impact.
- The system annual operating hours were verified by reviewing the customer's weekly system operating temperature graphs.

- The annual kWh impact was calculated by multiplying the kW difference by the annual operating hours.

The drive/ fan motor input power was monitored for two weeks at one minute intervals and recorded at 30 minute intervals for a two week period to determine the fan load profile.

Ex Post Basecase

The ex post basecase equipment consisted of the fan as described in the ex ante basecase. However, the ex post review rejected the ex ante assumption of discharge damper control as the basecase control technology. It appeared that the fan was designed to accommodate inlet dampers as flow control device. Inlet vane control was selected as the appropriate basecase for the ex post analysis.

Ex Post Operating Schedule

The operating schedule used in the ex post analysis was based on the operating records for 1998. These records indicated 6,487 annual operating hours. The facility typically is shut down all day Tuesday and most of the day Saturday, year-round.

Ex Post Production Level Changes

No production changes were caused by, or occurred as a result, of this measure. The ex post analysis is based on the post-retrofit operating hours and load profile, without adjustment for production.

Data Collected Ex Post

- Input power to the 60-hp fan drive was monitored at one minute intervals and recorded at 30 minute intervals for two weeks.
- Fan weekly operating logs were obtained from the customer.
- The fan motor was observed in operation and motor nameplate data obtained.
- Fan system design data were obtained from customer project records.

Ex Post Load Impacts

Table 4-134 shows the ex post kW data summary and annual operating hour calculation.

Table 4-134
Summary of Ex Post kW and Operating Hour Data
Project No. 49944

Total Hours Count	243
Sum of kWh	1,176.0
Overall Average kW	4.84
Full Operating hr.	175
Average Operating kW	6.72
Partial Operating Hours	68.0
Sum of Part Hours kW	33.2
Equiv. FL Hours (Part)	4.9
Total Equiv. FL Hours	179.9
Annual Equiv. FL Hours:	6,486.9

Table 4-135 shows the calculation of the annual kWh Impacts.

Table 4-135
Calculation of Ex Post Gross Annual kWh Impacts
Project No. 49944

Row	Description	
A	Measured Average Operating Input kW with VSD (Ex. P. Monitoring Data)	6.72 kW
B	Annual Equivalent Full Load Operating Hours (Ex. P. monitoring Data)	6,486.9 hours
C	**Postcase Annual kWh** (Row Ax Row B)	43,593 kWh
D	Fan Full Load kW (480 V*73.1 FLAmps*0.85 (Power Factor)*1.732)/1000	51.7 kW
E	ASD Percent of Full Operating Motor Load (Row A/Row D)	13.0%
F	Corresponding Basecase Operating % Full Load kW (Inlet Vane Damper) for same average airflow: (From Comparison Table "California Compliance Supplement, 1994")	51.1%
G	Basecase Operating kW (Inlet Vane Damper) for same average airflow: (Row D x Row F)	26.4 kW
H	**Basecase Annual kWh** (Row B x Row G)	171,233 kWh/year
I	Ex Post kWh Savings (Row H- Row C)	127,640 kWh/year

Ex Post TOU Period kWh Impacts

Gross kWh impacts for costing period *c* were determined by calculating a factor which represents the proportion of annual savings which occurs during each time-of-use period from the ex post monitoring results. The following steps were used:

1. The average post-retrofit kW (of the three 20-hp compressors) for each operating hour of each “Daytype” (Daytype 1 = Weekdays, Daytype 2 = Weekend/Holidays) was calculated from the monitoring data.
2. The total annual kWh for each hour of each daytype were calculated by multiplying the average hourly kW by the number of equivalent full production operating days occurred curing the first post-installation year. The monitoring data indicated 218 equivalent full production weekdays and 52 weekend operating days.

3. The kWh for the hours in each seasonal TOU period were summed
4. The sum for the hours which occur during each summer time-of-use period was multiplied by 5/12 to reflect TOU consumption during the five summer season months. The total kWh which occur during each winter TOU period were multiplied by 7/12 to calculate the total which applies to each TOU period during the winter season.
5. The kWh in each TOU period for the year were summed and the kWh for each TOU period divided by the total to calculate a "TOU Period weighting factor"
6. The total annual kWh impact was multiplied by the TOU Period weighting factor" to calculate the kWh impact in each TOU period.

The process for estimating the TOU factors and ex post load impacts by TOU period is shown in the following equations:

$$\left(\text{Total kWh usage for each hour}_{\text{daytype}}\right) = \left(\text{Average post-retrofit kW for each hour}_{\text{daytype}}\right) \times \left(\text{No. Days}_{\text{daytype}}\right),$$

where:

$$\text{No. Days}_{\text{daytype}} = 218 \text{ days for weekdays}$$
$$= 52 \text{ days for weekends}$$

$$\left(\text{Sum of kWh usage for each TOU period}\right) = \sum \left(\begin{array}{c}\text{Total kWH usage for each hour}_{\text{daytype}} \text{ in} \\ \text{each summer and winter TOU period}\end{array}\right)$$

$$\left(\text{Adjusted kWh usage for each TOU period}\right) = \left(\text{Sum of kWh usage for each TOU period}\right) \times \left(\text{Seasonal Adjustment Multiplier}\right)$$

where:

$$\text{Seasonal Adjustment Multiplier} = \left(\frac{5}{12}\right) \text{ for summer; and}$$

$$= \left(\frac{7}{12}\right) \text{ for winter.}$$

$$\left(\text{Total Annual kWh Usage}\right) = \sum_{p} \text{Adjusted kWh usage for each TOU period},$$

where:

p = the six TOU periods.

$$\left(\text{TOU Adjustment Factor for Each TOU period}\right) = \frac{\text{Adjusted kWh Usage for Each TOU period}}{\text{Total Annual kWh Usage}}$$

$$(\text{Ex Post kWh Savings by TOU period}) = (\text{Ex Post Gross kWh savings}) \times (\text{TOU Adjustment Factor for Each TOU Period}).$$

The results are summarized in Table 4-136.

Ex Post Average Gross kW Impacts

Average gross kW impacts were calculated for each costing period by dividing the total kWh impacts for the costing period by the total number of hours in the TOU period:

$$\text{Average Ex Post kW Reduced}_c = \frac{\text{Ex Post kWh Savings}_c}{\text{Hours}_c}$$

The results of this equation are shown in Table 4-136.

Table 4-136
Ex Post Load Impacts By TOU Period
Project No. 49944

Season	TOU Period	TOU Adjustment Factor	kWh Savings	Total Hours	Average kW
Column A	Column B	Column C	Column D	Column E	Column F
			(Col. C) x (139,836 kWh/year)		Column D ÷ Column E
Summer	**On-peak**	0.0851	11,902	749	15.9
	Semi-peak	0.1158	16,192	963	16.8
	Off-peak	0.2158	30,171	1,960	15.4
Winter	**On-peak**	0.0508	7,103	441	16.1
	Semi-peak	0.2305	32,228	1,911	16.9
	Off-peak	0.3021	42,240	2,736	15.4
Total		**1.0000**	**139,836**		

Ex Post Gross kW Impact Coincident with System Peak

The impact of this measure span the weekday daytime hours and is reasonably constant. The summer on-peak TOU period average kW impact is reported as the ex post peak coincident kW impact.

4.21.7 Summary of Ex Post Gross Impacts

The gross kWh and kW impacts are summarized and compared to the ex ante kWh and kW estimates in Table 4-137.

Table 4-137
Comparison of Ex Ante and Ex Post kWh and kW Impacts
Project No. 49944

	kWh	kW	Therms
Ex Ante	161,302	22.0	n/a
Ex Post	139,836	15.9	n/a
Realization Rate	86.7%	72.2%	n/a

The ex post gross impacts are 39,836 kWh per year, 86.7 % of the 161,302 kWh ex ante estimate. The ex post gross kW impacts were 15.9 kW, 72,2% of the ex ante 22 kW estimate.

The discrepancy is primarily a result of differences in the basecase equipment selected for the ex ante and ex post impact analysis. The ex ante estimates assumed that discharge damper flow controls would have been installed. The ex post analysis rejected the ex ante assumption and based the impact calculation on inlet vortex damper control. The discharge damper control device and strategy requires greater fan power for a given exhaust flow rate. The difference in ex post average kW savings was offset slightly by a small increase in operating hours (6,487) found in the ex post study versus the estimated annual operating hours (6,264) in the ex ante kWh calculation.

4.21.8 Net-To-Gross Ratio

The net-to-gross ratio for this project is 0.75. The customer did virtually all work associated with this project, however the customer worked closely with SDG&E staff to refine the project and to modify the project to improve the cost effectiveness of the project. Based on these findings SDG&E had a medium level of involvement in implementing the project. The financial incentives provided by the program had a major influence in obtaining management approval of the project. The site contact did not recall the paybacks associated with this project. Table 4-138 shows the paybacks for the project were between 0.5 to 2.0 years, thus, the net-to-gross ratio for a project with medium level of involvement and where the incentives had and influence on the customer's decision to implement the project is 0.75.

Table 4-138
Ex Post Net-To-Gross Ratio
Project No. 49944

Customer Cost	$8,168.83
Ex Ante Annual Savings	$9,170.00
Incentive	$1,000.00
Payback w/o Incentive	0.89
Payback with Incentive	0.78

4.22 Project No. 50009 - Retrofit Seven Plastic Injection Molding Machines With Variable Frequency Drives

4.22.1 Summary of Findings

Seven VFD's were installed on the seven injection machines. All were in full operation at the time of the ex post load impact evaluation. The ex ante results were estimated using an engineering methodology based on measured pre- and post retrofit kW for some machines and projected annual operating hours. The ex post estimates were based on post-retrofit measured kW for three machines and operating hours projected from short-term monitoring adjusted on the basis of customer interview.

Table 4-139 shows a comparison of the ex ante gross impact estimates with the ex post estimates.

Table 4-139
Gross Impact Results and Comparison with Ex Ante Estimate
Project No. 50009

	kWh	kW	Therms
Ex Ante	426,139	56.91	n/a
Ex Post	408,378	55.6	n/a
Realization Rate	95.8%	97.7%	n/a

The ex post gross annual kWh impact was 408,378 kWh. This is 95.8% of the ex ante estimate, 426,139 kWh. The primary reasons for the kWh discrepancy were small differences in the ex ante estimated kW impacts and operating hours and the ex post values kW and operating hours based on the post retrofit site monitoring and operating schedule. The average kW impacts were slightly greater than the ex ante estimates, however, the annual operating hours based on post retrofit measurements and adjusted for "downtime" were slightly lower than the operating hours used in the ex ante estimates.

The ex post gross kW impact was 55.6 kW, 97.7% of the ex ante estimate of 56.9 kW. The primary reason for the discrepancy is a difference in methodology and small differences between the ex post post-retrofit measured kW and the post-retrofit kW used in the ex ante saving projections.

4.22.2 Facility Description

The facility produces molded plastic components and assembles plastic products for the medical industry. Raw plastic beads are melted and pressed into molds in the injection molding (IM) machines. There are 16 IM machines at the facility, seven of the machines were the subject of this project.

4.22.3 Overview of Facility Schedule

- The facility operates 24 hours per day on weekdays and approximately half the weekends during the year as determined by production requirements.
- The IM machines affected by these measures are in active production a large proportion of the production hours. For the machines monitored, the fraction ranged from 86% to 96% of the total work hours, and averaged 90%.
- The ex ante impact estimates were based on 7,488 operating hours per year for the IM machines. This assumed 24 hours machine operation per day during all weekdays and half the weekend days in a year.
- The operating schedule for the ex post analysis was based on 24 hours per day operation all weekdays except seven holidays, and operation half the weekends each year. This totals 7,344 working hours per year (=(261-7) x 24 hr + (26 x 48 hr). Operating Logs inspected ex post indicated that machines were in operation an average 90% of the working hours.
- The non-scheduled production stoppage occurred at any time during the production hours. All non-production hours occurred during weekend off-peak hours.

4.22.4 Measure Description

Variable frequency drives (VFD's) were installed to control the speed of the hydraulic drive motors on seven plastic injection molding machines totaling 2,895 tons. Two machines are (JSW) 1,270 tons and are constant volume machines with 75-hp motors. The other five are Engels totaling 1,625 tons and are variable volume machines. Two of the Engels machines have 50-hp motors, and three machines have 60-hp motors.

Pre-Retrofit Conditions

The hydraulic drive power in seven injection molding (IM) machines (Engels Machine #'s 3,4,6,10,11 and JSW machines #14, and #15) was driven by constant speed motors without variable frequency control. The hydraulic fluid flow and pressure in the drive system was maintained by the position of solenoid valves which opened or closed to divert or restrict flow and induce a pressure drop in the hydraulic piping. The motor operated at constant speed and loaded and unloaded along the hydraulic pump curve as required to maintain the fluid pressure within the hydraulic system. The IM machines' rated capacity, motor horsepower and measured pre-retrofit average operating kW are shown in the ex ante impact estimate calculation in Table 4-140. The pump input power follows the pump curve, which in this case was nearly constant regardless of flow.

Post-Retrofit Conditions

- "Magnum" variable frequency drive and controls were installed on the injection molding machines described in the pre-retrofit description and Table 4-140. Hydraulic valves and pressure controls were modified such that the fluid flow and pressure drop occurred as a result of the motor speed rather than restrictions of diversions in the hydraulic piping. The motor speed, in turn, varies in response a pressure signal within the hydraulic system. Savings result because the motor power diminishes (approximately) as the cube of the reduction of fluid flow.

- The product, and production rate did not change from the pre-retrofit conditions.

4.22.5 Ex Ante Load Impact Estimates

The ex ante impacts were estimated using the VFD vendor's (Magnum) estimate of percent-savings for the Engels units based on tests of similar machines. The percent savings estimates used by the vendor was 30%. In the ex ante estimates, the analyst made adjustments for shorter operating hours: 7,488 hours per year were used in the final ex ante estimate versus 7,862 hours assumed by the vendor. The percent savings used for the five Engels machines in the ex ante analysis was 29.6% based on tests on identical machines versus the 30% "nominal" savings used by the vendor.

Test data from another source, Efficient Industrial Control Systems, was used to adjust the percent savings for the JSW machines from the vendor's estimate of 45% to the ex ante value used of 43.6%.

Ex Ante Basecase

The ex ante basecase equipment consists of the five Engels and two JSW injection molding machines operating under the pre-retrofit (valve) hydraulic pressure and flow control system as described under the "Pre-retrofit Conditions" Section above and in Table 4-140. The basecase operating kW for the Engels and JSW machines was taken from the vendor's savings analysis, and were based on measurements, according to the vendor. The ex ante analysis assumes identical pre- and post retrofit product mix and production rates for the machines for the operating hours described below.

Ex Ante Operating Schedule

- Hours of operation were 7,488 hours per year, based on the following schedule:

26 weeks, 24 hours/day, 7 days/week
26 weeks, 24 hours/day, 5 days/week

Ex Ante Data Sources

- VFD vendor's pre- and post retrofit measurements and savings analysis.
- Savings analysis conducted by Efficient Industrial Control Systems.
- Customer-reported annual operating hours.

Ex Ante Load Impact Estimates

The ex ante load impact estimates for this measure are shown in Table 4-140.

Table 4-140
Ex Ante Load Impact Estimates
Project No. 50009

Engels Inj. Molding Machines (5 machines)		Operating Hours	7,488	Based on the schedule: 26 weeks/year @ 24 hrs, 7 days/week and 26 weeks/year @ 24 hrs, 5 days/week.
	Pre-Retrofit Operating kW	Machine 6: Engels 225 Ton	10.5	Vendor's measurements: Average pre-retrofit kW of this unit under operating conditions at this site over approximately 1 hour operation.
		Machine 3: Engels 300 Ton	19.3	Vendor's measurements: Average pre-retrofit kW of this unit under operating conditions at this site over approximately 1 hour operation.
		Machine 4: Engels 300 Ton	32.6	Vendor's measurements: Average pre-retrofit kW of this unit under operating conditions at this site over approximately 1 hour operation.
		Machine 9: Engels 400 Ton	32.6	Vendor's measurements: Average pre-retrofit kW of this unit under operating conditions at this site over approximately 1 hour operation.
		Machine 10: Engels 400 Ton	32.6	Vendor's measurements: Average pre-retrofit kW of this unit under operating conditions at this site over approximately 1 hour operation.
		Total kW	127.6	Sum of kW for Five Engels Inj. Molding Machines
		Percent Savings (%) Due to VFD's	29.60%	Vendor's measurements: Average kW reduction over one hour for these units under operating conditions at this site.
		kW Reduced Five Engels Machines	**37.8**	(Total Pre-Retrofit Operating kW) x (Percent Savings)
		Annual kWh Savings Five Engels Machines	**282,819**	(kW Savings) x (Annual Operating Hours)
JSW Inj. Molding Machines (2 machines)				Vendor's analysis: based on measured savings for similar JSW unit under similar operating conditions
		Operating Hours	7,488	Based on the following schedule: 26 weeks/year @ 24 hrs, 7 days/week and 26 weeks/year @ 24 hrs, 5 days/week.
	Pre-Retrofit Operating kW	Machine 6: JSW 550 Ton	17.5	Vendor's measurements: Average pre-retrofit kW of this unit under operating conditions at this site over approximately 1 hour operation.
		Machine 7: JSW 720 Ton	26	Vendor's measurements: Average pre-retrofit kW of this unit under operating conditions at this site over approximately 1 hour operation.
		Total kW	43.5	
		Percent Savings (%) Due to VFD's	44%	Based on test performed by Efficient Industrial Control Systems of a similar 720 T unit.
		kWh Savings Two JSW Machines	**19.1**	(Total kW) x (Percent Savings)
		kW Savings Two JSW Machines	**143,320**	(kW Savings) x (Annual Operating Hours)
Total Energy Savings (kWh)			**426,139**	**kWh Savings (5 Engel) + kWh Savings (2 JSW)**
Total Demand Savings (kW)			**56.9**	**Total kWh Savings / 7,488 Operating Hours**

4.22.6 Ex Post Load Impact Estimates

The ex post methodology used a similar approach to the ex ante methodology, however, the post-retrofit operating hours and operating power were based on short term (one week) power monitoring, operating hour logs and customer-reported operating schedule for the first year operation of the system. Impact calculations were based on measurements made on three machines and extrapolated to the remaining four machines.

Ex Post Basecase

The ex post basecase consists of the seven injection molding machines operating without variable speed motor capacity controls as described in the ex ante basecase and pre-retrofit operating conditions section. The ex post basecase hours of operation were changed to match the hours of operation based on the post retrofit operating schedule determined during the ex post site survey.

Ex Post Operating Schedule

The operation schedule was 24 hours per day, five days per week, 254 weekdays per year and 24 hours per day for 52 weekend days per year. There was no daily variation in consumption patterns and machine downtime occurred at any time during the working hours.

Ex Post Production Level Changes

The equipment capacity and operating conditions and hourly production output did not change. No production related adjustments apply for this project.

Data Collected Ex Post

- Operating kW of three machines were monitored at one minute intervals for seven days.
- The drive vendor (Magnum) provided copies of all pre- and post retrofit short term monitoring data for each machine.
- Operating hours based on monitoring results were adjusted to account for annual production patterns and schedule reported by the customer.

Ex Post Load Impacts and Impacts by TOU Period

Annual Gross kWh Savings

The annual gross kWh impacts were calculated in the following steps:

1. The pre-retrofit (basecase) average operating kW for each of the seven machines was measured directly by the VFD vendor/installer for each machine. The values are shown in Column E of Table 4-142.

2. The post retrofit (postcase) operating kW for machines #3, #4 and #6 was calculated directly from the ex post monitoring data for those three machines for the hours the machines operated. The values are shown in Column F of Table 4-142.
3. The average *fraction kW reduced* for the three machines was calculated by dividing the total pre-retrofit average operating kW by the total post retrofit average operating kW.
4. The post-retrofit operating kW for the remaining four machines was calculated by multiplying the pre-retrofit operating kW by the quantity (=1 - *fraction kW reduced*) calculated in Step 3. (Column I of Table 4-142.)
5. The annual operating hours for the machines was calculated from the monitoring data combined with information provided by the customer regarding frequent weekend operation which was not observed during the monitoring period. A summary of the calculations and description of the operating kW and hours calculation is shown in Table 4-141.
6. The pre-retrofit annual kWh and post retrofit annual kWh were calculated by multiplying the respective pre- and post retrofit operating kW by the annual operating hours. The gross ex post annual kWh impacts were calculated as the difference between the pre- and post retrofit kWh.

$$\text{Ex Post Annual kWh Savings} = \sum_{i=1}^{7} (\text{Annual kWh}_{\text{Machine i,pre-retrofit}} - \text{Annual kWh}_{\text{Machine i,post-retrofit}})$$

Table 4-142 shows the ex post kWh savings calculations.

Table 4-141
Ex Post Post-Retrofit Operating kW and Operating Hours
For Three Injection Molding Machines
Project No. 50009

	Machine 1	Machine 2	Machine 3
Count of total Weekday Hours during monitoring period	134	134	134
Total kWh consumed during monitoring period.	2,588.21	1,847.95	2,175.56
Overall average operating kW (kWh/Hours)	19.31	13.79	16.24
IM Machine operating hours (Count of Hours w/ kW>0)	129	121	115
Operating kW Average (kWh/Operating Hours)	**20.06**	**15.27**	**18.92**
Annual Weekday IM Machine Operating Hours (251 days x 24 hr/days x operating hours during monitoring period/total hours during monitoring period)	5,868.54	5,504.60	5,231.64
Total annual weekday work hours (254 days x 24hr/day)	6,096	6,096	6,096
Fraction of work hours machines are in operation. (Oper. Hours/Total Hours)	0.9627	0.9030	0.8582
Average fraction of work hours machines operate		0.9080	
Total annual weekend/Holiday hours (111*24)	2,664	2,664	2,664
Annual weekend work hours reported by customer (26 Weekends x 48 hours /weekend)	1,248	1,248	1,248
Weekend operating hours (Work Hours x Fraction)	1,201	1,127	1,071
Total annual operating hours (Weekday + Weekend)	7,070	6,632	6,303
Average annual operating hours per machine		**6,668**	

Table 4-142
Ex Post kWh Savings Calculation
Project No. 50009

IM Machine #	Mfr.	Rated Tons	Motor HP	Basecase kW	Postcase kW - Measured	Postcase Percent Savings	Postcase Savings Source	Postcase kW	Annual Hours	Annual kWh Basecase	Annual kWh Postcase	Annual kWh Savings
Col. A	Col. B	Col. C	Col. D	Col. E	Col. F	Col. G	Col. H	Col. I	Col. J	Col. K	Col. L	Col. M
Ex Post Site Data	Ex Post Site Data	Ex Post Site Data	Ex Post Site Data	Ex Ante Pre-Retrofit Vendor Meas.	Ex Post Meas.	Calculated from Meas. Data	(M=Meas, A=Avg.)	Ex Post Meas. or Calc.	Ex Post Meas. or Op. Logs	E x J	Max of (F x J) or (I x J)	K - L
2	Engel	200	50	10.5		0.358	A	6.7	6,668	70,015	44,953	25,061
3	Engel	225	50	19.3	15.3	0.209	M		6,668	128,694	101,837	26,857
4	Engel	300	60	32.6	20.1	0.385	M		6,668	217,379	133,786	83,593
6	Engel	300	60	32.6	18.9	0.420	M		6,668	217,379	126,146	91,233
10	Engel	400	60	32.6		0.358	A	20.9	6,668	217,379	139,570	77,809
14	JSW	550	75	17.5		0.358	A	11.2	6,668	116,691	74,922	41,769
15	JSW	720	75	26		0.358	A	16.7	6,668	173,370	111,313	62,056
Total				**84.5**	**54.3**	**0.358**				**1,140,905**	**732,527**	**408,378**

kWh Impacts by TOU Period and Average Gross kW Impact

Gross kWh impacts for time-of-use period *c* were calculated by multiplying the total annual gross kWh impact by a factor calculated from the monitoring data that represents the proportion of energy consumption that occurs during each annual time-of-use period. The results are shown in Table 4-143. The *TOU Adjustment Factor* was calculated using the following steps:

1. For the monitored machines, the fraction of total operating hours that the machine operated during the monitoring period was calculated by dividing the hours with non-zero measured kW by the total elapsed weekday hours during the monitoring period. The fraction ranged from 0.86 to 0.96.
2. The annual operating hours during the on peak and part peak TOU periods for both winter and summer were calculated by multiplying the total hours during the respective TOU periods by the average operating fraction (0.903).
3. The operating hours during the weekend and weekday off peak periods were calculated by dividing the remaining annual total operating hours by 5/12 for the summer off peak period and 7/12 for the winter off peak period.
4. The TOU Adjustment Factor was calculated by dividing the total operating hours during the TOU period calculated in Step 3 by the total annual operating hours (6668).
5. The kWh impact during each seasonal TOU period is calculated by multiplying the total annual kWh impacts from Table 4-142 by the corresponding Impact Weighting Factor.
6. The average kW impacts during each TOU period is calculated by dividing the kWh impacts for the TOU period by the total annual hours during the TOU period.

Table 4-143
TOU Period kWh and kW Impacts
Project No. 50009

Season	Period	Total Hours	Operating Hours	TOU Adjustment Factor	kWh Savings	Average kW
Col. A	Col. B	Col. C	Col. D	Col. E	Col. F	Col. G
			Calculated from Monitoring Data and Customer Reported Weekend Hours	Col. D ÷ Total for Col. D	Col. E Total for x Col. F	F÷C
Summer	On-peak	749	680	0.1020	41,650	55.6
	Semi-peak	963	874	0.1311	53,550	55.6
	Off-peak	1,960	1,241	0.1861	75,996	38.8
Winter	On-peak	441	400	0.0600	24,523	55.6
	Semi-peak	1,911	1,735	0.2602	106,265	55.6
	Off-peak	2,736	1,737	0.2605	106,395	38.9
Total		**8,760**	**6,668**		**408,378**	

Gross kW Impact Coincident with System Peak

The average summer on peak period kW impacts are representative of the peak-coincident impacts for this site and are reported as the gross kW impact.

4.22.7 Summary of Gross Impacts

Table 4-144 summarizes the ex post gross kW and kWh Impacts and shows a comparison of the ex ante gross impact estimates with the ex post estimates.

Table 4-144
Results and Comparison with Ex Ante Estimate
Project No. 50009

	kWh	kW	Therms
Ex Ante	426,139	56.91	n/a
Ex Post	408,378	55.60	n/a
Realization Rate	95.8%	97.7%	n/a

The ex post gross annual kWh impact was 408,378 kWh. This is 95.8% of the ex ante estimate of 426,139 kWh. The primary reasons for the kWh discrepancy were small differences in the ex ante estimated kW impacts and operating hours and the evaluation calculated kW and operating hours based on the post retrofit site monitoring and operating schedule. The average kW impacts were slightly greater than the ex ante estimates, however, the annual operating hours based on post retrofit measurements and adjusted for “downtime” were slightly lower than the operating hours used in the ex ante estimates.

The ex post gross kW impact was 55.6 kW, 97.7% of the ex ante 56.9kW estimate. The primary reason for the discrepancy is a difference in methodology and small differences between the ex post post-retrofit measured kW and the post-retrofit kW used in the ex ante saving projections.

4.22.8 Net-To-Gross Ratio

The net-to-gross ratio for this project is 1.0. The customer was aware of the technology but was not sure how to estimate the retrofit savings on which to base a cost-benefit study. SDG&E worked with the vendor to estimate savings and incentive amounts and provided support in the internal decision-making process. Thus, SDG&E’s level of involvement was high.

4.23 PROJECT ID 50154 - INJECTION MOLDING MACHINE DRUM WITH INSULATION BLANKETS

4.23.1 Summary of Findings

The load impacts estimates for this site were based on the installation of insulating blanket on the heated screw barrels of 19 existing injection molding machines. Table 4-145 summarizes the ex ante and ex post load impact estimates for this project. The results of the ex post evaluation were different than the ex ante analysis due to differences in the ex ante and ex post hours of operation and the calculation of indirect HVAC effects between the ex ante and ex post analyses.

Table 4-145
Summary of Ex Post Load Impacts
Project No. 50154

	kWh	kW	Therms
Ex Ante	391,119	62.68	n/a
Ex Post	485,782	60.11	n/a
Realization Rate	124.2%	95.9%	n/a

4.23.2 Facility Description

This site manufactures plastic components used for 3-1/2" floppy disk cartridges, audio cassette housings, and plastic audio cassette cases. There are forty Nigata and Sumitomo injection molding machines that manufacture the various components. Assembly of floppy disks is also performed at this site using the cartridge halves and shutters manufactured onsite. Plastic resin pellets are melted in the screw barrels and injected under high pressure into molds to create the various components produced at this site.

4.23.3 Overview of Facility Schedule

This facility operates 24 hours per day, seven days per week, except during 14 holiday periods when the plant is shut down. The plant runs at capacity, utilizing four assembly lines and production levels are consistently high throughout the year. Slow downs occur only when injection molding equipment is taken down for repair.

The current shift schedule is two twelve-hour shifts per day, seven days per week for production workers, and one eight-hour shift per day, five days per week for office workers. Currently, the plant is operating forty injection molding machines and four floppy disk assembly lines. Planned day shift injection molding machine maintenance is performed on a regular basis on all of the injection molding machines. During maintenance, an injection molding machine must be shut down and all electrical input isolated. During 1998, total downtime for injection molding machines due to maintenance was 720 hours for the 40 injection molding machines. This equates to an average of 18 hours of maintenance downtime per year per machine. For the 19 pre- and post-retrofit machines total maintenance downtime was 342 hours per year (=19 machines $\times$ 18 hours/machine/year).

The ex post hours of machine operation are:

$$\text{Hour of Operation}_{\text{ex post}} = (8{,}760 \text{ hrs / year}) - (\text{Holidays}) - (\text{Maintenance Downtime})$$

$$= (8{,}760 \text{ hrs / yr}) - ((14 \text{ Holidays / yr}) \times (24 \text{ hrs / Holiday})) - (342 \text{ hrs / yr})$$

$$= 8{,}082 \text{ hrs / yr}$$

4.23.4 Measure Description

To make a plastic component by injection molding, plastic resin is softened and melted in the screw barrel of an injection molding machine, injected into molds, and then cooled. Approximately 75% of the heat required to melt the resin is generated by friction from the pellets rubbing against each other, the screw, and the barrel as the rotating screw forces the resin through the barrel cavity. The balance of the heat required to melt the resin is supplied by electric resistance heating bands wrapped around the screw barrel. The energy input to the heating bands varies according to the type of resin, shot size, and other parameters. The resistance heating bands, that also preheat the screw barrel and maintain the flowing temperature of the liquid resin, experience significant heat loss to the room environment unless they are insulated.

Plastic resin pellets are fed into the screw barrel from a hopper above the machine. As they are forced down the barrel by the rotating screw they are heated and gradually soften, melting at 500°F. Thermocouples sense the temperature of the resin, and modulate the heating cycle of the electric resistance heating elements to melt and then maintain the flowing temperature of the resin. Once the liquid resin reaches the end of the screw barrel it is injected under pressure into the molds by the turning screw. The steel screw barrel in which the resin is melted attains a surface temperature of approximately 500°F and is supplied un-insulated by the manufacturers of this equipment.

Nineteen injection molders were added over time as the throughput of the plant increased. The screw barrels of the 18 new Sumitomo and one new Nigata machines were supplied un-insulated. To improve the energy efficiency of these machines, the 19 bare steel screw barrels were wrapped with insulating pads made of 1-inch ceramic fiber batting sewn into heat resistant fiberglass fabric and held in place with Velcro straps. By retaining heat in the injection cylinder, this insulation reduces the power consumed by the electric resistance heaters and reduces radiation into the air conditioned building space.

Pre-Retrofit Conditions

- Nineteen injection molding machines equipped with bare steel injection cylinders.
- Eighteen Sumitomo machines utilize four resistance heating strips at 480 volts to pre-heat the screw barrel, melt resin pellets, and maintain plastic flowing temperature.
- One Nigata machine utilizes four resistance heating strips at 208 volts to pre-heat the screw barrel, melt resin pellets, and maintain plastic flowing temperature.
- The molding building is air conditioned by two 25-ton roof top packaged HVAC units.

Post-Retrofit Conditions

- Nineteen injection molding machines equipped with bare steel injection cylinders wrapped by one-inch thick insulating pads.
- Eighteen Sumitomo machines utilize four resistance heating strips per machine at 480 volts to pre-heat the screw barrel, melt resin pellets, and maintain plastic flowing temperature.
- One Nigata machine utilizes four resistance heating strip at 208 volts to pre-heat the screw barrel, melt resin pellets, and maintain plastic flowing temperature.
- The molding building air conditioned by the pre-retrofit roof top packaged HVAC units totaling 50-tons.

4.23.5 Ex Ante Load Impact Estimates

Pre-and post-retrofit monitoring was performed on the electric resistance heating bands to establish the power demand for resistance heating for each brand of injection molding machine. Insulating blankets were installed and post-retrofit monitoring was performed. The savings from reduced energy use through the electric resistance heating bands on the machine and the effects on the HVAC system of the reduced thermal loss to building space were analyzed.

Ex Ante Basecase Definition

The ex ante basecase is the 19 injection molding machines running with un-insulated screw barrels, and the building air conditioning system running continuously.

Ex Ante Operating Schedule

The ex ante operating schedule was for this facility to operate 24 hours per day, five days per week. The plant runs at capacity, utilizing six assembly lines and production levels are consistently high throughout the year. Slow downs only occur when injection molding equipment is taken down for repair.

The ex ante shift schedule is three eight-hour shifts per day, five days per week for production workers, and one eight-hour shift per day, five days per week for office workers.

The calculated ex ante hours of operation are therefore:

$$\text{Hoursof Operation}_{\text{ex ante}} = (8{,}760 \text{ hours / year}) - ((2 \text{ Days / weekend}) \times (24 \text{ hrs / day}) \times (52 \text{ weekends / yr}))$$

$$= 6{,}264 \text{ hours / year}$$

However, 6,240 hours per year were used for the ex ante analysis. The source of the discrepancy could not be determined.

Key Ex Ante Assumptions

- Assumed EER of 1.25 for air conditioning equipment.
- Assumed all heat released to conditioned space was eventually removed by HVAC units.

Ex Ante Algorithms

Monitoring established the following hourly average demand savings for an individual heating band on the two brands of injection molding equipment. There were four heating bands per machine.

Table 4-146
Pre- and Post-Retrofit Monitoring Results
kW per Individual Electric Resistance Heating Band
Project No. 50154

Brand	Quantity	Pre-Retrofit		Post-Retrofit		Voltage Factor Correction	Savings kW
		Voltage	kW	Voltage	kW		
Sumitomo	18	480	1.57	480	0.96	1	0.61
Nigata	1	208	1.68	208	1.39	2	0.58

Annual operating hours based on the ex ante operating schedule were estimated to be:

$$\text{Hours of Operation}_{\text{ex ante}} = (5 \text{ days / week} \times 52 \text{ weeks / yr}) \times 24 \text{ hrs / day}$$

$$= 6{,}240 \text{ hrs / yr}$$

For the 18 Sumitomo machines, annual energy savings were calculated to be:

$$\text{Annual kWh Savings}_{\text{18 Sumitome Machines}} = (18 \text{ machines}) \times (4 \text{ bands / machine}) \times (0.61\text{kW / band}) \times (6{,}240 \text{ hrs / yr})$$

$$= 274{,}061 \text{ kWh / yr}$$

and the demand reduction was calculated to be:

$$\text{kW Reduced}_{\text{18 Sumitomo Machines}} = (18\text{ machines}) \times (4\text{ bands / machine}) \times (0.61\text{kW / band})$$

$$= 43.92\text{ kW}$$

Similarly, kWh savings for the Nigata machine were calculated to be:

$$\text{kWh Savings}_{\text{Nigata Machine}} = (1\text{ machine}) \times (4\text{ bands / machine}) \times (0.58\text{ kW / band}) \times (6{,}240\text{ hrs / yr})$$

$$= 14{,}477\text{ kWh / yr}$$

The kW reduced was:

$$\text{kW Reduced}_{\text{Nigata Machine}} = (1\text{ machine}) \times (4\text{ bands / machine}) \times (0.58\text{ kW / band})$$

$$= 2.32\text{ kW}$$

The interactive effects of the reduced thermal loss to the building space resulting in savings from the air conditioning system were based on an assumed EER rating of 1.25 kW/ton. It was also assumed that the air conditioning system ran continuously, and that all of the heat added to the conditioned space was eventually removed by the HVAC system. The cooling load reduction was then found by converting the kWh savings from the electric resistance heaters to ton-hours and then multiplying that value times the HVAC system EER rating. The ex ante kWh savings from the HVAC interaction are:

$$\text{kWh Savings}_{\text{HVAC Interaction}} = \left[\frac{(274{,}061\text{ kWh} + 14{,}477\text{ kWh}) \times 3{,}413\text{ Btu / kWh}}{12{,}000\text{ Btu / ton}}\right] \times 1.25\text{ kW / ton}$$

$$= 102{,}581\text{ kWh}$$

The ex ante kW reduced by the HVAC interaction are:

$$\text{kW Reduced}_{\text{HVAC Interaction}} = \left[\frac{(43.92\text{ kW} + 2.32\text{ kW}) \times 3{,}413\text{ Btu / kWh}}{12{,}000\text{ Btu / ton}}\right] \times 1.25\text{ kW / ton}$$

$$= 16.44\text{ kW}$$

Total kWh savings was the sum of the heating element savings for all 19 injection molding machines, and the interactive A/C system savings. The total kWh saved were:

$$\text{Total kWh Saved} = \left(\text{kWh Savings}_{18\ \text{Sumitomo}}\right) + \left(\text{kWh Saving}_{\text{Nigata}}\right) + \left(\text{kWh Savings}_{\text{HVAC Interaction}}\right)$$

$$= 274{,}061\ \text{kWh} + 14{,}447\ \text{kWh} + 102{,}581\ \text{kWh}$$

$$= 391{,}119\ \text{kWh}$$

The total ex ante demand reduction was the sum of the demand reduction for all 19 injection molding machines and the interactive A/C Savings.

$$\text{Total kW Saved} = \text{kW}_{18\ \text{Sumitomo}} + \text{kW}_{\text{Nigata}} + \text{kW}_{\text{HVAC Interaction}}$$

$$= 43.92\ \text{kW} + 2.32\ \text{kW} + 16.44\ \text{kW}$$

$$= 62.68\ \text{kW}$$

Ex Ante Data Sources

- Measurements of actual pre- and post-retrofit power demands from electric resistance heating bands.
- Customer interviews.

4.23.6 Ex Post Load Impact Estimates

Ex ante monitoring data was analyzed to determine ex post power consumption patterns for the injection molding machine heating bands. These values were extrapolated to the 8,760 hours per year assuming constant plant production levels and the ex post operating schedule. Indirect impacts on the air conditioning system power demands from the heat reduction caused by the energy efficiency measures were calculated based on standard industry practice for lighting and HVAC interactions. Though this measure does not involve lighting, it is an analogous situation and results should give a closer estimation of the interactive effect than the ex ante approach.

Ex Post Basecase Definition

The ex post basecase is the 19 injection molding machines running with un-insulated screw barrels, on the ex post operating schedule. Package HVAC units operate to maintain the comfort levels in the manufacturing area.

Ex Post Postcase Definition

The ex post basecase is the 19 injection molding machines running with insulated screw barrels, on the ex post operating schedule. Package HVAC units operate to maintain the comfort levels in the manufacturing area.

Ex Post Operating Schedule

This facility operates 24 hours per day, seven days per week, except during 14 holiday periods when the plant is shut down. The plant runs at capacity, utilizing four assembly lines. Production levels are consistently high throughout the year. Slow downs occur only when injection molding equipment is taken down for repair.

The current shift schedule is two twelve-hour shifts per day, seven days per week for production workers, and one eight-hour shift per day, five days per week for office workers. Currently, the plant is operating forty injection molding machines and four floppy disk assembly lines. Planned day shift injection molding machine maintenance is performed on a regular basis on all of the injection molding machines. During 1998, total injection machine downtime due to maintenance was 720 hours. This equates to an average of 18 hours of maintenance downtime per year per machine. For the 19 post-retrofit machines total maintenance downtime was 342 hours per year (=19 machines × 18 hours/machine/year).

The ex post hours of operation are therefore:

$$\text{Hours of Operation}_{\text{ex post}} = (8{,}760 \text{ hrs/yr}) - (14 \text{ Holidays/yr} \times 24 \text{ hrs/Holiday}) - (342 \text{ hrs/yr})$$

$$= 8{,}082 \text{ hrs/yr}$$

Ex Post Production Level Changes

Installation of the energy efficiency measures did not affect the production level of the plant. The overall ex post production levels are the same as the ex ante levels. Post-retrofit injection molding machine operating hours (and thus total output) are the same as pre-retrofit operating hours.

Data Collected Ex Post

Ex ante monitoring data was used as the basis for the ex post analysis. For the ex ante analysis, pre-retrofit monitoring was performed on the resistance heating bands to establish the power demand for resistance heating for each brand of injection molding machine. Insulating blankets were installed and post-retrofit monitoring was performed. During the ex post site visit the installation of the blankets was confirmed, and nameplate data were gathered.

Ex Post Algorithms

Monitoring established the following hourly average demand savings for an individual heating band on the two brands of injection molding equipment.

Table 4-147
Ex Ante Pre- and Post-Retrofit Monitoring Results
Individual Heating Band Measurements Used for Ex Post Evaluation
Project No. 50154

Brand	Quantity	Pre-Retrofit		Post-Retrofit		kW Reduced
		Voltage	kW	Voltage	kW	
Sumitomo	18	480	1.57	480	0.96	0.61
Nigata	1	208	1.68	208	1.39	0.29

For the 18 Sumitomo machines, annual energy savings was calculated to be:

$$\text{Ex Post kWh Saving}_{\text{Sumitomo}} = (18\text{ machines}) \times (4\text{ bands / machine}) \times (0.61\text{kW / band}) \times (8{,}082\text{ hrs / yr})$$

$$= 354{,}961\text{ kWh / yr}$$

and the demand reduction was calculated to be:

$$\text{Ex Post kW Reduced}_{\text{Sumitomo}} = (18\text{ machines}) \times (4\text{ bands / machine}) \times (0.61\text{kW / band})$$

$$= 43.92\text{ kW}$$

Similarly, impacts for the Nigata machine were calculated to be:

$$\text{ExPost kWh Savings}_{\text{Nigata}} = (1\text{ machine}) \times (4\text{ bands / machine}) \times (0.29\text{ kW / band}) \times (8{,}082\text{ hrs / yr})$$

$$= 9{,}375\text{ kWh / yr}$$

and:

$$\text{Ex Post kW Reduced}_{\text{Nigata}} = (1\text{ machine}) \times (4\text{ bands / machine}) \times (0.29\text{ kW / band})$$

$$= 1.16\text{ kW}$$

Interactive savings with the air conditioning system were based on an article appearing in the November 1993 edition of the *ASHRAE Journal* entitled Calculating lighting and HVAC interactions by Rundquist, Johnson and Aumann. Though this project did not involve lighting, it is analogous to the method described in this article because lights are simply treated as heat sources, and the results of this type of analysis should provide a closer estimation of impacts than the ex ante method.

It was assumed that the air conditioning system runs continuously to maintain comfort levels in the manufacturing building spaces. From the above-referenced article, the value for the fraction of heat evolved to be removed by the cooling system is 0.52 for the San Diego area. Assuming a worst case system COP of 3.0 the indirect cooling kWh savings was:

$$\text{Ex Post kWh Savings}_{\text{HVAC Interaction}} = (354{,}961\text{ kWh} + 9{,}375\text{ kWh}) \times \left(\frac{0.52}{3.0}\right)$$

$$= 63{,}152\text{ kW}$$

The kW reduced due to the HVAC interaction was:

$$\text{Ex Post kW Reduced}_{\text{HVAC Interaction}} = \frac{(43.92\text{ kW} + 1.16\text{ kW})}{3.0}$$

$$= 15.03\text{ kW}$$

The total ex post kWh savings was the sum of the heating element savings for all 19 injection molding machines, and the interactive A/C system savings.

$$\text{Ex Post Total kWh Saved} = 354{,}961\text{ kWh} + 9{,}375\text{ kWh} + 63{,}152\text{ kWh}$$

$$= 427{,}488\text{ kWh}$$

The total ex post demand reduction was the sum of the demand reduction for all 19 injection molding machines and the interactive A/C Savings.

$$\text{Ex Post Total kW Reduced} = 43.92\text{ kW} + 1.16\text{ kW} + 15.03\text{ kW}$$

$$= 60.11\text{ kW}$$

Ex Post Load Impacts By Time-Of-Use Period

The injection molding machines at this facility operate continuously, with little variability. Thus, the allocation of kWh savings to the time-of-use (TOU) periods was based on the operating hours in each TOU period. The results are shown in Table 4-148.

Table 4-148
Ex Post kW and kWh Impacts by Time-of-Use Period
Project No. 46697

Time-of-Use Period	Annual Hours	kWh Adjustment Factor	kWh Savings	Average kW Reduced	kW Reduced Coincident with System Peak Period
Summer On-peak	678	0.0839	35,849	60.11	60.11
Summer Semi-peak	892	0.1103	47,168	60.11	
Summer Off-peak	1,912	0.2366	101,133	60.11	
Winter On-peak	420	0.0520	22,215	60.11	60.11
Winter Semi-peak	1,621	0.2005	85,714	60.11	
Winter Off-peak	2,560	0.3168	135,408	60.11	
Total	**8,082**	**1.0000**	**427,488**		

4.23.7 Net-To-Gross Ratio

The net-to-gross ratio for this project is 0.75. SDG&E had a medium level of involvement for this project, while the incentives played a role in gaining management approval for the measure.

Motivation

Motivation for the project was inspired by the cost reduction opportunity, and the improvement in safety resulting from the new equipment. This project was essentially phase 2 of a similar project that had been rebated at this site several years ago. Funding for the installations ran out before all machines were insulated during phase 1. The previously rebated project was inspired totally by the involvement of San Diego Gas and Electric Company, and was only approved and built because the rebate was large enough to improve the project economics to meet the customer's internal payback criteria. There were a number of iterations in the final project definition to meet financial hurdles the project had to meet. Table 4-149 shows that the project had an unincentivized payback of 1.22 years. The incentives reduced the payback to less than a year, making the project competitive with other capital projects.

Table 4-149
Ex Ante Project Payback Data
Project No. 50154

Customer cost	$98,510
Annual savings	$81,020
Incentive	$25,000
Payback w/o incentives	1.22
Payback w/ incentives	0.91

Non-Energy Costs and Benefits

Installation of the insulating pads improved plant safety by providing an engineered barrier between the high temperature screw barrel surface and operating personnel, greatly reducing the potential for contact burns.

Equipment Alternatives

No alternatives other than the ex post equipment were considered.

4.24 Project No. 51143 - Install Connection Pipe Between Buildings; Combine Systems Using Smaller Compressor

4.24.1 Summary of Findings

A compressed air pipe was installed between two buildings with 10-hp and 30-hp compressors, respectively. The 10-hp compressor now handles the load of both buildings.

Table 4-150 summarizes the ex post impacts and compares them with the ex ante estimates.

Table 4-150
Summary of Ex Post Load Impacts
Project No. 51143

	kWh	kW	Therms
Ex Ante	47,391	31.5	n/a
Ex Post	57,317	14.3	n/a
Realization Rate	120.9%	45.3%	n/a

The ex post evaluation found gross kWh impact of 57,317 kWh, 20.9% greater than the ex ante estimate of 47,391 kWh. The primary reason for the discrepancy was a difference in postcase operating hours and kW (based on ex post monitoring and operating logs) in the ex post calculations versus the projected postcase operating hours and estimated kW used in the ex ante estimates.

The ex post gross kW impact of 14.3 kW is 45.3% of the ex ante estimate, 31.5 kW. The primary reasons for the discrepancy were:

1. The use of different basecase kW estimates. The ex ante calculation used the *fully loaded kW* of the 30-hp basecase compressor kW in calculating the basecase demand, rather than the (weighted) average operating kW. The average provides a basecase value more representative of the pre-retrofit kW as it considers system diversity and cyclic loading patterns.
2. A difference in methodology between the ex ante and ex post kW impact calculation. The ex ante estimates used the difference in maximum operating load between the basecase and post retrofit compressors. The ex post gross kW impact is the average kW impact during the summer time-of-use period.

4.24.2 Facility Description

This is a manufacturing facility where various types of irrigation equipment are produced and assembled using metal and plastic components, some of which are produced on site. Activities at the site include injection molding, machining of plastic and metal parts, and assembly of sprinkler components, packaging, storage, shipping and administrative functions. This is a multiple building campus facility in an industrial park, with at least seven major buildings that house the administrative and manufacturing operations. Compressed air is required in several buildings for tool drive, controls, and blow off. This project involved compressed air systems serving two of the buildings: Building F and Building G.

4.24.3 Measure Description

There are two, separate compressed air systems in two of the buildings at the facility, Buildings F and G. These two buildings are adjacent to each other. The measure installed was a pipe connecting the two systems, thereby allowing the smaller 10-hp air compressor to meet the compressed air requirements for the two buildings. The second 30-hp air compressor is in place but is no longer used.

4.24.4 Ex Ante Load Impact Estimates

An engineering analysis was used to estimate the ex ante load impacts for this measure. Compressor total operating hours were calculated from operating logs (from the hour meter on the compressor). Compressor loaded and unloaded hours were estimated from short term observations. Compressor operating kW was measured by spot observations during the ex ante site visit.

Ex Ante Basecase

Buildings F and G are separated by 60 feet and have individual air compressors, both of which were used intermittently. The compressor in Building G, a 30-hp Ingersoll Rand screw compressor, ran loaded about 20% of the time during production hours. The air compressor in Building F, a 10-hp reciprocating unit, cycled on several minutes each hour for a total of approximately 655-equivalent operating hours per year.

Ex Ante Postcase

The close proximity of the buildings allowed combining the two compressor systems into a single system. Since the compressed air demands are small in each building the 10-hp I-R reciprocating unit in Building F was adequate for both buildings, using an existing 120-gallon receiver in Building G. A pipe was installed to connect the compressed air systems of the two buildings. The 10-hp compressor output pressure was raised and storage pressure was set at 175 psi and a Master Pneumatics-type regulator was installed to maintain line pressure of 90 psi downstream of the receiver to handle surges.

Ex Ante Load Impact Estimates

The ex ante load impact estimates for Project No. 51143 are shown in Table 4-151.

Table 4-151
Ex Ante Load Impact Estimates
Project No. 51143

Pre-Retrofit			
Make and Model	**kW**	**Hours On**	**Total kWh**
IR 30U Bldg G Unloaded	18	1,747	31,813.0
IR 30U Bldg G Loaded	31.464	440	13,844.0
IR 20T Bldg F	10.432	655	6,833.0
Dryer Bldg G	1.15	8,760	10,074.0
Total	**43.05**		**62,564**
Post-Retrofit			
Make and Model	**kW**	**Hours On**	**Total kWh**
IR 30U Bldg G	0	0	0.0
IR 20T	10.432	1,310	13,666.0
Dryer	1.15	1,310	1,507.0
Total	**11.58**		**15,173**
Energy Savings (kWh)			**47,391**
Demand Reduced (kW)	**31.47**		

Ex Ante Data Sources

- Site observations and “spot” power measurements of compressor power
- Site observations of operating schedule and cyclic loading patterns of the compressors
- Compressor operating hour logs from maintenance records

4.24.5 Ex Post Load Impact Estimates

An engineering analysis methodology similar to the ex ante method was used. A site visit was conducted to verify the installation of the measure ex post and to gather data and information that were used in the evaluation. The ex post calculations were based on ex post short term monitoring of the smaller operating compressor and on review of operating hour logs for the larger compressor for the pre-retrofit and post-retrofit periods.

Ex Post Basecase

The ex post basecase is the pre-retrofit operation as described in the ex ante basecase that consists of the two compressors in Buildings F and G operating independently to serve the loads within each building. However, the basecase compressor hours were adjusted to values obtained from customer’s maintenance records for the pre-retrofit period.

Ex Post Postcase

The ex post basecase is the post-retrofit operation as described in the ex ante postcase that consists of the 10-hp compressor in Building F serving the compressed air loads of both Buildings F and G. The compressor supply pressure was raised to allow for surges in flow. The ex post postcase compressor hours were adjusted to values obtained from customer's maintenance records.

Ex Post Operating Schedule

The facility operates continuously, however, the production systems and compressors affected by this modification typically operate 24 hours per day, Monday through Friday, year-round. Primary impacts occur during the first shift: between 7 A.M. and 5 P.M. Monday through Friday, year-round.

The 30-hp compressor was manually shut off and records indicate that it has been run only a few hours for exercise since the pipe was installed.

Ex Post Production Level Changes

No production changes were caused by, or occurred as a result of this project.

Data Collected Ex Post

Operating hours for the pre- and post retrofit compressors were obtained from maintenance records. A summary of the pre- and post-retrofit operating hours for the IR 30U (larger) compressor used in the ex post analysis is shown in Table 4-152.

Table 4-152
30-HP Air Compressor Operating Hour Data and Loading Calculations
Project No. 51143

Date	Dryer Hours	EP30U (Replaced) Compressor Hours	Operating Hours	Loaded Hours	Elapsed Days	Annual Operating Hours	Annual Loaded Hours	Annual Unloaded Hours
06/23/95	n/a	5,192						
04/12/96	1,475	8,895						
11/25/96	2,237	11,000						
05/08/97	2,337	11,901	Pre-Retrofit					
10/24/97	2,460	12,945	4,050	985	560	2,639.7	642.0	1,997.7
1/23/98	2,490	13,391						
04/24/98	2,492	13,397	Post Retrofit					
08/03/98	2,492	13,399	8	2	192	15.2	3.8	11.4

The post-retrofit compressor power was monitored at five minute intervals for 12 days.

Annual Ex Post Gross kWh Savings

The annual gross kWh savings was calculated by taking the difference between the product of the pre-retrofit compressors operating kW and the estimated annual operating hours for each compressor and the product of the post-retrofit compressor average operating kW (calculated from monitoring data) and its annual operating hours (projected based on post-retrofit monitoring data).

The annual energy use of the pre-retrofit and post retrofit compressors was calculated by the general formula:

$$kWh_{pre\text{-}retrofit} = \sum_{c=1}^{2} kW_c \times AnnualHours_{pre\text{-}retrofit,c}$$

where:

kW_c = operating kW for pre-retrofit compressor, c (10-hp and 30-hp units) based on short-term measurements; and

$\text{Annual Hours}_{pre\text{-}retrofit,c}$ = pre-retrofit operating hours for compressor c.

$$kWh_{post\text{-}retrofit} = kW_{10\text{-}hp} \times \text{Annual Hours}_{post\text{-}retrofit},$$

where:

$kW_{10\text{-}hp}$ = operating kW for post-retrofit 10-hp compressor based on short-term measurements;

$\text{Annual Hours}_{post\text{-}retrofit}$ = post-retrofit operating hours for 10-hp compressor.

Table 4-153 shows the pre- and post retrofit energy use and annual impact calculation.

Table 4-153
Ex Post Annual Load Impact Calculation
Project No. 51143

Bldg	Compressor	Average Operating kW	Source of Data on kW	Annual Operating Hours	Source of Operating Hour Data	Annual kWh
Pre-Retrofit						
G	IR 30 U Loaded	18.00	Measured ex ante (inc. cooler)	1,998	Hour log data	35,959
G	IR 30 U Unloaded	31.46	Measured ex ante (inc. cooler)	642	Hour log data	20,200
F	IR20T	8.11	est. from rating	655	est. Based on short term observations	5,311
F	Dryer Bldg F	1.15	est. from rating	655	est. Based on short term observations	753
Total Pre-Retrofit						**62,224**
Post-Retrofit						
G	IR 30 U Loaded	18.00	ex ante meas. (not operating ex post)	4	Operating Log	68
G	IR 30 U Unloaded	31.46	ex ante meas. (not operating ex post)	11	Operating Log	359
F	IR20T	0.57	12 day ex. p. monitoring	6,720	Ex Post monitoring	3,799
F	Dryer Bldg F	0.10	est. based on compr. Cycle	6,720	Ex Post monitoring	680
Total - Post-Retrofit						**4,906**
Total Ex Post kWh Savings						**57,317**

Ex Post TOU Period kWh Impacts

Gross kWh impacts for costing period *c* were determined by calculating a factor which represents the proportion of annual savings which occurs during each time-of-use period from the ex post monitoring results. The following steps were used:

1. The average post-retrofit kW (of the three 20 hp compressors) for each operating hour of each “Daytype” (Daytype 1 = Weekdays, Daytype 2 = Weekend/Holidays) was calculated from the monitoring data.
2. The total annual kWh for each hour of each day type were calculated by multiplying the average hourly kW by the number of equivalent full production operating days occurred curing the first post-installation year. The monitoring data indicated 261 equivalent full production weekdays and 104 part production weekend holiday operating days.
3. The kWh for the hours in each seasonal TOU period were summed
4. The sum for the hours which occur during each summer time-of-use period was multiplied by 5/12 to reflect TOU consumption during the five summer season months.

The total kWh which occur during each winter TOU period were multiplied by 7/12 to calculate the total which applies to each TOU period during the winter season.

5. The kWh in each TOU period for the year were summed and the kWh for each TOU period divided by the total to calculate a "TOU Period weighting factor"
6. The total annual kWh impact was multiplied by the TOU Period weighting factor" to calculate the kWh impact in each TOU period.

The process for estimating the TOU factors and ex post load impacts by TOU period is shown in the following equations:

$$\left(\text{Total kWh usage for each hour}_{\text{daytype}}\right) = \left(\text{Average post - retrofit kW for each hour}_{\text{daytype}}\right) \times \left(\text{No. Days}_{\text{daytype}}\right),$$

where:

$$\text{No. Days}_{\text{daytype}} = 261 \text{ days for weekdays}$$
$$= 104 \text{ days for weekends}$$

$$\left(\text{Sum of kWh usage for each TOU period}\right) = \sum \begin{pmatrix} \text{Total kWH usage for each hour}_{\text{daytype}} \text{ in} \\ \text{each summer and winter TOU period} \end{pmatrix}$$

$$\left(\text{Adjusted kWh usage for each TOU period}\right) = \left(\text{Sum of kWh usage for each TOU period}\right) \times \left(\text{Seasonal Adjustment Multiplier}\right)$$

where:

$$\text{Seasonal Adjustment Multiplier} = \left(\frac{5}{12}\right) \text{ for summer; and}$$
$$= \left(\frac{7}{12}\right) \text{ for winter.}$$

$$\left(\text{Total Annual kWh Usage}\right) = \sum_{p} \text{Adjusted kWh usage for each TOU period},$$

where:

p = the six TOU periods.

$$\left(\text{TOU Adjustment Factor for Each TOU period}\right) = \frac{\text{Adjusted kWh Usage for Each TOU Period}}{\text{Total Annual kWh Usage}}$$

$$\left(\text{Ex Post kWh Savings by TOU Period}\right) = \left(\text{Ex Post Gross kWh SWavings}\right) \times \left(\text{TOU Adjustment Factor for Each TOU Period}\right).$$

Table 4-154 summarizes the TOU period impacts:

Average Gross kW Impacts

Average gross kW impacts were calculated for each costing period by dividing the total kWh impacts for the costing period by the total number of hours in the TOU period:

$$\text{Average ex post kW reduced}_c = \frac{\text{Ex post kWh savings}_c}{\text{Hours}_c}$$

These results are shown in Table 4-154.

Table 4-154
Ex Post Load Impacts By TOU Period
Project No. 51143

Season	Period	TOU Adjustment Factor	kWh Impact	Total Hours	Average kW
Col. A	Col. B	Col. C	Col. D	Col. E	Col. F
		based on monitoring from " kW Data by hr."	from "Imp. Calc"		D/E
Summer	**On-peak**	0.1863	10,676	749	14.3
	Semi-peak	0.1777	10,183	963	10.6
	Off-peak	0.0527	3,023	1,960	1.5
Winter	**On-peak**	0.0249	1,427	441	3.2
	Semi-peak	0.4846	27,777	1,911	14.5
	Off-peak	0.0738	4,232	2,736	1.5
Total		**1.0000**	**57,317**		

Gross kW Impact Coincident with System Peak

The impact across the weekday daytime hours is reasonably constant. The summer on-peak TOU period average kW impact is reported as the ex post peak coincident kW impact.

4.24.6 Summary of Gross Impacts

Table 4-155 summarizes the gross ex post impacts and compares the ex ante and ex post impacts for this site.

Table 4-155
Ex Ante and Ex Post Gross Impact Estimates
Project No. 51143

	kWh	kW	Therms
Ex Ante	47,391	31.5	n/a
Ex Post	57,317	14.3	n/a
Realization Rate	120.9%	45.3%	n/a

The ex post evaluation found gross kWh impacts of 57,317 kWh, 20.9% greater than the ex ante estimate of 47,391 kWh. The primary reason for the discrepancy was a difference in postcase operating hours and kW (based on monitoring and operating logs) in the ex post calculations versus the projected postcase operating hours and estimated kW used in the ex ante estimates.

The ex post gross kW impact of 14.3 kW is 45.3% of the ex ante 31.5 kW estimate. The primary reasons for the discrepancy were:

1. The use of different basecase kW estimates. The ex ante calculation used the *fully loaded kW* of the 30-hp basecase compressor kW in calculating the basecase demand, rather than the (weighted) average operating kW. The average provides a basecase value more representative of the pre-retrofit kW as it considers system diversity and cyclic loading patterns.

A difference in methodology between the ex ante and ex post kW impact calculation. The ex ante estimates used the difference in maximum operating load between the basecase and post retrofit compressors. The ex post gross kW impact is the average kW impact during the summer time-of-use period.

4.24.7 Net-To-Gross Ratio

The net-to-gross ratio for this project was estimated to be 1.0. The SDG&E IEEI Program was the reason the measures were installed.

The site contact attended an SDG&E sponsored seminar on compressed air systems. He went back to his plant to review his compressed air system. He then applied for an SDG&E-sponsored compressed air consultant to prepare a study of the system. After the study, he only had time to install one of the recommendations. He wanted to do the remainder of the recommended work, but he “ran out of time.”

SDG&E staff (consultants) had a high level of involvement in this project by having originated the project concept and provided all technical and engineering analysis to support the recommendations.

5 MOTOR MEASURES

5.1 OVERVIEW

The methodology used to estimate the load impacts for motors installed under the 1997 Industrial EEI Program was described in Section 3. Table 5-1 provides a summary of the program for PY97. The motor measures were evaluated by gathering installation and operating information through an on-site visit or a telephone survey. The data was then processed as described in Section 2.3.

Table 5-1 shows that over 75 percent of the *ex ante* load impacts were included in the *ex post* evaluation.

Table 5-1
Summary of
Motor Measures
PY97 Industrial EEI Program

	No. Participants	No. Measures	*Ex Ante* Gross kWh	*Ex Ante* Gross kW	HP
Program	**213**	**253**	**430,182**	**107.57**	**6,470.00**
Survey	**120**	**157**	**329,106**	**82.36**	**5,280,00**
Percent Surveyed	**56%**	**62%**	**77%**	**77%**	**82%**

5.2 SUMMARY OF IMPACTS

Table 5-3 shows a summary of the gross program load impacts. The table indicates a realization rate of 0.76 for kWh and 0.68 for kW.

Table 5-2
Summary of Ex Post Load Impacts
Motor Measures
PY97 Industrial EEI Program

	kWh Savings	kW Reduced
Ex Ante Gross	430,181	107.57
Ex Ante Net	322,636	80.68
Ex Post Gross Load Impacts	463,977	85.07
Ex Post Net Load Impacts	218,042	54.68
Gross Realization Rate	107.86%	79.09%
Net Realization Rate	67.58%	67.77%
Ex Post NTGR	0.47	0.64

5.3 EX POST LOAD IMPACT ESTIMATES

The *ex post* load impact of each motor measures was estimated using the approach described in Section 3.4. The results for motor evaluation participants were aggregated to the stratum level, as shown in Table 5-3. Gross realization rates were calculated for each stratum. The realization rates were applied to the total gross load impacts for the stratum and then summed to the program level.

Table 5-3
Ex Post Gross Load Impacts
PY97 Industrial EEI Program
Motor Measures

	Total Ex Ante Gross		Ex Ante Gross Surveyed		Ex Post Gross		Gross Realization Rate per Stratum		Total Gross Ex Ante		Total Gross Ex Post	
Strata	kWh savings	kW Reduced	kWh savings	kW Reduced	kWh savings	kW Reduced	kWh Savings	kW Reduced	kWh Savings	kW Reduced	kWh Savings	kW Reduced
1	34,711	8.71	11,448	2.890	10,414	2.001	91.0%	69.2%	34,711	8.71	31,575	6.03
2	157,884	39.39	57,594	14.410	71,477	13.347	124.1%	92.6%	157,884	39.39	195,941	36.48
3	237,586	59.47	221,680	55.600	220,630	39.788	99.5%	71.6%	237,586	59.47	236,461	42.56
Total	430,181	107.57	290,722	72.900	302,520	55.136			430,181	107.57	463,977	85.07
Gross Realization Rate											107.9%	79.1%

The net load impacts were estimated using a similar approach. Net load impacts were calculated for ex ante and ex post survey participants. The ex post net-to-gross ratios were estimated as described in Section 3. The net realization rates were estimated for each strata. These net realization rates were applied to the total ex ante net load impacts to calculate the ex post net load impacts, as shown in Table 5-4. The program net-to-gross ratio was calculated by dividing the total ex post net load impacts by the total ex post gross load impacts.

Table 5-4
Ex Post Net Load Impacts
PY97 Industrial EEI Program
Motor Measures

		Total Ex Ante Net		Surveyed Ex Ante Net		Ex Post Net Surveyed		Net Realization Rate by Stratum		Total Ex Ante Net		Ex Post Net Load Impacts	
Stratum	**Ex Ante NTGR**	**kWh Savings**	**kW Red.**	**kWh Savings**	**kW Red.**	**kWh Savings**	**kW Red.**	**kWh Savings**	**kW Red.**	**kWh Savings**	**kW Red.**	**kWh Savings**	**kW Red.**
1	**0.75**	26,033	6.533	8,586	2.1675	5,214	0.94	0.33	0.33	26,033	6.53	8,586	2.17
2	**0.75**	118,413	29.543	43,196	10.8075	31,064	5.73	0.36	0.37	118,413	29.54	43,196	10.81
3	**0.75**	178,190	44.603	166,260	41.7	142,608	24.73	0.93	0.93	178,190	44.60	166,260	41.70
Total		322,636	80.678	218,042	54.675	178,886	31.40			322,636	80.68	218,042	54.68
Net Realization Rate												67.58%	66.77%
Ex Post Net-To-Gross Ratio												0.47	0.64

6 LIGHTING MEASURES

6.1 OVERVIEW

During PY97 San Diego Gas & Electric installed lighting measures as part of its *Industrial Energy Efficiency Incentives Program (Industrial EEI Program)*.

This section describes the methodology and presents the results of the first year *ex post* load impact evaluation of the lighting measures installed through the Industrial EEI Program during PY97. Table 6-1 shows an *ex ante* summary of the program the definition of participant. This shows that 11,978 individual measures were installed saving an estimated 3,846,05 kWh per year at the sites of 101 facilities defined as participants. A participant is defined as a Project No. (called the Site_nbr on program tracking databases).

Table 6-1
Summary of *Ex Ante* Load Impacts By Participant
Lighting Measures
PY97 Industrial EEI Program

		Ex Ante Gross		Ex Ante Net	
Participant	Measure Quantity	kWh Savings	kW Reduced	kWh Savings	kW Reduced
1	4	1,124	0.12	1,124	0.12
2	8	2,247	0.25	2,247	0.25
3	4	1,349	0.52	1,079	0.42
4	8	1,899	0.53	1,519	0.42
5	4	1,123	0.13	1,123	0.13
6	7	1,966	0.22	1,966	0.22
7	3	853	0.09	853	0.09
8	10	2,808	0.31	2,808	0.31
9	4	1,163	0.13	1,163	0.13
10	10	2,808	0.32	2,808	0.32
11	11	3,089	0.35	3,089	0.35
12	4	1,123	0.13	1,123	0.13
13	6	1,745	0.2	1,745	0.20
14	3	842	0.1	842	0.10
15	3	842	0.1	842	0.10
16	7	1,965	0.22	1,965	0.22
17	11	3,088	0.35	3,088	0.35
18	4	1,163	0.13	1,163	0.13
19	8	2,246	0.26	2,246	0.26
20	10	2,808	0.32	2,808	0.32
21	3	843	0.09	843	0.09
22	3	842	0.1	842	0.10
23	9	2,527	0.29	2,527	0.29
24	8	2,246	0.26	2,246	0.26
25	8	2,247	0.25	2,247	0.25
26	5	1,424	0.17	1,424	0.17

(continued)

Table 6-1 (continued)
Summary of *Ex Ante* Load Impacts By Participant
Lighting Measures
PY97 Industrial EEI Program

		Ex Ante Gross		Ex Ante Net	
Participant	Measure Quantity	kWh Savings	kW Reduced	kWh Savings	kW Reduced
27	2	562	0.06	562	0.06
28	9	2,527	0.29	2,527	0.29
29	11	3,089	0.35	3,089	0.35
30	5	1,454	0.17	1,454	0.17
31	7	1,965	0.22	1,965	0.22
32	6	1,745	0.2	1,745	0.20
33	1	281	0.03	281	0.03
34	6	1,685	0.19	1,685	0.19
35	4	1,163	0.13	1,163	0.13
36	6	1,685	0.19	1,685	0.19
37	3	842	0.1	842	0.10
38	10	2,889	0.33	2,889	0.33
39	7	1,965	0.23	1,965	0.23
40	3	842	0.1	842	0.10
41	4	1,123	0.13	1,123	0.13
42	7	1,965	0.22	1,965	0.22
43	7	1,965	0.22	1,965	0.22
44	2	562	0.06	562	0.06
45	11	3,088	0.36	3,088	0.36
46	2	562	0.06	562	0.06
47	6	1,685	0.19	1,685	0.19
48	3	842	0.1	842	0.10
49	12	3,440	0.39	3,440	0.39
50	16	4,503	0.51	4,503	0.51
51	52	13,139	1.5	10,511	1.20
52	119	8,665	3.3	7,267	2.77
53	25	14,024	2.41	12,622	2.17
54	68	12,604	3.49	10,083	2.79
55	20	5,616	0.64	5,616	0.64
56	13	3,650	0.41	3,650	0.41
57	51	14,319	1.64	14,319	1.64
58	24	6,738	0.77	6,738	0.77
59	17	4,924	0.56	4,924	0.56
60	38	10,669	1.22	10,669	1.22
61	19	5,466	0.62	5,466	0.62
62	21	5,896	0.67	5,896	0.67
63	32	8,984	1.03	8,984	1.03
64	12	3,369	0.39	3,369	0.39
65	17	4,774	0.54	4,774	0.54
66	17	4,773	0.54	4,773	0.54
67	37	10,388	1.18	10,388	1.18
68	17	4,813	0.55	4,813	0.55
69	27	7,580	0.87	7,580	0.87
70	37	10,389	1.18	10,389	1.18
71	15	4,211	0.48	4,211	0.48
72	21	5,896	0.67	5,896	0.67
73	25	7,019	0.81	7,019	0.81
74	22	6,177	0.71	6,177	0.71
75	19	5,334	0.61	5,334	0.61
76	28	7,862	0.9	7,862	0.90
77	13	3,650	0.42	3,650	0.42
78	429	366,910	105.05	327,138	93.83

(continued)

Table 6-1 (continued)
Summary of *Ex Ante* Load Impacts By Participant
Lighting Measures
PY97 Industrial EEI Program

		Ex Ante Gross		Ex Ante Net	
Participant	Measure Quantity	kWh Savings	kW Reduced	kWh Savings	kW Reduced
79	108	1,164,076	245.99	1,047,668	221.39
80	35	34,332	5.1	30,899	4.59
81	1,249	102,737	23.8	82,248	19.05
82	727	33,604	7.54	28,131	6.30
83	1,712	200,188	46.41	160,150	37.13
84	249	57,433	13.3	45,946	10.64
85	795	79,941	19.04	65,827	15.72
86	3,000	547,447	126.9	437,958	101.52
87	296	51,125	7.98	44,935	6.93
88	2	46,252	0	41,627	0.00
89	114	313,397	37.65	282,057	33.89
90	2	67,641	45.61	60,877	41.05
91	105	175,113	32.93	157,602	29.64
92	59	16,585	1.9	16,585	1.90
93	1,305	94,382	21.88	75,506	17.50
94	143	40,149	4.58	40,149	4.58
95	117	32,849	3.75	32,849	3.75
96	67	21,367	2.47	19,196	2.22
97	35	25,583	6.49	23,025	5.84
98	55	15,884	1.81	15,884	1.81
99	54	15,232	1.74	15,232	1.74
100	139	37,242	15.75	33,229	14.06
101	60	16,846	1.92	16,846	1.92
Total	**11,978**	**3,846,053**	**818.47**	**3,382,703**	**713.89**

Table 6-2 shows there were101 projects where measures were installed, comprising almost 6,059,409 square feet.

Table 6-2
Lighting Measures
PY97 Industrial EEI Program

Number of Projects	101
Total Square Feet (SF)	6,059,409
Smallest Building, SF	1,000
Largest Building, SF	450,000

6.2 SUMMARY OF EX POST LOAD IMPACT ESTIMATES

Table 6-3 shows a summary of the ex post load impacts for the Industrial Sector Lighting Measures installed during PY97.

Table 6-3
Summary of Ex Post Load Impacts
Lighting Measures
PY97 Industrial EEI Program

		kWh Savings	kW Reduced
Ex Ante	Total Gross	3,846,053	818.47
	Total Net	3,382,703	713.89
Ex Post	Total Gross	3,729,651	761.92
	Total Net	3,647,831	745.21
	Net-To-Gross Ratio	0.98	0.98
	Gross Realization Rate	97.0%	93.1%
	Net Realization Rate	107.8%	104.4%

6.3 *EX POST* EVALUATION APPROACH

To evaluate the lighting measures, on-site verification visits were conducted at a sample of buildings. During these visits:

- the installation of the measures was verified and quantified;
- light loggers were installed and remained in place for a period of time to estimate hours of operation and/or interviews were conducted to verify operating characteristics if logging was not possible; and
- spot measurements of a sample of fixtures were taken to estimate *ex post* connected watts.

The data collected were used to estimate adjustment factors for:

- measure installation
- hours of operation
- post-retrofit connected watts

These factors were combined to provide ex post adjustment factors that were used to extrapolate the sample ex post load impacts to the program population.

6.4 *EX POST* LOAD IMPACT ESTIMATES

A simplified engineering approach with verified inputs was used to evaluate the lighting program. On-site surveys of measure installation, spot measurement of post-retrofit fixture wattages, and the monitoring of the hours of operation were data collection methods used.

6.4.1 Sampling

The sample for lighting measures was selected at the building level, as identified by the Project No. (known as the *site_nbr* on the tracking system datasets), with individual lighting measures being aggregated by building. Total load impacts for each building were used as the sampling variable. A stratified sample was developed using the Dalenius-Hodges approach. A sample design with three strata was used. Buildings to be surveyed in Strata 1 and 2 were randomly selected. Stratum 3 was a certainty group. Table 6-4 provides an overview of the sample design.

Table 6-4
Ex Ante Load Impacts by Measure Category
Lighting Measures
PY97 Industrial EEI Program

Stratum	N	Ex Ante kWh Savings	n	Min. kWh Savings	Max kWh Savings
1	48	80,866	2	281	3,088
2	29	208,872	2	3,369	14,319
3	24	3,556,315	24	15,231	1,164,076
Total	**101**	**3,846,053**	**28**		

6.4.2 Ex Post kWh Savings for Nonresidential Buildings

This section presents the estimation of *ex post* kWh savings for the measures installed in nonresidential buildings during PY97.

Estimation of Adjustment Factors

Several adjustment factors were estimated for hours of operation, measure installation and post-retrofit connected watts, as described previously. These factors were developed to ultimately adjust the gross *ex ante* load impacts to reflect the conditions observed during the *ex post* on-site verification survey. This section describes the estimation of these adjustment factors.

Measure Installation

Measure installations were verified and quantified. An adjustment factor was calculated for each measure in each building surveyed by the following equation:

$$\text{RR Measure Installation}_{\text{Measure Level}} = \frac{\text{Verified Ex Post Measure Counts}}{\text{Ex Ante Measure Count}}$$

An adjustment factor for each building surveyed was estimated by calculating the weighted average of RR Measure Installation$_{\text{Measures Level}}$ based on ex ante kWh savings.

$$\text{RR Measure Installation}_{\text{Building}} = \sum\left(\text{RR Measure Installation}_{\text{Measure Level}} \times \frac{\text{Ex Ante kWh for Measure}}{\text{Ex Ante kWh for Building}}\right)$$

Table 6-5 shows examples of these calculations for two projects.

Table 6-5
Example of Calculation of Adjustment Factor Measure Installation
Lighting Measures
PY97 Industrial EEI Program

Project No.	Strata	Measure Description	Ex Ante Quan.	Verified Quan.	RR Meas. Installation Measure Level	Ex Ante kWh for Measure	Ex Ante kWh for Project	kWh Measure / kWh Proj.	AF Meas x (kWh Measure /kWh Bldg)	AF Meas. Install. Project Level
50410	1	Exit Sign LED 1 Side with Battery	6	6	1.0000	1685	2,247	0.7499	0.7499	
50410	1	Exit Sign LED 2 Side with Battery	2	2	1.0000	562		0.2501	0.2501	
50410 Total							**2,247**	**1.0000**		**1.0000**
39646	3	4FO32/1B4T8-4L	28	28	1.0000	48384	326,168	0.1483	0.1483	
39646	3	1MH250	89	89	1.0000	97128		0.2978	0.2978	
39646	3	1MH250	118	118	1.0000	146703		0.4498	0.4498	
39646	3	Install Occupancy Sensors	52	52	1.0000	7808		0.0239	0.0239	
39646	3	Install Occupancy Sensors	53	53	1.0000	16901		0.0518	0.0518	
39646	3	Install Occupancy Sensors	6	6	1.0000	983		0.0030	0.0030	
39646	3	Install Occupancy Sensor	1	1	1.0000	607		0.0019	0.0019	
39646	3	T-8 El Bal (4ft/2la)	17	17	1.0000	726		0.0022	0.0022	
39646	3	32 Watt lamp	34	34	1.0000	264		0.0008	0.0008	
39646	3	11-15W CFL	6	1	0.1667	1095		0.0034	0.0006	
39646	3	2FO17/1B2-17T8/1R2-D2	17	17	1.0000	3146		0.0096	0.0096	
39646	3	21-25W CFL	8	0	0.0000	2423		0.0074	0.0000	
39646 Total							**326,168**	**1.0000**		**0.9898**

Table 6-6 shows the Realization Rate for Measure Installation at the Project Level for each of the surveyed buildings.

Table 6-6
Adjustment Factor Measure Installation - Project Level
Lighting Measures
PY97 Industrial EEI Program

Project No.	Stratum	AF Meas. Installation @ Project Level
48403	1	1.0000
50410	1	1.0000
49553	2	1.0000
50809	2	1.0000
39646	3	0.8799
46257	3	1.0000
46445	3	1.0000
46505	3	1.0000
46630	3	1.0000
46894	3	1.0000
47060	3	1.0000
47448	3	1.0000
47590	3	0.6667
47701	3	1.0000
47702	3	1.0000
47758	3	1.0000
48035	3	0.0000
48129	3	1.0000
48643	3	1.0000
48800	3	1.0000
48986	3	1.0000
49022	3	1.0000
49082	3	1.0000
49334	3	1.0000
49551	3	1.0000
49842	3	1.0000
50114	3	1.0000
50661	3	1.0000

Hours of Operation

The *ex post* hours of operation for the lighting fixtures was estimated using light loggers that record the number of hours the light fixtures are on. Two types of light loggers were used: (1) run-time loggers that gather data on an aggregate basis; and (2) time-of-use (TOU) loggers that collect data allowing the estimation of the number of hours a fixture is turned-on on a time differentiated basis. The TOU logger data were downloaded from the logger via a serial port of a PC, and are accessible through proprietary software called SmartWare Ver. 3.2 from Pacific Science & Technology, Inc.

The *ex post* hours of operation was estimated for each site through the installation of light loggers at each facility, except for LED Exit Sign measures. In most cases several loggers were installed throughout the building. Each building was surveyed for the space use, as determined by the homogeneity of lighting use within the space use type. For example, open office space is used differently from private office space, thus, they would be logged separately. The percent of building space by space type was recorded for each logger installed. The percent of time the lights are on (*percent on*) was calculated for each logger. *Building-specific percent on* were calculated by taking a weighted average of the logger *percent on* within a building, weighting by the space use type. The ex post hours of operation for each building was calculated by multiplying the *building-specific percent on* by 8,760 hours per year. Ex ante building-specific weighted average hours of operation was calculated for using *ex ante* gross kWh savings as the weight, to account for the magnitude of impacts of the individual measures. Adjustment factors were calculated for each building by dividing the *ex post* hours by *ex ante* hours.

Table 6-7 shows examples of the calculations for the Realization Rate for Hours of Operation.

Table 6-7
Example of Calculation of Adjustment Factor for Hours
Lighting Measures
PY97 Industrial EEI Program

Project No.	Space Use	Space Use Weight	Percent On	Weighted Part Percent On	Weighted Percent On	Ex Post Hours	Ex Ante Hours	Adjustment Factor Hours-Building
46630	production	0.275	0.564	0.155				
46630	production	0.275	0.539	0.148				
46630	open office	0.150	1.000	0.150				
46630	open office	0.150	1.000	0.150				
46630	open office	0.150	1.000	0.150				
46330	**Total**				**0.753**	**6,599**	**4,176**	**1.5803**
47701	open office	0.200	0.329	0.066				
47701	warehouse	0.400	0.506	0.202				
47701	production	0.200	0.697	0.139				
47701	production	0.200	0.274	0.055				
47701	**Total**				**0.462**	**4,050**	**6,766**	**0.5985**

Table 6-8 shows the adjustment factors for hours at the building level for each surveyed building.

Table 6-8
Adjustment Factor for Hours - Project Level
Lighting Measures
PY97 Industrial EEI Program

Project No.	Stratum	Adjustment Factor Hours
48403	1	1.0000
50410	1	1.0000
49553	2	1.0000
50809	2	1.0000
39646	3	0.9142
46257	3	1.0867
46445	3	0.5729
46505	3	1.3883
46630	3	1.5803
46894	3	0.7575
47060	3	0.9322
47448	3	0.7807
47590	3	2.0306
47701	3	0.5986
47702	3	0.0111
47758	3	0.4140
48035	3	0.0000
48129	3	1.0949
48643	3	1.0000
48800	3	1.2082
48986	3	1.0000
49022	3	1.0000
49082	3	0.7049
49334	3	1.2633
49551	3	1.0000
49842	3	1.0000
50114	3	1.1495
50661	3	1.0000

Post-Retrofit Connected Watts

The connected watts of postcase light fixtures were measured ex post. These spot measurements were used to estimate the adjustment factor for connected watts for the fixtures installed under the program for each project surveyed. These measurements were divided by the *ex ante* assumptions of the connected watts of post-retrofit fixtures to estimate the adjustment factor for connected watts.

Volts and amps were measured. The power factor was assumed to be 1.00.

An adjustment factor for connected watts was estimated for each measure in each project. The adjustment factor was calculated by dividing the *ex ante* watts by the *ex post* watts for each measurement. Thus, if *ex post* watts is greater than *ex ante*, then the *ex post* load impacts will be less than the *ex ante* and the adjustment factor would be less than 1.0. Conversely, if the *ex post* watts were less than *ex ante*, then the *ex post* load impacts will be greater than the *ex ante*, and the adjustment factor would be greater than 1.0. A weighted average adjustment factor was estimated for each project. The weights were based on the kWh savings for each measure. Table 6-9 shows an example of the calculation of the adjustment factor for connected watts at the project level.

Table 6-9
Example of Calculation of Adjustment Factor for Connected Watts - Project Level
Lighting Measures
PY97 Industrial EEI Program

Project No.	Fixture Description	No. Fix.	Meas. Volts	Meas. Amps	Power Factor	Ex Post Watts	Ex Ante Watts	AF Watts EA/EP Measure Level	Ex Ante kWh Savings per Measure	Ex Ante kWh Savings per Project	AF Watts Project Level
50809	Exit Sign LED 1 sided	1	7.53	0.240	1.000	6.8	7.95	1.1691	3,650	4,212	
50809	Exit Sign LED 2 sided	1	7.65	0.240	1.000	6.8	7.95	1.1691	562	4,212	
50809	**Total**										**1.1691**
46630	T8 EL BAL 4ft/2LA	1	269.7	0.220	1.000	59.3	58	0.9781	12,055	21,125	
46630	T8 EL BAL 4ft/2LA REF	1	268.9	0.230	1.000	61.8	58	0.9385	9,070	21,125	
46630	**Total**										**0.9611**

Calculation of Ex Post kWh Impacts

The ex post kWh savings were estimated by calculating an overall adjustment factor for each surveyed building. The following equation was used:

$$\begin{aligned}\text{Adjustment Factor}_{\text{Overall, Building}} &= \text{Adjustment Factor}_{\text{Measure Installation}} \\ &\times \text{Adjustment Factor}_{\text{Hours}} \\ &\times \text{Adjustment Factor}_{\text{Watts}}\end{aligned}$$

For the surveyed buildings in Strata 1 and 2, the average of the Adjustment $\text{Factor}_{\text{Overall, Building}}$ was calculated for each stratum, resulting in the Adjustment $\text{Factor}_{\text{Overall, Stratum}}$. The ex post kWh impacts for each stratum were estimated by multiplying the Adjustment $\text{Factor}_{\text{Overall, Stratum}}$ by the total ex ante kWh savings for the stratum.

$$\text{Adjustment Factor}_{\text{Overall, Stratum i}} = \frac{\sum_{j=1}^{n} \text{Adjustment Factor}_{\text{Overall, Building in Stratum i}}}{n}$$

where:

n = number of surveyed buildings in Stratum i

For the Stratum 3, the certainty stratum, the ex post kWh savings for all projects in the stratum were estimated by multiplying the Adjustment $\text{Factor}_{\text{Overall, Building}}$ by the ex ante kWh savings.

The total program ex post kWh savings was calculated by summing the ex post kWh savings for the three strata.

The results of these calculations is shown in Table 6-10.

Table 6-10
Ex Post Gross kWh Savings Estimate
Lighting Measures
PY97 Industrial EEI Program

Project No.	Stratum	Ex Ante kWh Savings	Adj. Factor Measures Installed	Adj. Factor Hours of Operation	Adj. Factor Connected Watts	Overall Adj. Factor Bldg.(Meas x Hrs x Watts)	Overall Adj. Factor Stratum	Ex Ante kWh Savings Stratum	Ex Post Gross kWh Savings
48403	1	1,124	1.0000	1.0000	1.3033	1.3033			
50410	1	2,247	1.0000	1.0000	1.2328	1.2328			
Stratum 1 Total							**1.2680**	**80,859**	**102,532**
49553	2	3,440	1.0000	1.0000	1.3475	1.3475			
50809	2	4,503	1.0000	1.0000	1.1691	1.1691			
Stratum 2 Total							**1.2583**	**208,868**	**262,816**
39646	3	366,910	0.8799	0.9142	1.0156	0.8170		366,910	299,774
46257	3	1,164,076	1.0000	1.0867	1.0265	1.1155		1,164,076	1,298,530
46445	3	34,332	1.0000	0.5729	0.9144	0.5238		34,332	17,985
46505	3	102,737	1.0000	1.3883	0.9853	1.3679		102,737	140,535
46630	3	33,604	1.0000	1.5803	0.9611	1.5188		33,604	51,037
46894	3	200,188	1.0000	0.7575	0.8992	0.6812		200,188	136,367
47060	3	57,433	1.0000	0.9322	0.8667	0.8079		57,433	46,401
47448	3	79,941	1.0000	0.7807	1.0030	0.7831		79,941	62,599
47590	3	547,447	0.6667	2.0306	0.8095	1.0959		547,447	599,965
47701	3	51,125	1.0000	0.5986	1.0105	0.6048		51,125	30,922
47702	3	46,252	1.0000	0.0111	1.0000	0.0111		46,252	512
47758	3	313,397	1.0000	0.4140	1.0531	0.4360		313,397	136,629
48035	3	67,641	0.0000	0.0000	1.0000	0.0000		67,641	-
48129	3	175,113	1.0000	1.0949	1.0384	1.1370		175,113	199,095
48643	3	16,585	1.0000	1.0000	0.9938	0.9938		16,585	16,481
48800	3	94,382	1.0000	1.2082	0.9039	1.0921		94,382	103,073
48986	3	40,149	1.0000	1.0000	1.2221	1.2221		40,149	49,064
49022	3	32,849	1.0000	1.0000	1.1558	1.1558		32,849	37,967
49082	3	21,367	1.0000	0.7049	0.9504	0.6700		21,367	14,315
49334	3	25,583	1.0000	1.2633	0.9752	1.2320		25,583	31,517
49551	3	15,884	1.0000	1.0000	1.2517	1.2517		15,884	19,882
49842	3	15,232	1.0000	1.0000	0.9138	0.9138		15,232	13,919
50114	3	37,242	1.0000	1.1495	0.9017	1.0365		37,242	38,602
50661	3	16,846	1.0000	1.0000	1.1357	1.1357		16,846	19,132
Total Gross kWh Savings								**3,846,042**	**3,729,651**
Gross Realization Rate									**97.0%**

6.4.3 Net Load Impacts

The net load impacts were calculated by estimating a net-to-gross ratio for each survey participant using the methodology described in Section 3.2. The project NTGR's were averaged to the stratum level for Strata 1 and 2, where they were applied to the ex post gross load impacts for the stratum. The NTGR's for Stratum 3 were applied to the individual project ex post gross load impacts. These net impacts were summed to the program level, as shown in Table 6-11.

Table 6-11
Ex Post Net kWh Savings Estimate
Lighting Measures
PY97 Industrial EEI Program

ID No.	Stratum	Ex Post Gross kWh Savings	Ex Post NTGR	NTGR Stratum	Net kWh Savings
48403	1		1.00		
50410	1		1.00		
Stratum 1 Total		**102,532**		**1.0000**	**102,532**
49553	2		1.00		
50809	2		1.00		
Stratum 2 Total		**262,816**		**1.0000**	**262,816**
39646	3	299,774	1.00	1.0000	299,774
46257	3	1,298,530	1.00	1.0000	1,298,530
46445	3	17,985	1.00	1.0000	17,985
46505	3	140,535	1.00	1.0000	140,535
46630	3	51,037	1.00	1.0000	51,037
46894	3	136,367	0.40	0.4000	54,547
47060	3	46,401	1.00	1.0000	46,401
47448	3	62,599	1.00	1.0000	62,599
47590	3	599,965	1.00	1.0000	599,965
47701	3	30,922	1.00	1.0000	30,922
47702	3	512	1.00	1.0000	512
47758	3	136,629	1.00	1.0000	136,629
48035	3	-	0.00	0.0000	0
48129	3	199,095	1.00	1.0000	199,095
48643	3	16,481	1.00	1.0000	16,481
48800	3	103,073	1.00	1.0000	103,073
48986	3	49,064	1.00	1.0000	49,064
49022	3	37,967	1.00	1.0000	37,967
49082	3	14,315	1.00	1.0000	14,315
49334	3	31,517	1.00	1.0000	31,517
49551	3	19,882	1.00	1.0000	19,882
49842	3	13,919	1.00	1.0000	13,919
50114	3	38,602	1.00	1.0000	38,602
50661	3	19,132	1.00	1.0000	19,132
Total kWh Savings		**3,729,651**			**3,647,831**
Total Net Ex Ante Savings					**3,382,703**
Net Realization Rate					**107.8%**
Ex Post NTGR					**0.98**

6.4.4 Ex Post kW Impacts

The *ex post* kW impact estimate was based on interviews with the site contact. During the interview a determination was made, based on report operating patterns, whether all or some of the lights at a facility would be operating at the time of SDG&E's system peak. Typically, a hot weekday during August, September or early October. During 1998 the system peak took place on August 31, 1998 at 3:30 P.M. The responses were used to estimate an adjustment factor that was used to adjust the ex ante kW estimate for each stratum. The results for the strata were summed to the program level. Table 6-12 shows the results of these calculations.

Table 6-12
Ex Post kW Impact Estimate
Lighting Measures
PY97 Industrial EEI Program

ID No.	Stratum	Ex Ante kW Reduced Project	Ex Ante kW Reduced Stratum	Fraction On at Peak	On Peak Adjustment Factor	Ex Post Peak kW
48403	1	0.12		1.00		
50410	1	0.25		1.00		
Stratum 1 Total			**9.87**		**1.00**	**9.87**
49553	2	0.39		1.00		
50809	2	0.51		1.00		
Stratum 2 Total			**29.01**		**1.00**	**29.01**
39646	3	105.05		1.00	1.00	105.05
46257	3	245.99		1.00	1.00	245.99
46445	3	5.10		1.00	1.00	5.1
46505	3	23.80		1.00	1.00	23.8
46630	3	7.54		1.00	1.00	7.54
46894	3	46.41		1.00	1.00	46.41
47060	3	13.30		1.00	1.00	13.3
47448	3	19.04		1.00	1.00	19.04
47590	3	126.90		1.00	1.00	126.9
47701	3	7.98		1.00	1.00	7.98
47702	3	0.00		0.00	0.00	0
47758	3	37.65		1.00	1.00	37.65
48035	3	45.61		0.00	0.00	0
48129	3	32.93		1.00	1.00	32.93
48643	3	1.90		1.00	1.00	1.9
48800	3	21.88		0.50	0.50	10.94
48986	3	4.58		1.00	1.00	4.58
49022	3	3.75		1.00	1.00	3.75
49082	3	2.47		1.00	1.00	2.47
49334	3	6.49		1.00	1.00	6.49
49551	3	1.81		1.00	1.00	1.81
49842	3	1.74		1.00	1.00	1.74
50114	3	15.75		1.00	1.00	15.75
50661	3	1.92		1.00	1.00	1.92
Total kW Reduced						**761.92**
Total Ex Post Gross kW Reduced						761.92
Total Ex Ante Gross kW Reduced						818.47
Gross Realization Rate						93.1%
Ex Post NTGR						0.98
Ex Post Net kW Reduced						745.21
Ex Ante Net kW Reduced						713.89
Net Realization Rate						104.4%

A

REVISED TABLE E-3

B

TABLE 6 - PROCESS MEASURES

SAN DIEGO GAS & ELECTRIC

M&E PROTOCOLS TABLE 6 - RESULTS USED TO SUPPORT PY97 SECOND EARNINGS CLAIM FOR INDUSTRIAL ENERGY EFFICIENCY INCENTIVES PROGRAM

FIRST YEAR LOAD IMPACT EVALUATION, February 1999, STUDY ID NO. 1019

Designated Unit of Measurement: Load Impacts per Project

End Use: Process

				5. A. 90% Confidence Level				5. B. 80% Confidence Level			
				Lower Bound	Upper Bound	Lower Bound	Upper Bound	Lower Bound	Upper Bound	Lower Bound	Upper Bound
1. Average Participant Group and Average Comparison Group		**Part Group**	**Comp Group**	**Part Group**	**Part Group**	**Comp Group**	**Comp Group**	**Part Group**	**Part Group**	**Comp Group**	**Comp Group**
A. Pre-install usage:	Pre-install kW	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Pre-install kWh	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Base kW	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Base kWh	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Base kW/ designated unit of measurement	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Base kWh/ designated unit of measurement	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
B. Impact year usage:	Impact Yr kW	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Impact Yr kWh	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Impact Yr kW/designated unit	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Impact Yr kWh/designated unit	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2. Average Net and Gross End Use Load Impacts		**Avg Gross**	**Avg Net**	**Avg Gross**	**Avg Gross**	**Avg Net**	**Avg Net**	**Avg Gross**	**Avg Gross**	**Avg Net**	**Avg Net**
	A. i. Load Impacts - kW	56.97	56.35	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	A. ii. Load Impacts - kWh	446,156	431,679	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	A. iii. Load Impacts - therm	58,449	48,380	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	B. i. Load Impacts/designated unit - kW	53.8814	53.2672	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	B. ii. Load Impacts/designated unit - kWh	514,296.3	497,633.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	B. iii. Load Impacts/designated unit - therm	53,657	44,412	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	C. i. a. % change in usage - Part Grp - kW	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	C. i. b. % change in usage - Part Grp - kWh	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	C. ii. a. % change in usage - Comp Grp - kW	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	C. ii. b. % change in usage - Comp Grp - kWh	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
D. Realization Rate:	D.A. i. Load Impacts - kW, realization rate	0.67	0.66	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	D.A. ii. Load Impacts - kWh, realization rate	0.79	0.77	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	D.A. iii. Load Impacts - therm, realization rate	1.15	1.06	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	D.B. i. Load Impacts/designated unit - kW, real rate	0.67	0.67	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	D.B. ii. Load Impacts/designated unit - kWh, real rate	0.79	0.77	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	D.B. iii. Load Impacts/designated unit - therm, real rate	1.15	1.06	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3. Net-to-Gross Ratios		**Ratio**		**Ratio**	**Ratio**			**Ratio**	**Ratio**		
	A. i. Average Load Impacts - kW	0.99		N/A	N/A			N/A	N/A		
	A. ii. Average Load Impacts - kWh	0.97		N/A	N/A			N/A	N/A		
	A. iii. Average Load Impacts - therm	0.83		N/A	N/A			N/A	N/A		
	B. i. Avg Load Impacts/designated unit of measurement - kW	0.99		N/A	N/A			N/A	N/A		
	B. ii. Avg Load Impacts/designated unit of measurement - kWh	0.97		N/A	N/A			N/A	N/A		
	B. iii. Avg Net Load Impacts/designated unit of measurement - therm	0.83		N/A	N/A			N/A	N/A		
	C. i. Avg Load Impacts based on % chg in usage in Impact year relative to Base usage in Impact year - kW	N/A		N/A	N/A			N/A	N/A		
	C. ii. Avg Load Impacts based on % chg in usage in Impact year relative to Base usage in Impact year - kWh	N/A		N/A	N/A			N/A	N/A		
	C. iii. Avg Load Impacts based on % chg in usage in Impact year relative to Base usage in Impact year - therm	N/A		N/A	N/A			N/A	N/A		
4. Designated Unit Intermediate Data		**Part Group**	**Comp Group**	**Part Group**	**Part Group**	**Comp Group**	**Comp Group**	**Part Group**	**Part Group**	**Comp Group**	**Comp Group**
	A. Pre-install average value	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	B. Post-install average value	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
6. Measure Count Data		**Number**									
	A. Number of measures installed by participants in Part Group	65									
	B. Number of measures installed by all program participants in the 12 months of the program year	84									
	C. Number of measures installed by Comp Group	N/A									
7. Market Segment Data		**SIC**	**Percent**								
	Distribution by 3 digit SIC	154	2.9								
		205	5.9								
		282	2.9								
		283	8.8								
		308	8.8								
		339	2.9								
		343	2.9								
		344	2.9								
		347	2.9								
		351	2.9								
		352	2.9								
		357	2.9								
		358	2.9								
		367	17.6								
		372	8.8								
		373	2.9								
		376	5.9								
		381	2.9								
		382	2.9								
		384	2.9								
		399	2.9								

C

TABLE 6 - MOTOR MEASURES

SAN DIEGO GAS & ELECTRIC

M&E PROTOCOLS TABLE 6 - RESULTS USED TO SUPPORT PY97 SECOND EARNINGS CLAIM FOR INDUSTRIAL ENERGY EFFICIENCY INCENTIVES PROGRAM

FIRST YEAR LOAD IMPACT EVALUATION, February 1999, STUDY ID NO. 1019

Designated Unit of Measurement: Load Impacts per Horsepower

End Use: Motors

				5. A. 90% Confidence Level				5. B. 80% Confidence Level			
				Lower Bound	Upper Bound	Lower Bound	Upper Bound	Lower Bound	Upper Bound	Lower Bound	Upper Bound
1. Average Participant Group and Average Comparison Group		**Part Group**	**Comp Group**	**Part Group**	**Part Group**	**Comp Group**	**Comp Group**	**Part Group**	**Part Group**	**Comp Group**	**Comp Group**
A. Pre-install usage:	Pre-install kW	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Pre-install kWh	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Base kW	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Base kWh	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Base kW/ designated unit of measurement	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Base kWh/ designated unit of measurement	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
B. Impact year usage:	Impact Yr kW	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Impact Yr kWh	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Impact Yr kW/designated unit	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Impact Yr kWh/designated unit	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2. Average Net and Gross End Use Load Impacts		**Avg Gross**	**Avg Net**	**Avg Gross**	**Avg Gross**	**Avg Net**	**Avg Net**	**Avg Gross**	**Avg Gross**	**Avg Net**	**Avg Net**
	A. i. Load Impacts - kW	0.40	0.26	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	A. ii. Load Impacts - kWh	2,178	1,024	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	A. iii. Load Impacts - therm	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	B. i. Load Impacts/designated unit - kW	0.0129	0.0083	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	B. ii. Load Impacts/designated unit - kWh	70.3	33.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	B. iii. Load Impacts/designated unit - therm	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	C. i. a. % change in usage - Part Grp - kW	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	C. i. b. % change in usage - Part Grp - kWh	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	C. ii. a. % change in usage - Comp Grp - kW	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	C. ii. b. % change in usage - Comp Grp - kWh	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
D. Realization Rate:	D.A. i. Load Impacts - kW, realization rate	0.79	0.68	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	D.A. ii. Load Impacts - kWh, realization rate	1.08	0.68	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	D.A. iii. Load Impacts - therm, realization rate	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	D.B. i. Load Impacts/designated unit - kW, real rate	1.29	1.11	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	D.B. ii. Load Impacts/designated unit - kWh, real rate	1.05	0.66	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	D.B. iii. Load Impacts/designated unit - therm, real rate	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3. Net-to-Gross Ratios		**Ratio**		**Ratio**	**Ratio**			**Ratio**	**Ratio**		
	A. i. Average Load Impacts - kW	0.64		N/A	N/A			N/A	N/A		
	A. ii. Average Load Impacts - kWh	0.47		N/A	N/A			N/A	N/A		
	A. iii. Average Load Impacts - therm	N/A		N/A	N/A			N/A	N/A		
	B. i. Avg Load Impacts/designated unit of measurement - kW	0.64		N/A	N/A			N/A	N/A		
	B. ii. Avg Load Impacts/designated unit of measurement - kWh	0.47		N/A	N/A			N/A	N/A		
	B. iii. Avg Net Load Impacts/designated unit of measurement - therm	N/A		N/A	N/A			N/A	N/A		
	C. i. Avg Load Impacts based on % chg in usage in Impact year relative to Base usage in Impact year - kW	N/A		N/A	N/A			N/A	N/A		
	C. ii. Avg Load Impacts based on % chg in usage in Impact year relative to Base usage in Impact year - kWh	N/A		N/A	N/A			N/A	N/A		
	C. iii. Avg Load Impacts based on % chg in usage in Impact year relative to Base usage in Impact year - therm	N/A		N/A	N/A			N/A	N/A		
4. Designated Unit Intermediate Data		**Part Group**	**Comp Group**	**Part Group**	**Part Group**	**Comp Group**	**Comp Group**	**Part Group**	**Part Group**	**Comp Group**	**Comp Group**
	A. Pre-install average value	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	B. Post-install average value	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
6. Measure Count Data		**Number**									
	A. Number of measures installed by participants in Part Group	253									
	B. Number of measures installed by all program participants in the 12 months of the program year	157									
	C. Number of measures installed by Comp Group	N/A									
7. Market Segment Data		**SIC**	**Percent**								
	Distribution by 3 digit SIC	152	2.0								
		171	3.0								
		173	2.0								
		179	1.0								
		205	1.0								
		208	2.0								
		225	1.0								
		232	1.0								
		235	1.0								
		251	1.0								
		259	1.0								
		271	3.0								
		275	5.9								
		279	1.0								
		282	1.0								
		283	1.0								
		287	1.0								
		305	1.0								
		308	4.0								
		335	3.0								
		339	1.0								
		344	2.0								
		351	3.0								
		354	1.0								
		357	4.0								
		358	3.0								
		359	1.0								
		362	2.0								
		366	5.0								
		367	13.9								
		371	1.0								
		373	4.0								
		376	3.0								
		381	1.0								
		382	5.0								
		384	5.9								
		385	1.0								
		394	4.0								
		399	3.0								

D

TABLE 6 - LIGHTING MEASURES

SAN DIEGO GAS & ELECTRIC
M&E PROTOCOLS TABLE 6 - RESULTS USED TO SUPPORT PY97 SECOND EARNINGS CLAIM FOR INDUSTRIAL ENERGY EFFICIENCY INCENTIVES PROGRAM
FIRST YEAR LOAD IMPACT EVALUATION, FEBRUARY 1999, STUDY ID NO. 1019

Designated Unit of Measurement: LOAD IMPACTS PER AFFECTED SQUARE FOOT PER 1000 HOURS OF OPERATION.
End Use: Interior Lighting

				5. A. 90% CONFIDENCE LEVEL				5. B. 80% CONFIDENCE LEVEL			
				LOWER BOUND	UPPER BOUND	LOWER BOUND	UPPER BOUND	LOWER BOUND	UPPER BOUND	LOWER BOUND	UPPER BOUND
1. Average Participant Group and Average Comparison Group		**PART GRP**	**COMP GRP**	**PART GRP**	**PART GRP**	**COMP GRP**	**COMP GRP**	**PART GRP**	**PART GRP**	**COMP GRP**	**COMP GRP**
A. Pre-install usage:	Pre-install kW	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Pre-install kWh	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Base kW	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Base kWh	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Base kW/ designated unit of measurement	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Base kWh/ designated unit of measurement	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
B. Impact year usage:	Impact Yr kW	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Impact Yr kWh	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Impact Yr kW/designated unit	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Impact Yr kWh/designated unit	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2. Average Net and Gross End Use Load Impacts		**AVG GROSS**	**AVG NET**	**AVG GROSS**	**AVG GROSS**	**AVG NET**	**AVG NET**	**AVG GROSS**	**AVG GROSS**	**AVG NET**	**AVG NET**
	A. i. Load Impacts - kW	7.5438	7.3783	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	A. ii. Load Impacts - kWh	36,927	36,117	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	B. i. Load Impacts/designated unit - kW	0.1117	0.0000	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	B. ii. Load Impacts/designated unit - kWh	0.1358	0.0000	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	C. i. a. % change in usage - Part Grp - kW	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	C. i. b. % change in usage - Part Grp - kWh	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	C. ii. a. % change in usage - Comp Grp - kW	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	C. ii. b. % change in usage - Comp Grp - kWh	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Realization Rate:	D.A. i. Load Impacts - kW, realization rate	0.9309	1.0439	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	D.A. ii. Load Impacts - kWh, realization rate	0.9697	1.0784	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	D.B. i. Load Impacts/designated unit - kW, real rate	0.9310	0.0000	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	D.B. ii. Load Impacts/designated unit - kWh, real rate	0.9700	0.0000	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3. Net-to-Gross Ratios		**RATIO**		**RATIO**	**RATIO**			**RATIO**	**RATIO**		
	A. i. Average Load Impacts - kW	0.98		N/A	N/A			N/A	N/A		
	A. ii. Average Load Impacts - kWh	0.98		N/A	N/A			N/A	N/A		
	B. i. Avg Load Impacts/designated unit of measurement - kW	0.98		N/A	N/A			N/A	N/A		
	B. ii. Avg Load Impacts/designated unit of measurement - kWh	0.98		N/A	N/A			N/A	N/A		
	C. i. Avg Load Impacts based on % chg in usage in Impact year relative to Base usage in Impact year - kW	N/A		N/A	N/A			N/A	N/A		
	C. ii. Avg Load Impacts based on % chg in usage in Impact year relative to Base usage in Impact year - kWh	N/A		N/A	N/A			N/A	N/A		
4. Designated Unit Intermediate Data		**PART GRP**	**COMP GRP**	**PART GRP**	**PART GRP**	**COMP GRP**	**COMP GRP**	**PART GRP**	**PART GRP**	**COMP GRP**	**COMP GRP**
	A. Pre-install average value	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	B. Post-install average value	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

6. Measure Count Data		**NUMBER**
	A. Number of measures installed by participants in Part Group	10,897
	B. Number of measures installed by all program participants in the 12 months of the program year	11,978
	C. Number of measures installed by Comp Group	N/A

7. Market Segment Data		**SIC or CZ**	**PERCENT**
	Distribution by 3 digit SIC - Commercial/Industrial	SIC3	Percent
		152	2
		171	3
		173	2
		179	1
		205	1
		208	2
		225	1
		232	1
		235	1
		251	1
		259	1
		271	3
		275	5.9
		279	1
		282	1
		283	1
		287	1
		305	1
		308	4
		335	3
		339	1
		344	2
		351	3
		354	1
		357	4
		358	3
		359	1
		362	2
		366	5
		367	13.9
		371	1
		373	4
		376	3
		381	1
		382	5
		384	5.9
		385	1
		394	4
		399	3

E

TABLE 7

M&E PROTOCOLS TABLE 7
DATA QUALITY AND PROCESSING DOCUMENTATION
For 1997 Industrial Energy Efficiency Incentives Program
First Year Load Impact Evaluation
February 1999
Study ID No. 1019

A. OVERVIEW INFORMATION

1. **Study Title and Study ID:** 1997 Industrial Energy Efficiency Incentives Program: First Year Load Impact Evaluation, February 1997, Study ID No. 1019.

2. **Program, Program Year(s), and Program Description (design):** 1997 Industrial Energy Efficiency Incentives Program for the 1997 program year. The Program is designed to help industrial customers control energy costs by providing incentives for the installation of energy efficient equipment at their facilities.

3. **End Uses and/or Measures Covered:** All end uses combined disaggregated by process, interior lighting and motors.

4. **Methods and models used:** Site-specific simplified engineering models with verified inputs.

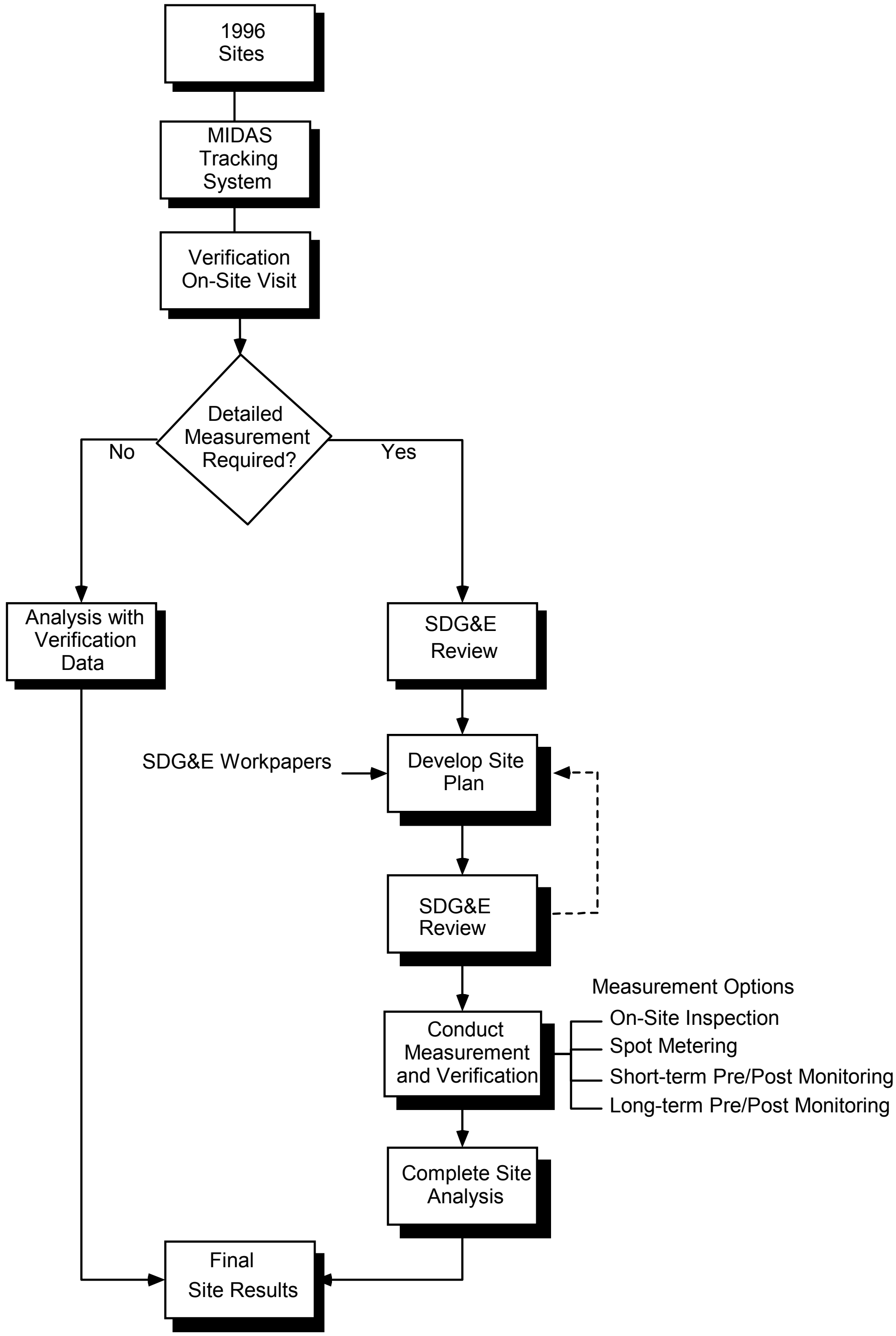
5. **Participant and comparison group definition:** For the load impact analysis, the participants in the 1997 Industrial Energy Efficiency Incentives Program are defined as having at least one of the aforementioned measures installed.

6. **Analysis sample size:**

Electric Participant Sample for 1997 Industrial Energy Efficiency Incentives Program			Gas Participant Sample for 1997 Industrial Energy Efficiency Incentives Program		
Measure Type	No. of Projects	No. of Measures	Measure Type	No. of Projects	No. of Measures
Interior Lighting	28	10,897	Interior Lighting	0	0
Process	18	60	Process	3	5
Motors	120	157	Motors	0	0
Total			Total	0	0

B. DATABASE MANAGEMENT

1. Flow Charts:



2. **Data sources:** the data came from the following sources:

   - Customer name, address, installed measures, and participation date from the program tracking database.
   - Electric and gas consumption history, where applicable, from the Customer Master File.
   - *Ex ante* engineering assumptions and analyses from program project files.
   - *Ex post* on-site survey data, including spot measurements, monitoring and verification of measure installation.

3. **Data Attrition:**

   a. **Participant Sample - Load Impact Analysis**

      No attrition.

   b. **Nonparticipant Sample - Load Impact Analysis**

      Not applicable.

4. **Data Quality Checks**

   Not applicable for this evaluation.

5. **All data collected** for this analysis were utilized.

C. SAMPLING

1. **Sampling procedures and protocols:** Process: : a stratified sample based on kWh savings. The Dalenius-Hodges stratification protocol with the Neyman Allocation was employed; the ex ante load impacts for the study participants were greater than 70 percent of the total ex ante gross load impacts were included in the survey for process measures. Lighting: a stratified sample based on kWh savings. The Dalenius-Hodges stratification protocol with the Neyman Allocation was employed. Motors: : a stratified sample based on kWh savings. The Dalenius-Hodges stratification protocol with the Neyman Allocation was employed.

2. **Survey information:** On-site inspections were conducted that included a review of operations logs, interviews of on-site staff, and measurements of the measures in operation.

3. **Statistical Descriptions:** Not applicable.

D. DATA SCREENING AND ANALYSIS

1. Outliers: Not applicable.

Missing data points: Not applicable.

Weather adjustments were implicit in the engineering models used in the evaluation.

2. "Background" variables: Not applicable.

3. Screening procedures: Not applicable.

4. Regression statistics: Not applicable.

5. Specification:

a. Not applicable.

b. Not applicable.

c. Not applicable.

d. Not applicable.

e. Not applicable.

6. Error in measuring variables: On-site observation of measure installation and on-site measurements were taken to mitigate possible errors from project files.

7. Autocorrelation: Not applicable.

8. Heteroskedasticity: Not applicable.

9. Collinearity: Not applicable.

10. Influential data points: Not applicable.

11. Missing Data: Not applicable.

12. Precision: Not applicable. Standard errors and other statistically based measures of precision are not applicable to the site-specific engineering analyses employed in this analysis.

E. DATA INTERPRETATION AND APPLICATION

1. **Calculation of net impacts:** Not applicable.

2. **Processes, choices made and rationale for E.1:** Not applicable.