Does It Keep The Drinks Cold and Reduce Peak Demand? An Evaluation of a Vending Machine Control Program

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ABSTRACT

As part of the state of California's response to the well-publicized imbalance of electricity supply and demand, the California Legislature, through Senate Bill 5X, allocated funds for California municipal utilities to achieve electric demand reductions. As part of its SB5X portfolio of programs, SMUD implemented a Vending Machine Control Program through a third-party vendor. The vending machine controller uses an infrared sensor to detect occupancy of the surrounding environment, and powers down the vending machine during periods of no occupancy. SMUD's goal for this program was to deploy several thousand controllers within a short timeframe targeting primarily school districts and offices. The preliminary savings targets, based on limited information provided by the contractor, are to reduce summer capacity by 600 kW during the peak hours of 2 to 6 P.M. and reduce energy consumption by 3.0 million kWh/yr.

Limited objective data are available that verify the savings claims made by the controller manufacturer of savings averaging over 40% per unit. An evaluation study was undertaken to estimate the actual energy savings and demand reduction achieved by these controllers. Data loggers were used on a sample of units to measure power consumption with and without the controller and accurately measure the energy and demand impacts.

Introduction and Product Description

This section briefly describes the technology, the evaluation methodology, and presents preliminary analysis results of the monitoring activity.

The Vending Machine Control Program was rolled out mid-September 2001 and will continue until it is fully subscribed. As of April 2002, there were 2,256 controllers installed with estimated savings totaling 290 kW and 3.278 million kWh.

The vending machine controller manages the power to a vending machine by completely powering down the machine when the area is unoccupied, while still maintaining the desired product temperature, using the following strategy:

- The control automatically determines whether or not the compressor of the vending machine is operating.
- The control uses a custom occupancy sensor to determine if there is anyone within 40 feet of the machine. It waits for 15 minutes of vacancy, then completely powers off the vending machine, including compressor and display lighting. If the compressor is still running, power down is delayed until the cycle-in-process is completed.

- Once powered off, the control will monitor the room's temperature, and based on this measurement will automatically re-power the vending machine in 1.5 to 3.0 hours. At which time it runs a complete cooling cycle and then powers down again.
- If a customer approaches the vending machine while powered down, the control will sense the person's presence and power up immediately.

In some installations, the vending machine control installer de-lamped the vending machine, further reducing the vending machine's connected load.

SMUD's goal for this program is to reduce summer demand by 600 kW and reduce annual energy consumption by 3.0 million kWh, based on a target of 5,000 installations anticipated by the contractor. SMUD's program eligibility requirements include:

- Vending machine is used for refrigerated, non-perishable beverages (e.g. soda)
- Vending machine must be located indoors or in an area that is protected from vandalism, theft, and weather
- Vending machine is an upright unit (no chest type or manually operated machines)
- The vending machine is not in an area that experiences excessive foot traffic (e.g. in front of a store that is open 24 hours a day). Preferred locations are schools, office building break rooms, factory break rooms, etc.

The analysis used monitoring data from a sample of controlled vending machines to measure individual vending machine control savings and calculate overall program impacts. Brand Electronics digital power meters were used to measure and record the vending machine power draw over time. The loggers were installed on vending machines equipped with controls to record "post-controls" data for a period of 10 to 14 days. The controls were then disabled and "pre-controls" data were collected for an additional 5 to 10 days.

Post-controls and pre-controls data were compared to determine demand and energy savings resulting from the vending machine controls. Peak kW savings were calculated for the hours of 2 PM to 6 PM, and 1 PM to 9 PM during non-holiday weekdays. Peak kW and energy savings were calculated for each monitored machine. The individual results were then projected to represent the population of vending machines receiving controls through the program. Net savings were assumed to be equal to gross savings.

Sample Design

The sample for the Vending Machine Program was selected in phases. The decision to select the sample in phases was driven by the need to perform the on-site data collection as the implementation of the program was still on going.

At each sample selection phase, a random sample of buildings was selected with inclusion probabilities approximately proportional to the number of vending machine installations at the site. If the site had only a small number of installations, we attempted to monitor all installations at the site, while a sample of vending machines were selected for monitoring at sites with a large number of installations.

This paper reports on the results of monitoring the first 30 vending machines from the panned sample of 80 units. These 30 units were located at seven buildings drawn from a population of 950 buildings.

Case Weights and Extrapolation of Results

Model-Based Statistical Sampling (MBSS) methods were used to calculate the case weights used to extrapolate the sample findings to the program population. Model-based sampling methods and stratified ratio estimation were also used to analyze the data, i.e., to extrapolate the findings from the sample sites to the target population of all program participants and to evaluate the statistical precision of the results.

Calculating the Case Weights

Balanced stratification is the method we used to calculate the case weights. In this approach, the sample sites are sorted by the stratification variable, number of installations, and then divided equally among the strata. Then the first stratum cut point is determined midway between the values of the stratification variable for the last sample case in the first stratum and the first sample case in the second stratum. The remaining strata cut points are determined in a similar fashion. Then the population sizes are tabulated within each stratum. Finally the case weights are calculated in the usual way.

A sample of seven sites has been divided among four strata. Then the strata cut points shown in column two were calculated from the number of installations for the sample sites. Next the population sizes shown in column three were calculated from the stratum cut points. The final step was to calculate the case weights shown in the last column. For example, the case weight for the 2 sites in the first stratum is 806 / 2 = 403.

Figure 1. Balanced Stratification Example

Stratum	Max. # Units	Pop. Size	Pop. # Units	Sample Size	Case Weight
1	4	806	1,128	2	403
2	8	105	546	2	52.5
3	34	37	464	2	18.5
4	60	2	118	1	2
Total		**950**	**2,256**	**7**	

Data Collection & Analysis

Monitoring of Vending Machines

To estimate the energy and summer peak demand impacts of the Vending Machine Controls Program, the evaluation team plans to install data loggers on a sample of 80 participating vending machines. The impact analysis is based upon the monitored vending machine data. The overall sample design assumes a projected population of 5,000. A sample of 80 with an error ratio of 0.8 is expected to provide a relative precision of ±15% at the 90% level of confidence. At this time, we have monitored a sample of 30 vending machines.

The M&V plan requires monitoring of pre and post conditions for the sample of vending machines. The monitoring equipment is only installed on vending machines that are equipped with vending machine controls. The monitoring equipment records average demand over a user selected time interval. The loggers have been programmed to collect 5-minute interval data for up to 4 weeks.

Once installed, the monitoring equipment records "post-controls" conditions (controls installed) for 10 to 14 days. The M&V team disables the controls and monitoring continues for another 5 to 10 days. This second period represents the "pre-controls" condition. The M&V team then returns to remove the monitoring equipment and reconnect the controls.

During the installation of the metering equipment the M&V team verifies the implementation contractor's record of unit location characteristics, including indoor vs. outdoor locations, and whether the units had display lighting, were non-lit, or had been de-lamped at the time the controls were installed. The data are then used to expand the metered data to the program population.

The metered data are extracted from the loggers, cleaned, and divided into pre-controlled and post-controlled segments. The pre and post data files are then loaded into the Visualize-IT™ software, RLW's data visualization and analysis software. Visualize-IT is a Windows application designed to help explore, summarize and analyze time-series interval data. Visualize-IT is used to prepare various graphs for analyzing and summarizing data. Using this tool, the data were viewed for reasonableness and accuracy.

Hourly average weekdays and hourly average weekends were exported from Visualize-IT for further analysis. The pre and post averages were placed into a spreadsheet and compared to determine hourly average savings for weekdays and weekends. The reported peak savings are the average of the weekday hourly savings over the peak time periods considered. The pre and post average weekdays and weekends were annualized to estimate the annual energy consumption for pre-controls and post-controls conditions.

The pre-controls monitored data represents the baseline for measuring individual vending machine control savings and overall program impacts. The post-controls data are subtracted from the pre-controls data to determine demand and energy savings resulting from the vending machine controls. Peak kW savings are calculated for the hours of 2 PM to 6 PM during non-holiday weekdays. Peak kW and energy savings are calculated for each monitored machine, and then the individual results are projected to represent the population of vending machines receiving controls through the program.

Estimated Savings

The Vending Machine Control program savings reported in the tracking database are calculated by the program vendor based on limited test data. The program calculations are based on the following energy consumption assumptions:

Cold Drink Vending Machine Type	Wattage
Typical Glass Front	400 – 900
Typical Illuminated Front	340 – 550
De-lamped	180 - 290

Based on monitored test data from a sample of 61 vending machine control, the program savings by location type and machine type (lamped or delamped) are shown in Figure 2.

Figure 2. Estimated Program Savings

Location Type	% Delamped	Annual kWh Savings			Ave. Peak Period kW Reduction	
		Delamped	Lamped	%	Delamped	Lamped
K-12	23%	1161	1927	55%	0.11	0.17
University	8%	908	1507	43%	0.07	0.10
Office	8%	971	1612	46%	0.06	0.09
Hotel	8%	971	1612	46%	0.10	0.15
Retail	8%	823	1367	39%	0.03	0.05
Other	8%	823	1367	39%	0.07	0.10

Figure 3 presents a summary of program activity through April 2002, describing the total number of vending machine controls installed and the estimated energy savings. The data show that most of the controls were installed in retail buildings, and therefore most of the estimated energy savings were from retail installations. However, retail has the lowest kW reduction per installation of any building type. The fourth column shows that hotels and schools have the highest kW reduction per installation. The last column shows that the estimated savings per installation are lowest for retail and office and highest for schools.

Figure 3. Estimated Energy Savings through April 2002

Building Type	No. of Installs	Demand Reduction		Energy Savings	
		kW	KW/Install	Total kWh	KWh/Install
Hotel	214	31	0.146	333,964	1,561
K-12 School	327	51	0.156	572,572	1,751
Office	366	32	0.087	574,171	1,561
Other	345	34	0.097	456,469	1,323
Retail	888	43	0.049	1,174,911	1,323
University	166	11	0.097	169,221	1,459
Total	**2,256**	**202.27**	**-**	**3,278,308**	**-**

Monitoring Results

The average weekday profiles generated from the monitored data for office, school, and retail are presented in the graphs in Figure 5 through Figure 8. The average energy savings and peak period demand reduction calculated for these machines are presented in Figure 4. The peak period is defined as the weekday hours from 2 P.M. and 6 P.M. The percent energy savings (% kWh) are calculated relative to energy use without the controls. The table and graphs also indicates the number of vending machines used to generate the average profiles (for example, for retail n=5). The table shows an average overall energy savings of 28%.

Figure 4. Savings for Monitored Vending Machines

Location Type	No of Units	kWh Savings	% kWh Savings	kW Reduction
Office	17	2,586	28%	0.022
Retail	5	2,180	30%	0.025
School	8	2,167	29%	0.027
All	**30**	**2,406**	**28%**	**0.030**

Figure 5 shows the average profile for the seventeen office installations. One of the vending machines was delamped as part of the program. The average peak demand reduction between the hours of 2 P.M. and 6 P.M. is 22 W.

Figure 6 shows the average profile for the eight school installations. Two of the vending machines were delamped as part of the program. The average peak period demand reduction is 48 W.

The monitoring results for retail are presented in Figure 7 and Figure 8. Three of the five vending machines were delamped as part of the program. Figure 7 shows that the five retail installations are achieving average peak period demand reduction of 55 W. Since it was anticipated that retail applications were not appropriate for these controls, the relatively large savings when compared to the office and school installations are surprising. Figure 8 shows the results for the two vending machines that did not have delamping. The average peak period demand reduction for the two machines is -1 W, indicating that the savings for the retail installations are due primarily to the delamping effort.

The last two figures (Figure 9 and Figure 10) present combined results for all monitored installations. Figure 9 shows peak period demand reduction of 42 W for installations including delamping. Figure 10 shows the results for the vending machine controls excluding the impact of delamping. The resulting peak period demand reduction is 16 W.

The average daily profiles indicate that significant energy savings are being achieved during non-peak hours, however the vending machines are not turning off during peak hours. Two factors may account for this. The controller occupancy senses is based on a 40-foot range. Therefore it will sense occupant activity within the surrounding space even if no one is directly in front of the machine. For example if the machine is located in a hallway alcove the sensor will register “occupancy” even if a person is walking down the hallway past the machine. The other factor is room temperature. Since the controller is sensing room (or surrounding space) temperature, the afternoon temperatures may be high enough to mandate that the machine’s compressor remain on. This would be particularly true for vending machines in unconditioned space, outdoors, or in areas that receive afternoon sun.

Figure 5. Average Weekday Profile for Office

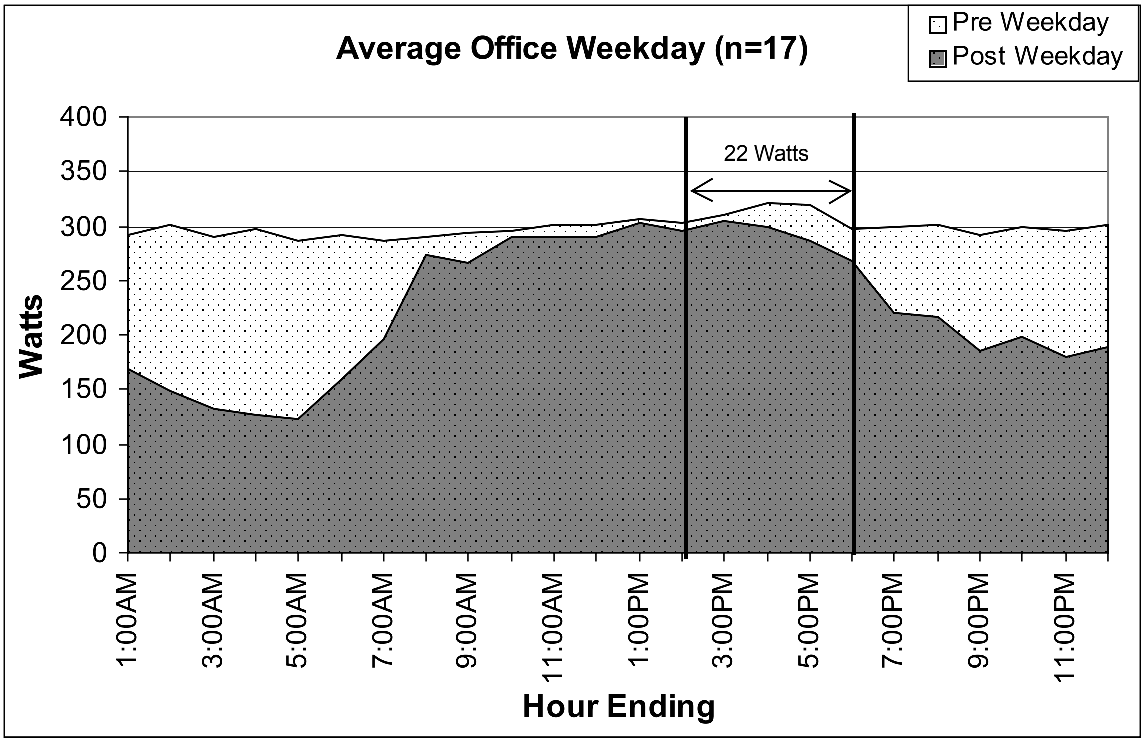


Figure 6. Average Weekday Profile for School

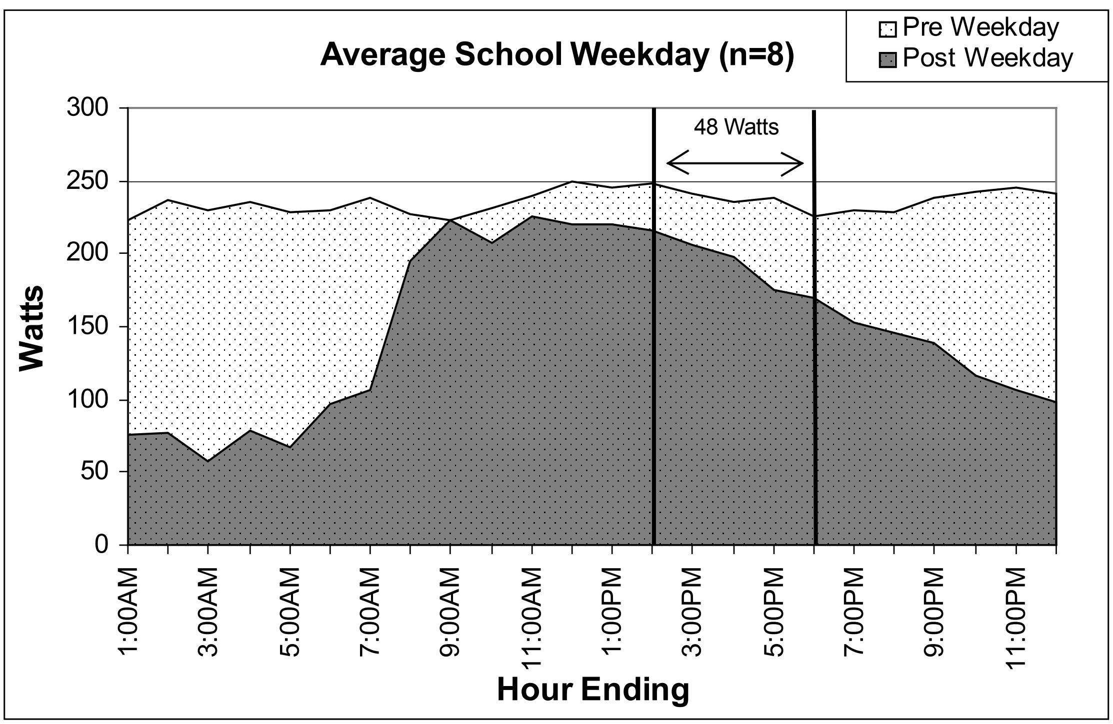


Figure 7. Average Weekday Profile for Retail

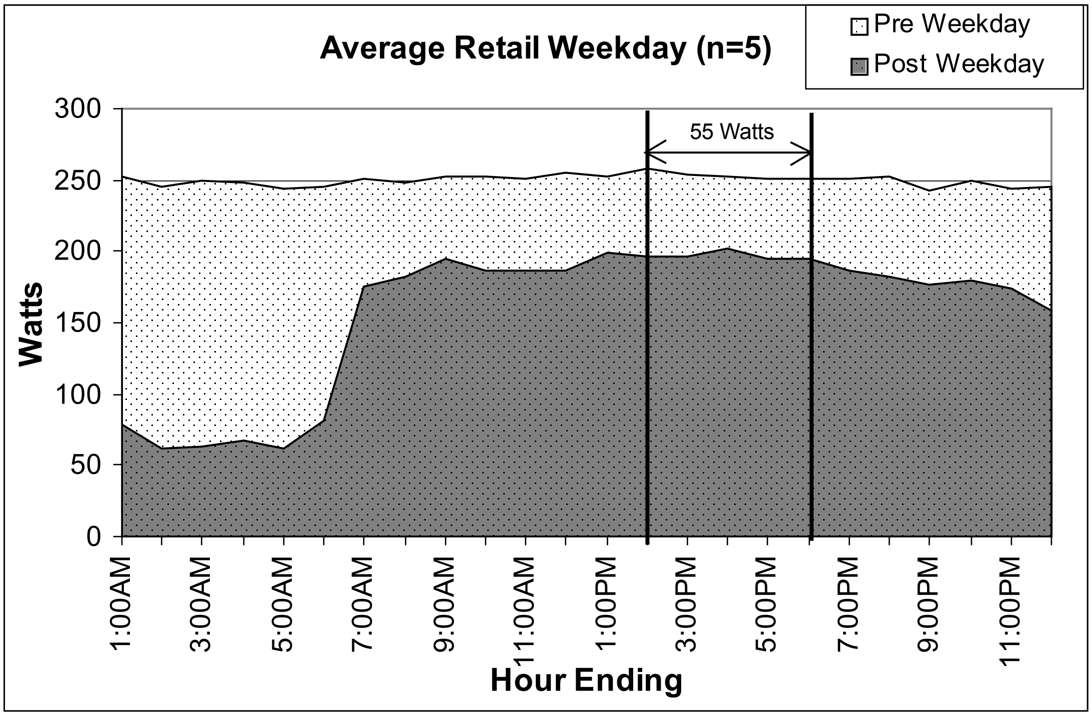


Figure 8. Average Weekday Profile for Retail without Delamping

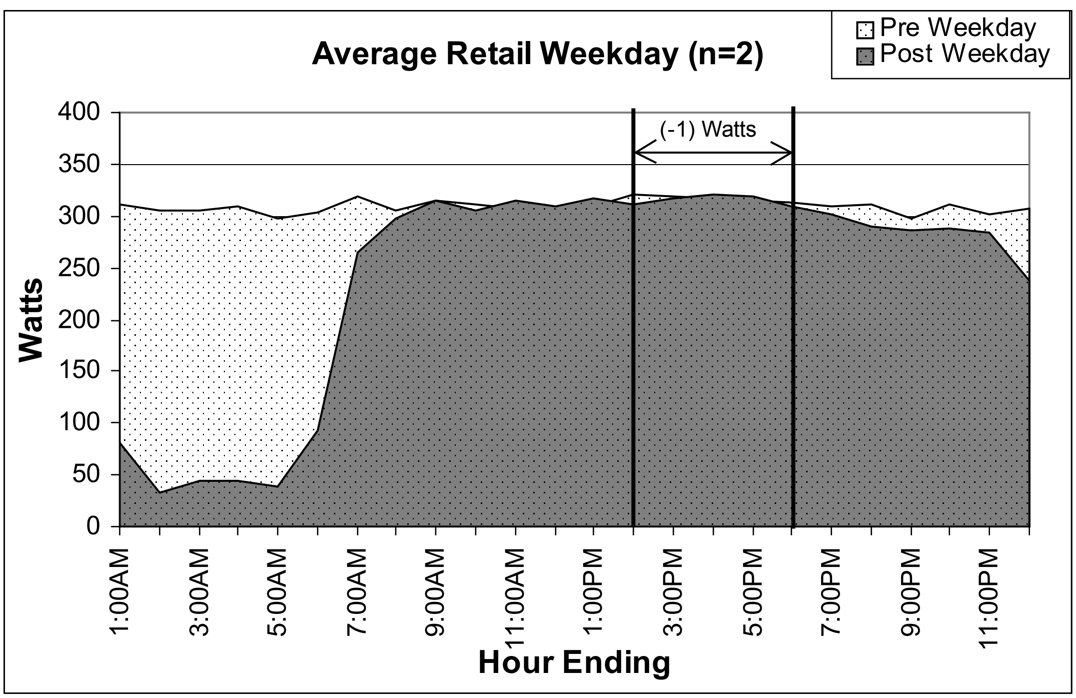


Figure 9. Average Weekday Profile for all Monitored Installations

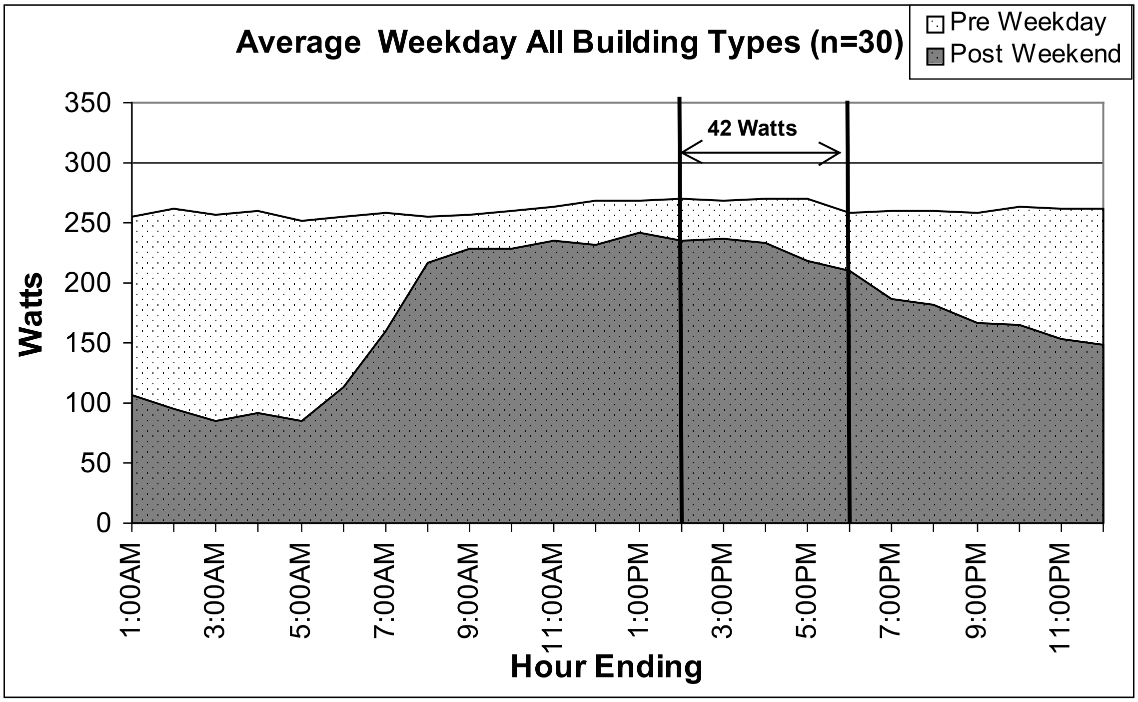
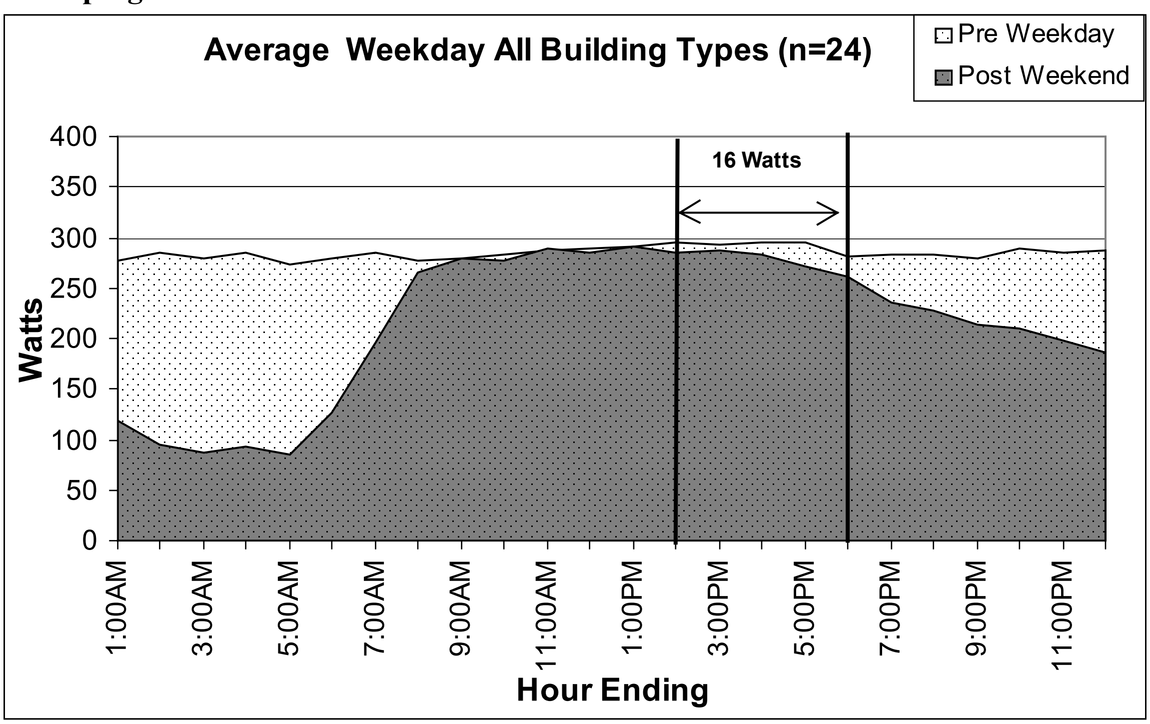


Figure 10. Average Weekday Profile for all Monitored Installations Without Delamping



Measured Savings

Based on the monitored, or measured, results we developed program level savings estimates. The measured savings presented in this paper are based on the analysis of the first 30 vending machines from the panned sample of 80 units. Final results for the vending machines measured savings study will include and 80 cases and will be completed in 2002. The available vending machine monitoring results were applied to the current program population (2,256 machines) as described previously. The program level energy savings are summarized in Figure 11. These results show that the measured average peak period demand reduction is 91 kW and the energy savings are 1.9 GWh, representing 37% of the baseline usage to date. The table also shows the relative precision and 90% confidence interval.

Figure 11. Program Measured Results

Program Level Results	Measured Savings Estimate	Relative Precision	90% Confidence Interval	
			Lower Bound	Upper Bound
kW Average Reduction	91	92.4%	7	175
kWh Savings	1,930,537	18.8%	1,567,318	2,293,757
kWh% Savings	37%	28.8%	26.4%	47.7%

Realization Rates

Figure 12 shows the program realization rates for energy savings and demand reduction. These results show that the measured energy savings (kWh) are 59% of the expected program savings. The table also shows that the demand reduction (kW) realization rate is 45%. While these results appear to suggest a low level of performance, it must be kept in mind that the original program estimates were rough estimates from the vendor, based on relatively limited monitored data. The M&V results provide useful information for developing refined savings and demand reduction estimates for the program.

Figure 12. Measurement and Verification Summary Results

	Program Estimate	M&V Results	Realization Rate
KWh Savings	3,278,308	1,930,537	59%
KW Average Reduction	202	91	45%

Summary

The M&V results indicate that the Vending Machine Control program is producing roughly half of the energy and demand savings proposed by the vendor. In addition to the reasons given above, the relatively low savings-to-date may be due to less than ideal, or in some cases inappropriate, applications. Initially SMUD had hoped to minimize application of the technology in high traffic areas, such as retail. However, at this time, retail is the segment that has dominated the installations. Therefore, one would expect the realization rates for demand reduction to be not as good as anticipated.

As part of the M&V activity, we will utilize the realization rates to improve the estimate of program impacts. Not much is known about the actual savings achievable from this type of program. Based on SMUD's ongoing M&V effort, we can improve the estimates as time goes on. We hope that in the end we will have enough diversity to develop new estimates of savings by location type and application (lamped vs delamped).