Impact Evaluation of Pacific Gas and Electric Company's 1994 Industrial HVAC Programs

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This paper discusses the impact evaluation of the 1994 industrial-sector HVAC measures installed through Pacific Gas and Electric Company's (PG&E's) retrofit energy-efficiency programs. PG&E provided financial incentives for 264 energy-efficiency projects at 170 industrial sites in 1994. These incentives were delivered through PG&E's Retrofit Express and Retrofit Customized Programs. Measures included new chillers, cooling towers, variable-speed motor drives, energy management systems (EMS), and other HVAC upgrades. PG&E's ex-ante program savings estimates totaled 13,000 annual MWh, 3,900 peak kW, and 120,000 therms. Although the evaluation included development of ''net-to-gross'' ratios and net realization rates, this paper is limited to evaluation of gross savings at sample sites.

Customer sites were categorized into 10 groups by size of savings and then by technology. Sixty-six sites within the top seven groups accounted for approximately 96 percent of total program savings. Within these groups, a sample of 32 sites, representing 77 percent of total savings, was selected for on-site surveys and DOE-2 analysis. The 32 sample sites were evaluated using the DOE-2 energy simulation program in order to obtain an accurate assessment of energy and coincident peak demand savings by time-of-use period.

Evaluation results show gross realization rates of 83 percent for electrical energy, 39 percent for peak demand, and 59 percent for therms.[1] Results indicate a range of measured versus predicted performance. Equipment efficiency improvements (i.e. new chillers) performed as predicted. However, measures that rely on operational and/or control changes for savings (e.g. cooling towers and EMS retrofits) often did not perform as predicted.

INTRODUCTION

In 1994, PG&E provided financial incentives for 264 industrial-sector HVAC projects at 170 industrial sites. These incentives were delivered through PG&E's Retrofit Express and Retrofit Customized Programs. Program measures included new chillers, cooling towers, variable-speed motor drives, energy management systems (EMS), variable-volume air handlers, and other HVAC upgrades. PG&E's ex-ante program savings estimates totaled 13,000 annual MWh, 3,900 peak kW, and 120,000 therms. The DOE-2 energy simulation program was used to evaluate the majority of the energy-efficiency projects in the evaluation sample in order to obtain an accurate assessment of energy and demand savings by time-of-use period. Using DOE-2 required detailed on-site audits to define the baseline load profile and verify equipment performance and control strategies.

The paper provides an overview of the sample design methodology, a summary of gross savings results for the detailed analysis sites, and a brief discussion of reasons why certain measures did not perform as predicted. However, the focus of the paper is on the use of DOE-2 in the measurement of gross savings. The paper provides detailed examples of how DOE-2 was used to assess savings at the four sites with largest energy savings.

SAMPLE DESIGN METHODOLOGY

The sample design used information on the distribution of savings across sites and across measures. Customer sites were categorized into 10 groups by size of avoided-cost savings[2] and then by technology, based on the type of measure installed and rebate amount. The avoided-cost savings was used to determine the level of detail for data collection and depth of analysis. Table 1 summarizes the research design and sample plan regarding how sites were grouped together by savings and technology.

Four sites with savings amounts significantly higher than the rest were assigned to ''Group A: Largest Savings.'' These sites had total avoided costs greater than $4,000,000 with annual savings per site in excess of 800,000 kWh. They provided 49% of the total peak kilowatt (kW) savings and

Table 1. Research Design Summary and Sample Size for Detailed Analysis

	Population			Sample (On-Site Surveys & DOE-2)		
Measure Group	#	Avoided Cost	%	#	Avoided Cost	%
Group A: Sites with Largest Savings	4	$4,007,041	42.0	4	$4,007,041	42.0
Group B: Medium—Various	10	$1,908,734	20.0	6	$1,096,060	11.5
Group C: Smaller sites	14	$804,049	8.4	5	$321,198	3.4
Group CH: Chiller Replacement	8	$637,537	6.7	4	$399,176	4.2
Group CHT: Chiller and Tower	2	$428,377	4.5	2	$428,377	4.5
Group CT: Cooling Tower	11	$784,547	8.2	4	$548,847	5.8
Group V: VSDs	17	$598,933	6.3	11	$541,884	5.7
Group 2: Pkg unit w therm/timeswitch	52	$217,333	2.9	0	$0	0.0
Group 3: Thermostat & timeclock only	8	$61,710	0.6	0	$0	0.0
Group 4: Window film	44	$89,983	0.9	0	$0	0.0
Total	*170*	*$9,538,244*	*100.0*	*34*	*$7,447,485*	*77.0*

42% of avoided costs. Group A represents the three largest measure-groups: energy management systems (EMS), chiller replacement, and cooling towers. These sites received the highest priority. The evaluation for Group A sites consisted of site surveys, interviews with key staff, measurements of lighting and equipment loads, collection of equipment performance data, and detailed DOE-2 simulations.

The on-site audit included interviews with measurements of lighting and equipment loads, chilled water and condenser water temperatures, chiller power consumption, and cooling tower throughout the building.

Other sites were assigned to groups based on the dominant measure. Several homogeneous, measure-specific categories were identified to allow for a sampling strategy and similar technical approach within each group. These measure-specific groups include:

- Group CH: Chiller Replacement (only);
- Group CHT: Chiller and Cooling Tower replacement;
- Group CT: Cooling Tower (only); and
- Group V: Adjustable Speed Motor Drives (ASDs) for HVAC fans.

The remaining medium and smaller measures consist primarily of sites in which the dominant measure was a Customized Program measure that did not fit into a specific technology category under the Express Program. These are generally categorized ''controls,'' ''building shell,'' or general HVAC system modification (i.e., economizer, VAV conversion, chiller optimizer, etc.). Groups 2, 3, and 4 included 104 sites with small savings. Measures at these sites were verified, but no analysis was performed.

MEASURE EVALUATION USING DOE-2.1E

The DOE-2.1E building energy simulation program was used to model 31 out of 34 of industrial sites in the sample design. Modifications were required to model certain measures. Custom performance curves from manufacturers data were developed for chiller replacement measures. In general, detailed on-site audits and equipment or whole-building metered data were used for calibration.

A primary advantage of using DOE-2 for the project was in obtaining an accurate assessment of electricity and peak demand savings by time-of-use period. The powerful features available in DOE-2 for modeling building energy systems make it a very useful tool for evaluating the performance of industrial HVAC measures. Automated features such as the ‘‘parameters’’ and ‘‘input macros’’ features provide significant flexibility and economy in terms of loading and running the DOE-2.1E model. The ‘‘input macros’’ feature also provides the platform for VisualDOE (Eley 1995) and other programs that help simplify the creation of the building description language (BDL) input files.

The main disadvantage in using DOE-2 for the project was in fitting the unique systems and control strategies found at an industrial site into the DOE-2 model. For example, one site employed a unique EMS strategy of turning off 176 fan-powered boxes at night to conserve energy. This measure couldn't be modeled in DOE-2 without modifying the program (which was done). Many sites had multiple chillers of the same type, but with different operating efficiencies and performance curves. Many sites also had multiple cooling towers with different configurations and efficiencies. We found ways to model the chillers by substituting one set of performance curves for another to make a second or third hermetic reciprocating chiller with different efficiency. However, the sites with multiple cooling towers could not be modeled explicitly. For these sites we simply averaged the efficiencies of the towers (an acceptable albeit imperfect solution).

Since production, not energy, is the main priority at industrial sites, most facilities managers had more important things to do than spend time answering questions regarding the evaluation. In general, it was difficult to get detailed information to model the building energy systems. A few hours on site was generally all the time allowed to collect building data. Often we had to perform ‘‘detective’’ work in order to identify the equipment operation and control strategy, and describe it to the model in a way that reflected the actual operating strategy. In other cases we were forced to use incomplete information. Many sites included in the project were very complicated, having multiple buildings and multiple functions within each building. Most sites had large loads both inside and outside the conditioned spaces. These loads were often more than ten times larger than the HVAC loads. Many sites had multiple electric meters some with HVAC equipment for one building coming off another building's electric meter. This presented problems in terms of getting hourly metered data for the HVAC equipment and whole building. Some sites included areas that were ‘‘off limits’’ and inaccessible to our survey engineers due to confidential or proprietary processes or technologies. This made our job more difficult since the HVAC loads in these inaccessible areas were served by the cooling plant and had to be modeled in order to evaluate measure energy savings. Patience and persistence proved to be very helpful in understanding and in evaluating measure energy savings at each site.

Use of Visual DOE

Visual DOE (v. 1.0) was used as a BDL builder for 80 percent of the sites. Visual DOE provides a quick means to build a basic model for a site. However, the Visual DOE models were too limited and basic for this project. In order to increase the accuracy and detail to the model, modification of the input file produced by Visual DOE was necessary. The amount of modification necessary depended on the site and how well it had been represented in the original model. Typically zone dimensions and the systems serving the zones had to be modified. Additional attention was paid to the equipment being retrofitted in order to ensure that the actual retrofit and its operating strategy was accurately reflected in the pre and post models.

Visual DOE2 was only available at the end of the project and only the Beta version was reviewed. Visual DOE2 was far more flexible in zoning a facility and in its description of the systems serving the facility. Much of the customization that was needed in the earlier Visual DOE models could have been avoided with Visual DOE2.

Weather Types—Advantages and Disadvantages

In performing DOE 2.1E analysis, a choice of weather files needs to be made. Three types of weather files were available: Typical Meteorological Year (TMY), Adjusted TMY and Real Weather Data (CEC 1992, NCDC 1995).

Real weather from a PG&E weather station was used on a select number of sites both to validate the use of Adjusted TMY weather data and to ensure maximum accuracy for select sites (PG&E 1995). Adjusted TMY was determined to provide an excellent compromise between accuracy on local conditions and long term patterns and was used for the pre and post savings runs for all sites. Standard TMY data represents a good starting point for energy evaluation but were not used where more accurate information was available.

Standard TMY weather data are constructed by reviewing individual months of weather data from each weather station over a 23 year period. A typical month for each of the 12 calendar months from the long term period of record is chosen and then these 12 months are used to form the TMY. The basis of the selection for a typical month consists of 13 daily indices calculated from the hourly values of dry bulb and wet bulb temperature, wind velocity, and solar radiation. Month/year combinations that have statistics ‘‘close’’ to the long term statistics are candidates for typical months. Final selection of a typical month includes consideration of persistence of the weather patterns. TMY weather data represents a long term average for relatively large areas and suffers from representing diverse areas and not well representing individual areas.

An improvement on the TMY data is the adjusted TMY weather file. The California Energy Commission provides a program to adjust weather data to a particular city in California (CEC 1995). The program includes exact location adjustments which shrink or stretch the TMY temperatures as appropriate to the specific site. This type of data compared favorably with the Real Weather Data and was used for the energy savings and calibrations.

Real weather data are collected on an hourly basis at several PG&E weather stations. Collected data include dry bulb temperature and relative humidity. DOE 2.1E uses several additional pieces of weather information including wetbulb temperature, solar radiation, cloud cover, wind speed and direction, and other related pieces of weather information. In order to generate the wetbulb, humidity ratio and enthalpy values, a nominal barometric pressure of 29.92 in. Hg. was used along with the hourly drybulb and relative humidity values, and were processed using a psychometric program. We then replaced the corresponding TMY values with the new real data and left the other TMY values that were not represented in the new data.

Post Processing

Energy use at industrial sites is driven more by production activity than weather factors. At most sites included in the evaluation, peak demand occurred at a different hour than the PG&E system peak demand. PG&E required that peak demand savings for each site be reported at the system peak coincident hour for three summer and two winter time-of-use periods. PG&E also required that energy (kWh) savings be reported for the same five time-of-use periods. A post processor was developed to take the hourly DOE-2 simulation results and extract peak demand at the PG&E peak coincident hour. The post processor also extracted energy use during the same time-of-use periods.

Peak Days by Weather Zone

As the month chosen for inclusion in the TMY weather files (adjusted files have the same weather patterns) may differ between zones, peak days would need to be identified for each weather zone. As each project was analyzed, the correct peak days for the weather zone where the facility was located would need to be used. This was handled by the post processor which would pick off the correct hours for both pre and post data.

DOE-2 Analysis of Group A and ASD Sites

Characteristics for the four industrial sites with largest energy savings (Group A) are provided in Table 2. Sites A1 and A4 installed energy management control systems (EMS) and sites A2 and A3 installed new chillers and cooling towers. Interviews with key facilities managers and on-site surveys provided information necessary for the DOE-2 analysis. In addition, submetered or whole-building electric data and monthly billing data were obtained for calibration purposes. A slightly different approach was used to calibrate each site to measured data. Simulations were calibrated to within (5 percent of annual utility bills and (10 percent of monthly utility bills. This was considered acceptable for the project.

DOE-2 Analysis and Results for Site A1

A new energy management computer control system (EMS) was installed at site A1. Reported energy savings for the EMS are based on scheduling controls for the terminal fan powered boxes and the main air handling units. The site has 188 fan powered boxes and 10 main air handlers. The main air handlers work in tandem (i.e., 2 per plenum) to supply air to all zones during occupied hours. During unoccupied hours, the EMS turns off one-half of the main air handler fans (5 main fans) and 176 of the fan powered boxes. DOE-2 could not explicitly model either of these two measures. At our request, the Simulation Research Group at Lawrence Berkeley National Laboratory (SRG/LBNL) made modifications to the Powered Induction Unit (PIU) module in DOE-2 to provide a BDL zone fan schedule command (Buhl 1995, Hirsch 1995). However, SRG/LBNL was unable to provide DOE-2 program modifications to allow us to simulate turning off one-half of the main air handlers. We simulated the EMS control of main air handlers with a post-processor by subtracting one-half of the supply and return fan energy during unoccupied hours. We verified that one-half of the fans were off during unoccupied hours with field measurements. DOE-2 simulations for site A1 were calibrated within ± 10 percent using hourly whole building data and monthly billing data (kWh and kW) for the period before the retrofit was installed.

Reported savings for the EMS are 681,942 kWh/year (see Table 3). DOE-2 simulation results show energy savings of 119,371 kWh/year. As mentioned above, the reported savings are based on controlling 176 fan powered boxes to be turned off at night during unoccupied periods. An investigation of fan operating conditions revealed that the fan power boxes were at low speed or completely off during a considerable portion of the night before the EMS was installed.

Table 2. *Group A Industrial Site Characteristics*

	Site A1	Site A2	Site A3	Site A4
EEM	EMS	Chiller/Tower	Chiller/Tower	EMS
Calibration Method	Whole Bldg. Data	Whole Bldg. Data	Submetered Data	Submetered Data
Total Area (ft^2)	442,110	423,711	750,000	246,504
Number of Bldgs.	2	2	1	8
HVAC Systems	SVAV, Series, PIU	VAV, RHFS	RHFS	PSZ, RHFS
Chiller (tons)	1,630	3,600	2,812 pre-EEM 2,914 post-EEM	819 Pkg. Sys. 196 Herm. Rec.
Number of Chillers	4	6	3	25 PSZ, 1 Chiller
Tower (tons)	1,833	3640 pre-EEM 4017 post-EEM	3,600 pre-EEM 3,500 post-EEM	variable process
Tower Modules	4	4	3 pre-EEM 9 post-EEM	multiple
Equipment (W/ft^2)	1.4	2-11	2-7	2-58
Lighting (W/ft^2)	1.9	1-2	2	2

Table 3. *Evaluation Results vs. Reported Savings for Group A Industrial Sites*

	Site A1	Site A2		Site A3		Site A4	Total
Measure	EMS	Chiller	Tower	Chiller	Tower	EMS	All
Reported Savings kWh	681,942	896,070	123,760	581,460	584,896	1,114,212	3,982,340
Evaluation kWh	119,371	1,908,946	6,296	545,893	182,304	385,616	3,148,426
kWh Realization Rate	18%	213%	5%	94%	31%	35%	79%
Reported kW Savings	0	320	171	328	810	4	1,633
Evaluation kW	0	361	−3	218	14	−50	540
kW Realization Rate	100%	113%	−2%	66%	2%	−1250%	33%

DOE-2 Analysis and Results for Site A2

Two new 839 ton hermetic centrifugal chillers and a new 1,194 ton cooling tower were installed at site A2. The new chillers were rated at 0.511 kW/ton (ARI conditions) based on manufacturers data. Custom performance curves were developed for the new chillers based on data obtained from the manufacturer (see Table 4). The alternative baseline chillers were assumed to be 0.72 kW/ton as per California Title 20 standards. DOE-2 default performance curves were used for the baseline chillers. DOE-2 simulations for site A2 were calibrated using the same approach as for site A1.

Reported savings for the two new chillers are 896,070 kWh/year and 320 kW (see Table 3). Evaluation results show energy savings of 1,908,946 kWh/year and peak demand savings 355 kW. These higher savings are due to longer operating hours. The Express Program methodology assumed 2,100 full-load hours. The two new lead chillers actually operate 8,760 hours per year at between 30 and 100 percent of full load.

The new tower was oversized by 40 percent based on an 8.8° F approach temperature and a 68° F 0.5% ASHRAE design wet bulb temperature. Performance data for the new tower were obtained from the manufacturer. The alternative non-EEM tower would have been sized at 850 tons based on standard design using a 15° F approach temperature. The PG&E Industrial HVAC Program provided a sliding-scale incentive to lower the tower design approach temperatures to 4° to 10° F above the 0.5% ASHRAE design wet bulb temperature. Reported program savings assume the tower setpoint is 15° F above the 0.5% ASHRAE design wet bulb temperature. At site A2, the facilities manager was already operating the cooling tower at a setpoint temperature of 76.8° F before the new tower was installed. Savings for the new tower are also diluted by the fact that it was installed in parallel with three similar-sized existing towers. These two factors reduced the tower savings by 95 percent (see Table 3). Peak demand savings are almost nonexistent with the new tower (see Table 3). The larger tower has a bigger horsepower fan that offsets any gains due to oversizing on peak cooling days.

DOE-2 Analysis and Results for Site A3

One new 1,309 ton hermetic centrifugal chiller and a new 3,500 ton nine module cooling tower were installed at site A3. The new chiller was rated at 0.57 kW/ton (ARI conditions) based on manufacturers data. Custom performance curves were developed for the new chiller based on data obtained from the manufacturer (see Table 5). The alternative baseline chiller was assumed to be 0.72 kW/ton as per California Title 20 standards. DOE-2 default performance curves were used for the baseline chiller.

DOE-2 simulations were calibrated using hourly chiller data. Chiller kW and chiller tons were obtained from the energy management system for a period of four months in the summer. Hourly DOE-2 results were compared to the sub-metered chiller data and adjustments were made to BDL input file until the hourly data sets agreed within (10 percent.

Reported savings for the new chiller are 581,460 kWh/year and 328 kW (see Table 3). Evaluation results show energy savings of 545,893 kWh/year and peak demand savings 218 kW. The difference in peak demand savings is due to a discrepency in the PG&E Express Program reporting methodology.

Table 4. *DOE-2 Coefficients for New Hermetic Centrifugal Chiller at Site A1*

Coefficient	EIR-FT	CAP-FT	EIR-FPLR
a	−2.679908	−5.391102	0.169297
b	0.080478	0.105400	0.501853
c	−0.000792	−0.003465	0.328849
d	0.037548	0.093316	n/a
e	−0.000062	−0.001343	n/a
f	−0.000287	0.002738	n/a

Table 5. *DOE-2 Coefficients for New Hermetic Centrifugal Chiller at Site A2*

Coefficient	EIR-FT	CAP-FT	EIR-FPLR
a	11.856971	0.721582	0.243844
b	−0.651009	−0.001300	0.465497
c	0.006753	−0.002290	0.290659
d	0.090621	0.007757	n/a
e	−0.000611	−0.000888	n/a
f	0.000380	0.002813	n/a

The new tower was not oversized. Performance data for the new tower were obtained from the manufacturer. The new tower design approach temperature is 4° F above the 0.5% ASHRAE design wet bulb temperature or 73° F. Reported program savings assume the tower setpoint is 15° F above the 0.5% ASHRAE design wet bulb temperature. At site A3, the facilities manager was already operating the cooling tower at a setpoint temperature of 78° F before the new tower was installed. This reduced the tower savings by 69 percent (see Table 3). Similar to site A2, peak demand savings are almost nonexistent with the new tower (see Table 3). The new tower is not oversized, but has to work harder at the lower setpoint temperature (73° F versus 78° F). Thus, tower fan energy offsets any gains in compressor efficiency savings.

DOE-2 Analysis and Results for Site A4

A new EMS was installed at site A4 to provide automatic operation and control of the packaged HVAC equipment serving eight buildings. Before the EMS was installed all HVAC equipment was scheduled on 24 hours per day, seven days per week. After the EMS was installed the HVAC equipment schedules were set to 12, 18, and 24 hours per day depending on the zone.

DOE-2 simulations were calibrated using whole building hourly submetered data for a set of 8 buildings. The submetered data were grouped into weekday and weekend/holiday periods. DOE-2 simulations were created for each building and results were compared to the measured data. Once the results for all building were within ±10 percent, the DOE-2 simulations were combined and the total site simulations were run. Comparisons for the combined simulations were then compared to the combined measured data and adjustments were made to the BDL input file until both data sets were within ±10 percent.

Reported savings for the EMS installed at site A4 are 1,114,212 kWh/year (see Table 3). DOE-2 simulation results show energy savings of 385,616 kWh/year. Reported energy savings for the EMS measure assumed mostly 24-hour and 7 day per week operation of packaged HVAC units before the retrofit and 10-hour operation six days per week after the retrofit. However, the packaged units are actually on for 12, 18, and 24 hour periods after the retrofit. Therefore, savings for turning off the packaged units are only 35 percent of expected.

DOE-2 Analysis and Results for ASD Sites

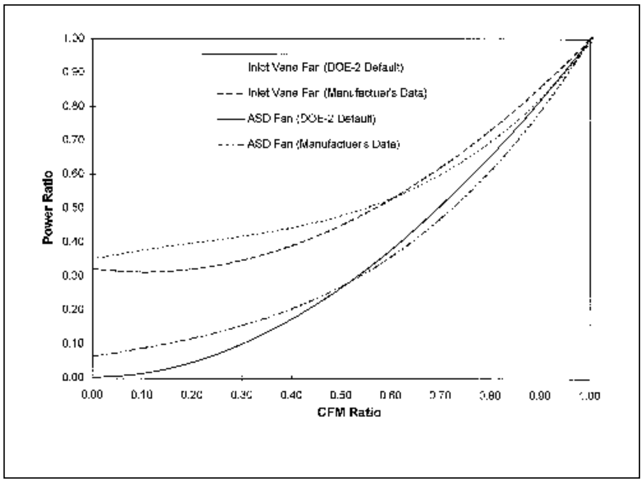
Seven ASD fan sites were evaluated using DOE-2. These sites represented about 50 percent of ASD savings (576,883 kWh), but only 6 percent of the total reported program savings. The other ASD sites were evaluated using a modified bin model and measured data. The pre-retrofit condition at each DOE-2 site was a packaged variable volume system (PVAVS) with constant speed fans and inlet vane control. The retrofit involved removing the inlet vanes and adding adjustable speed drives. The ASD fans are designed to maintain approximately 1.5 to 1.75 inches of total static pressure. Measured fan power, air flow rates, minimum cfm ratios, and default fan performance curves were used to model each PVAVS. The DOE-2 evaluation results indicated gross annual savings of 669,720 kWh; a realization rate of 116 percent for the seven sites.

Potential problems exist when using the default DOE-2 curves to evaluate energy savings for ASD fans. These problems can be illustrated by developing a set of custom performance curves for the inlet vane and ASD fan control strategies using manufacturers data. Coefficients and performance curves based on manufacturer's data are shown in Table 6 and Figure 1. The manufacturer's ASD fan curve includes the power required to maintain static pressure at low flow

Table 6. *DOE-2 Default and Custom Coefficients for Inlet Vane and ASD Fan Control Strategies (based on PVAVS w/forward-curved fan)*

Coefficient	DOE-2 Default Inlet Vane	Custom Inlet Vane	DOE-2 Default ASD	Custom ASD
a	0.35071223	0.32137620	0.00153028	0.06239894
b	0.30805350	−0.17790313	0.00520806	0.24370530
c	−0.54137360	0.88995010	1.10862420	−0.00242530
d	0.87198823	−0.03356508	−0.11635563	0.69666946

Figure 1. *DOE-2 Default Versus Custom Fan Performance Curves*



rates, while the DOE-2 default ASD curve does not. At low flow rates the manufacturer's inlet vane curve is 10% to 20% lower than the DOE-2 default curve.

Three of the seven DOE-2 sites were reexamined using the manufacturer's curves, and energy savings are generally 25% to 35% lower than the original evaluation results obtained using the DOE-2 default curves. Extrapolating the results based on the manufacturer's curves would reduce gross savings by approximately 200,000 kWh and lower the realization rate from 116% to 81% for the seven DOE-2 sites

This example, underscores the importance of checking the DOE-2 default values. In addition, checks must be made of subtle differences between DOE-2 system types. The original BDL input files for the DOE-2 sites were modeled with packaged variable-air volume (PVAV) systems. The supply fans were specified with ASD control, but the return fans defaulted to inlet vane control. For most other DOE-2 system types the return fans will default to the control specified for supply fans. However, the PVAV system requires separate keywords for supply and return fan control (since changed in version 113 of DOE-2.1E). If both fans had been properly specified the overestimate in savings due to using the DOE-2 default curves would have been much greater (about 90%).

OVERALL EVALUATION RESULTS

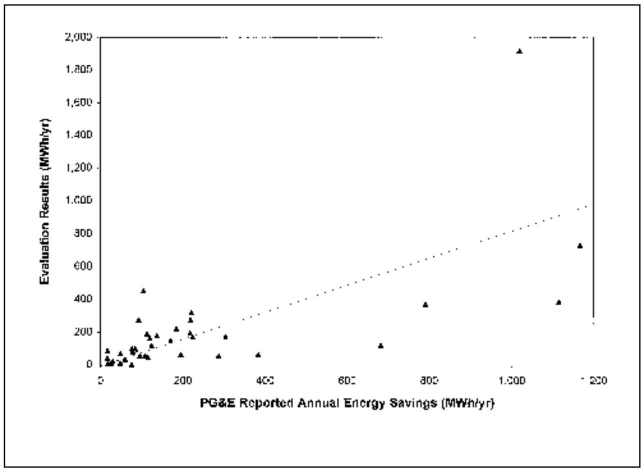
A summary of the gross evaluation results and realization rates for the detailed analysis sites are shown in Table 7 and Figure 2. Overall gross realization rates are 83 percent for

Table 7. *Evaluation Results for All Analyzed Sites*

	Large Savings	Medium Savings	Small Savings	Chiller Only	Chiller & Tower	Tower Only	ASD Fans	Total
Reported kWh	4,175,378	1,792,938	549,556	471,587	368,276	422,486	1,147,047	8,927,268
Evaluation kWh	3,496,634	600,665	680,707	1,032,545	165,955	324,507	1,113,241	7,414,254
kWh Realization	84%	34%	124%	219%	45%	77%	97%	83%
Reported kW	1,881	368	2	168	265	396	—	3,079
Evaluation kW	697	124	− 2.3	164	49	127	43	1,201
kW Realization	37%	34%	—	98%	18%	32%	—	39%
Reported therms	67,338	19,303	26,222	1,534	—	—	—	114,397
Evaluation therms	16,401	− 1,149	50,180	2,568	—	—	− 103	67,897
Therm Realization	24%	—	191%	167%	—	—	—	59%

Note: Total gross realization rates are based on unweighted results for the analyzed sites and do not represent overall program results. When sample weights are included the overall program realization rates are 87 percent for kWh, 39 percent for peak kW, and 57 percent for therms.

Figure 2. *Evaluation Results Versus PG&E Reported First Year Annual Energy Savings*



electrical energy (kWh), 39 percent for peak demand (kW), and 59 percent for therms. Realization rates vary significantly among the measure groups. Chillers were nearly at expectations for kW and nearly double the expected kWh savings. This is due to the fact that the PG&E Express program savings methodology assumed a moderate number of chiller operating hours. In actual practice the new chillers were being operated more hours at full-load operation. Low realization rates in Groups A, B, and C are primarily a result of system control modifications not performing as expected. Cooling tower kW and kWh savings were below projections. The evaluation found that actual tower control strategies conditions varied from the assumptions used in the PG&E's program audit methodology.

CONCLUSIONS

Evaluation results proved that savings are highly dependent on operations schedules, equipment performance and HVAC loads. Results indicate a range of measured versus predicted performance. Equipment efficiency improvements (i.e. new chillers) performed as predicted. However, measures that rely on operational and/or control changes for savings (e.g., cooling towers and EMS retrofits) often did not perform as predicted

DOE-2 is a useful tool for evaluating the performance of industrial HVAC measures. Care must be exercised in order to fit the unique systems, loading conditions, and control strategies found at an industrial site into the DOE-2 model. Default values must be checked to ensure that equipment performance at the site is modeled properly. Although some measures such as EMS strategies and chiller and tower configurations cannot be explicitly modeled with DOE-2, most measures can be modeled with reasonable accuracy.

For purposes of program level achievements and regulatory reporting, compensating errors in methodology or assumptions used in the program left the utility in reasonably good shape. However, for general technical awareness there are some serious problems that are likely to enter into the selling of EMS, ASD fan, and cooling tower retrofits. Care must be taken to avoid over-selling measures on the basis of energy savings that might not be realized.

ENDNOTES

1. Gross realization rates for the analyzed sites are based on unweighted results and do not represent overall program results. When sample weights are included the overall program realization rates are 87 percent for kWh, 39 percent for peak kW, and 57 percent for therms.

2. Avoided costs are net present value of overall energy savings (kWh, kW, and therms).

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