Small Commercial HVAC Pilot Program

Final Impact Evaluation

For

Energy Trust of Oregon

By

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EXECUTIVE SUMMARY

The Small Commercial HVAC Pilot Program was a test to determine the feasibility of repairs and tune-up for small commercial packaged systems. These systems are frequently located on the rooftop of small businesses.

The pilot test was initiated in order to take advantage of new opportunities. There is now a better understanding of why repairs have previously been ineffectual and better products directed at improving performance. An investigation by New Building Institute has resulted in new sensors that will assure improved economizer operation. The industry now offers less expensive and easier to use programmable controls. Finally, a simplified protocol to verify savings has been proposed. Part of reason for this test was to gain experience with this new protocol and to determine if it provides better assurance of savings.

Results from the pilot test are very encouraging. We monitored 13 of 15 units at one location and reached the following conclusions:

- Savings averaged 2,074 annual kWh or 37% of HVAC cooling and ventilation consumption.
- The savings were due to a variety of treatment measures. Most important were proper scheduling and programming of night setback and the addition or repair of economizers. (Economizing means using outdoor air for cooling instead of running the air conditioner.) Repair of air leaks and cleaning coils were also of benefit. The verification methodology does not allow savings to be isolated to specific treatments.
- For about one third of the cases, the tune-up repairs did not result in savings. This is a small amount of "dry holes" and it is probably not necessary to attempt to screen out such cases prior to treatment.
- Before the repairs, most of the systems exhibited problems. Outside air intakes were disabled which meant that no ventilation was occurring in most of the businesses. Those units that had economizers did not have two-stage wiring so the economizers were ineffectual.
- While we were not able to directly measure gas impact, we compute small gas savings averaging 2.4 annual therms. The savings are due to lockout of outside air during morning warm-up and are accomplished by the new programmable controls.
- Unit cost averaged $1,685 for labor and materials (without counting administrative expense). The estimated Benefit Cost Ratio is 1.22 indicating that a cost-effective service was provided.

INTRODUCTION

The Small Commercial HVAC Pilot Program explored the opportunity to provide a conservation service to small businesses. Previous program outreach has been difficult to cost-justify. The energy savings from small customers are, of course, also small. Yet outreach and marketing to reach large numbers of such customers carries a large transaction cost[1]. In part, the Pilot Program tests the feasibility of specifying a standard repair treatment that can be applied by contractors in a production mode in order to reduce deployment costs.

The specification for the repair treatment relies on newly available products. The treatment requires the contractor to complete the following:

1. Install a new programmable thermostat. Set up proper scheduling and night setback.
2. Install drop-in economizers where appropriate. Ensure that economizers are connected with two-stage control wiring. Install the new sensors that permit better economizer operation. Properly set economizer changeover point.
3. Repair noticeable air leaks around roof curbs.
4. Clean coils.

These treatment measures are inter-related. Recent studies have shown that existing economizers are frequently connected with improper wiring. If the wiring does not allow for two stages of cooling, the economizer is likely to be ineffectual. Part of the value of the new thermostat is that it requires the contractor to properly connect 2-stage control wiring. As additional benefit, the new controls are easier to program. This allows the contactor to better schedule HVAC operations to match the customer's occupancy.

A recent investigation by New Building Institute confirmed problems with the most common temperature sensors. The manufacturer has responded with a new and more accurate sensor that allows better specification of the economizer changeover point – the temperature at which cooling switches away from compressor cooling and toward economizer cooling[2]. We were pleased to find that these new sensors are now included in new products, even those of other manufacturers.

Repair of noticeable air leaks, cleaning of coils and "opportunistic" repair of broken equipment are included by the contractor as part of a normal procedure.

[1] Small Commercial HVAC Pilot Program Market Progress Evaluation Report, No. 1, http://www.nwalliance.org/research/reports/135.pdf

[2] Commercial Rooftop HVAC Energy Savings Research Program Draft(A) Final Project Report, New Building Institute, March 25, 2009

METHODOLOGY

NBI has suggested a simplified procedure for verifying the operation of small HVAC units[3]. The procedure relies on an "Energy Signature" plot such as Figure 1. This graph shows the average HVAC energy (excluding space heating) consumed for the day versus the average daily ambient temperature. One expects to see the line sloping upward. This indicates that, as temperature increases, more cooling energy is consumed. At some balance temperature, the energy falls to a minimum representing ventilation that occurs independently of temperature. Including the ventilation energy points on the graph helps to establish where that minimum occurs even though the observed data points do not necessarily reach down to the balance temperature.

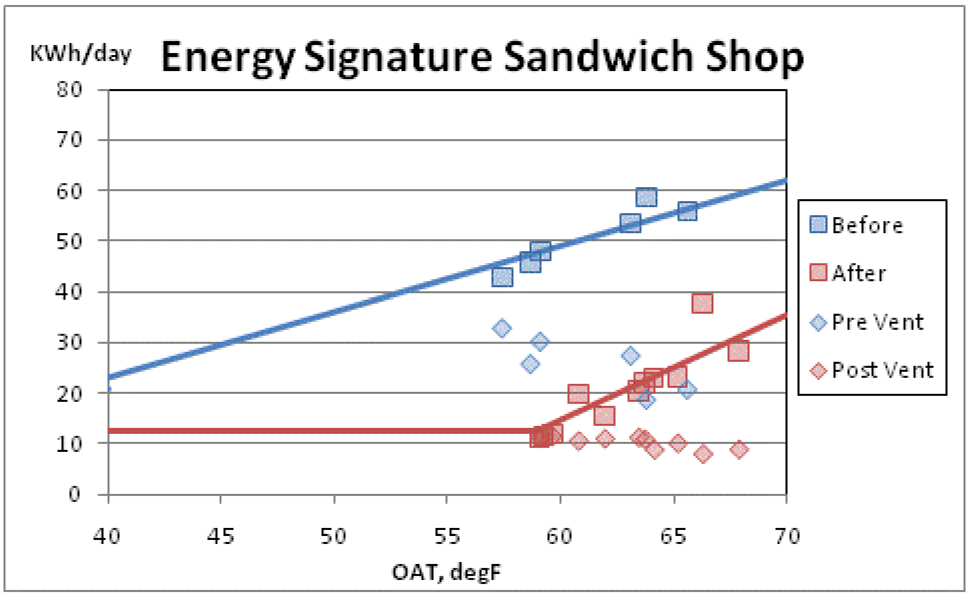

Figure 1. Example Energy Signature Plot

The observations in Figure 1are accomplished with a minimum amount of metering. Short term measurements include (1) energy consumption by the HVAC unit and (2) temperature of the delivered air. The delivery temperature allows isolation of the heating intervals. Note that this reduced amount of monitoring does not allow an explicit measurement of economizing. Economizing is a type of ventilation but to distinguish it requires that we monitor the control signal being provided to the HVAC unit. The abbreviated data collection protocol does not include collecting that additional data. However, when economizing is properly implemented, it will show up as a reduction in overall HVAC consumption in the Energy Signature plot. Thus, the verification methodology provides an assessment of the overall impact of the combined treatment measures – but it does not allow savings to be separately attributed to specific treatments.

It is suggested that the slope and intercept parameters developed in the Energy Signature plot can be used to extrapolate savings to the rest of the year. That is, given that we know the average daily temperate, we can compute the expected daily HVAC consumption from the plot. It is at this point that questions occur. Are data developed from a short period of observation sufficient to extrapolate to the

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[3] New Buildings Institute, *ibid.*

rest of the year? Do the observed data span a sufficient range of temperatures? Or are data collected in one season insufficient to extrapolate to another season? As will be discussed, the Pilot test examined these issues.

FIELD IMPLEMENTATION

The monitoring part of the project focused on one location. This building is a strip mall containing a representative mix of small business types. Included are two sit-down restaurants, a fast food outlet, a retail store, an office and professional services (dentist, veterinarian, hair salon). We skipped one vacant space and one space (a dry cleaner) did not have a packaged HVAC unit. Otherwise, the businesses all had essentially the same HVAC system consisting of a rooftop packaged HVAC unit that discharged directly into the space below. This location was appealing because it was easy to direct the contractor to just follow the same standard repair protocol on all units. Figure 2 shows how the site consists of a row of essentially the same HVAC unit.

Figure 2. Site Layout

Three of the HVAC units already had economizers. However, only one was functional. The other two units did not have two-stage controls. For the existing economizers, the installation included installing proper controls, new temperature sensors and proper specification of the economizer change over temperature. The other units received a drop-in economizer with the exception of one seldom-used unit that served only a stock room in the retail space.

To our surprise, the repair visit revealed that, with one exception, outside ventilation was disabled on all the units. The outside air intake vents were physically locked shut. This means that most of the businesses were not receiving sufficient air for ventilation.

None of the businesses had proper scheduling of HVAC operations. In several cases, it was apparent that the occupants "tweaked" the thermostat during the day in order to start HVAC operations. In many cases, the controls were not setup for shutdown over the weekend or at night.

All the units received a pressure wash of the coils. Coils were noticeably dirty on the Pub (near the hamburger grill exhaust) and the Pizza Kitchen (copious flour dust).

The HVAC units were mounted in a roof curb that lacked proper sealing. Thus, there was noticeable air leakage around the curb on several units. The contractor installed a curb seal on all the units that successfully reduced leakage. However, no measurements were made to quantify the exact amount of leakage.

Even though measurements were abbreviated, metering installation was still challenging task. We installed metering to measure true power on all the units. This procedure was to avoid any issues related to differing power factor for different HVAC operations. We experienced equipment problems on two HVAC units. However, both of these units had an identical twin serving the same space so we have every reason to think that the observed performance is typical of both units.

Although equipment installation was accomplished within one day, it took another four days for the technicians to arrange for proper programming and scheduling using the new thermostats.

PROGRAM RESULTS

ANALYSIS METHODOLOGY

Data were collected at one-minute intervals in order to bin energy consumption into heating or cooling events. This requires a database operation to merge all the data streams and assure that they are correctly aligned by time of day. At that point the raw data were aggregated to hourly values for subsequent analysis. Thus, the analysis did not have to deal with overly-bulky raw data files.

Development of the energy signature plot was time-consuming and difficult to automate. In some cases, such as shown previously in Figure 1, the energy signature plots clearly follows a slope and intercept form and can easily be modeled with a linear regression. In other cases, such as shown in Figure 3, the model fit is not so clear and the regression must be forced through a zero point. In these cases, some judgment is necessary to estimate a fit to the observed data points.

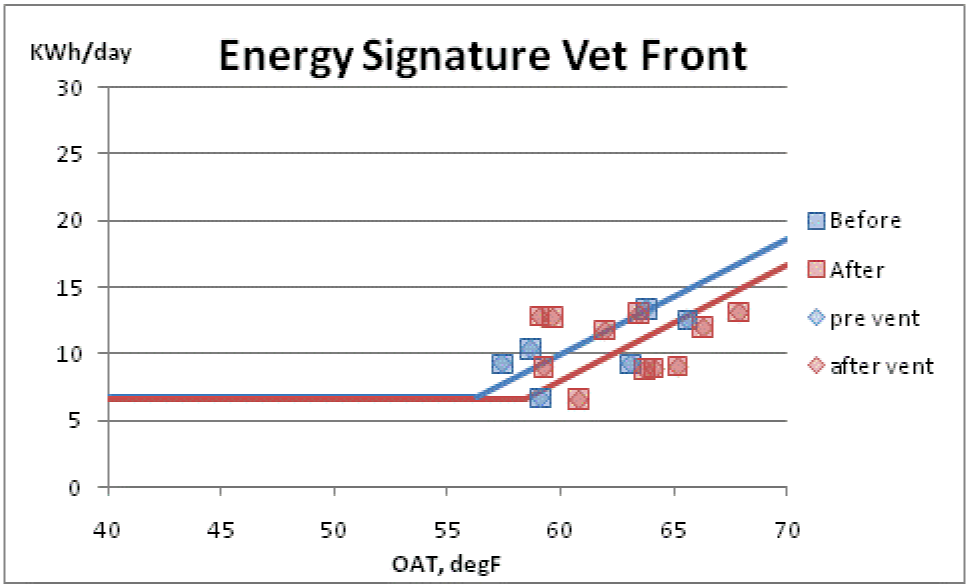

Figure 3. Example of Difficult Fit

The difficulty of data fit leads to concern whether the models will correctly extrapolate to annual consumption. One test is to observe whether one observes similar savings under both pre- and post-retrofit conditions. The result of this test is shown in Figure 4. Here one uses the extrapolation model fit to the actual weather conditions for one of the conditions. That is, the "Before" conditions are based on the actual weather before retrofit compared to "after retrofit" estimate extrapolated to the same weather. As can be seen, the "before" and "after" weather conditions lead to savings estimates that are similar but not exactly the same.

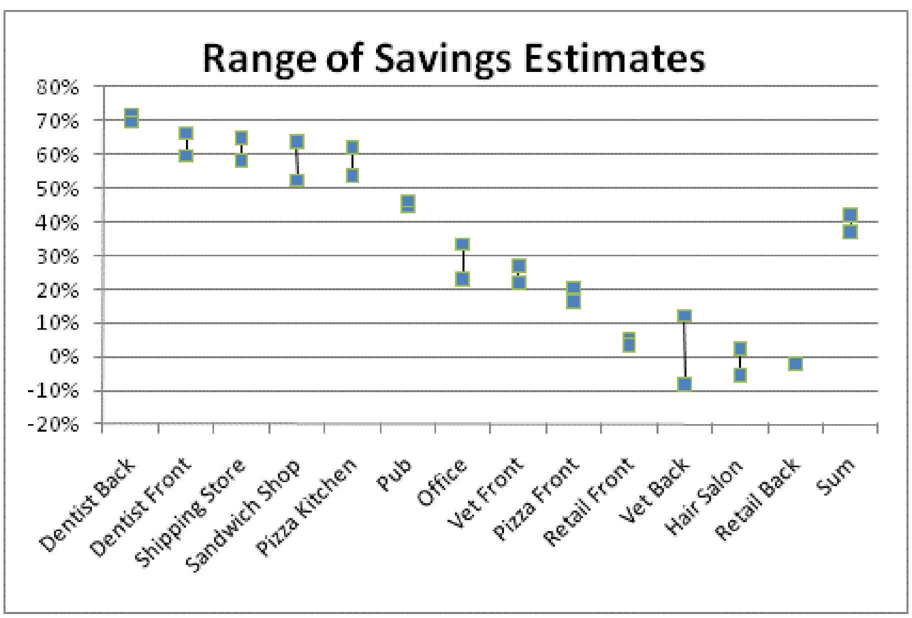

Figure 4. Range of Savings Estimates

What accounts for the differences in savings estimate shown in Figure 4? The difference has to do with the relative amount of change expected for compressor cooling (the sloped part of the energy signature) versus the ventilation savings (the flat part of the energy signature). Average daily temperatures were different during pre- and post-retrofit periods. Thus, the methodology leads to slightly different savings estimates depending on whether the dominant source of savings is coming from air conditioning or operations scheduling. Economizer improvement will result in air conditioning savings; while scheduling improvements will often result in ventilation savings.

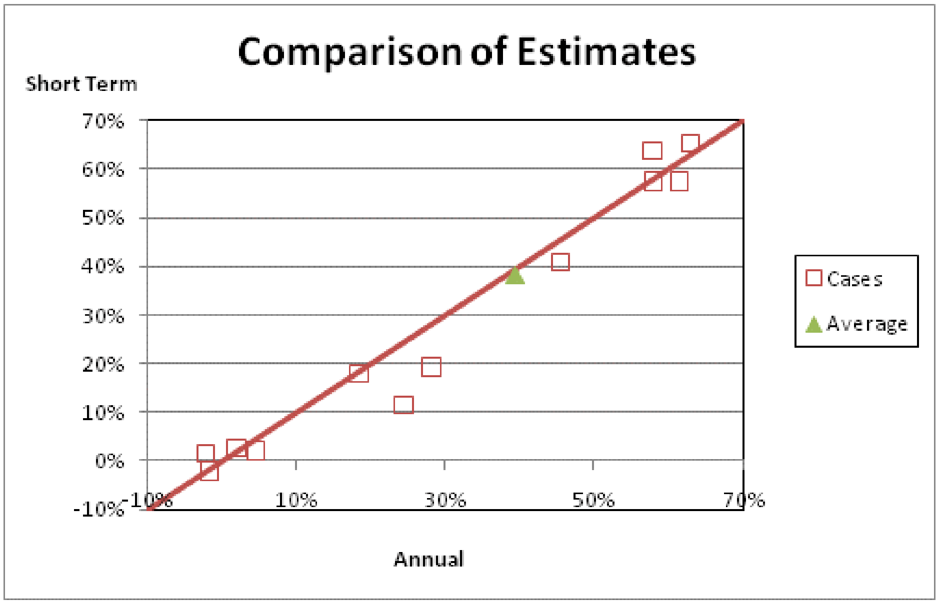

Figure 5. Comparison of Estimates

The next question is whether the extrapolation method yields consistent results on an annual basis. Annual results are estimated as the sum of the energy signature parameters applied to average daily temperature over the course of an average weather year. Figure 5 shows a comparison of the annual savings estimate compared to that derived during the short term monitoring. (The short term estimate is defined as the average of the pre- and post-retrofit estimates shown in Figure 4.) Note that the reference line is not a regression fit to the data points. If there were perfect agreement between the estimates, the observations would be aligned along the 45-degree reference line. In general, the agreement is close. Average estimated savings on an annual basis agree closely with the average short term results shown in Figure 4.

ENERGY SAVINGS RESULTS

Savings results shown in Table 1 are sorted in order of decreasing savings percentage. Review of the treatment demonstrates that adding economizer functionality and improved scheduling were both important to achieve savings. Note that all cases also received coil cleaning and sealing of air leaks although it is not possible to isolate the treatment impact. Ventilation was important for the Hair Salon due to their use of chemicals. This was the only unit that had a working outside air inlet. For all the other units, the air intake had been locked in the closed position. Thus, one expects that there should be some increase in ventilation rate resulting in negative savings. The fact that savings are generally positive demonstrates that the treatments were effective.

The savings percentage represents estimated savings compared to ventilation and cooling HVAC consumption, That is, electric energy consumed during space heating is not included. For these cases, space heating adds about 10% to the annual HVAC consumption based on billing analysis. Table 1 shows that the 13 cases that were monitored averaged 38% savings. The results can be extrapolated to 15 cases assuming that results are the same for the “twin” systems. For 15 cases, savings are slightly lower averaging 37%.

For about one third of the cases, savings are small or even negative. This fraction of “dry holes” is small. Of course, those units that are rarely used provide little savings. However, that is not always the case. It is not always possible to predict the cases with low savings. Hence, one concludes that any attempt to screen cases prior to repairs in not likely to be effective.

The new thermostats are a crucial factor for savings. These thermostats assure that 2-stage wiring is available for economizer controls as well as allowing improved scheduling. In addition, these thermostats allow for dampers to be closed during morning warm-up which will provide natural gas savings. It was not possible to monitor gas impacts during the study; however, it was possible to collect information to compute gas impact.

Table 1. Energy Savings Results – 13 Cases

Case	Pre-retrofit kWh	Post-retrofit kWh	KWh Saved	% Saved	Treatment
Dentist Back	5,826	1,645	4,181	72%	New economizer, new thermostat, implemented setback
Dentist Front	7,827	2,716	5,112	65%	New economizer, new thermostat, implemented setback
Pizza Kitchen	3,192	1,159	2,033	64%	New economizer, new thermostat, implemented setback
Sandwich Shop	15,131	6,432	8,699	57%	New economizer, new thermostat, implemented setback
Shipping Store	2,949	1,255	1,694	57%	New economizer, new thermostat, implemented setback
Pub	5,716	3,381	2,334	41%	Restored non-functioning economizer, set changeover to 63 deg, new thermostat, implemented setback
Office	4,658	3,759	899	19%	New economizer, existing thermostat, implemented setback
Pizza Front	12,941	10,632	2,309	18%	No economizer, new thermostat, implemented setback
Vet Front	3,561	3,150	411	12%	Restored non-functioning economizer, set changeover to 63 deg, new thermostat, implemented setback
Hair Salon	4,026	3,922	104	3%	New economizer, new thermostat, implemented setback, increased ventilation
Retail Front	2,421	2,371	49	2%	Existing economizer was functional, set changeover to 63 deg, new thermostat,

					implemented setback
Vet Back	4,231	4,169	62	1%	New economizer, new thermostat but no setback
Retail Back	316	323	-7	-2%	Cleaning but no other treatment, unit is seldom in use
Average	5,600	3,455	2,145	38%	
All units (15 cases)			2,074	37%	

During short term monitoring, we observed instances when space heating occurred. Although the weather was warmer during pre-retrofit, there were instances of space heating that occurred sporadically during the day. This suggests that occupants were manually adjusting the thermostat. Following the retrofit, despite cooler weather, there was less space heating and it almost always occurred as morning warm-up. Assuming that night time temperatures fall to the same setback temperature (say, 68 degrees), the amount of morning warm-up time should be about the same regardless of how cold outside ambient gets at night. That is, warm-up is expected to be a function of the thermal mass and internal gains within each space, as well as the heater output rate. There are expected to be differences in the balance temperature, which is the outdoor temperature necessary to trigger a heating event. We were able observe instances of the warm-up length and balance temperature for seven cases. We estimated similar results for one other case, with the exception that balance temperature was lower than what occurred during the monitoring study period. Generally, the balance temperatures agreed with that observed during monthly billing analysis. For the remaining five cases, we assumed no warm-up savings. These cases represented the restaurant sites with large internal gains and the retail store which opened late in the morning.

We then computed an estimate of savings during warm-up. To do so, we assumed that the fixed percentage of outside air is decreased from 25% to 10%. Although this study did not directly measure airflow, we assume a rate of 350 cfm per ton. Figure 6 shows the estimated space heat savings as a percent of annual space heating. The annual estimate of space heating comes from billing analysis of monthly bills using EZSim.

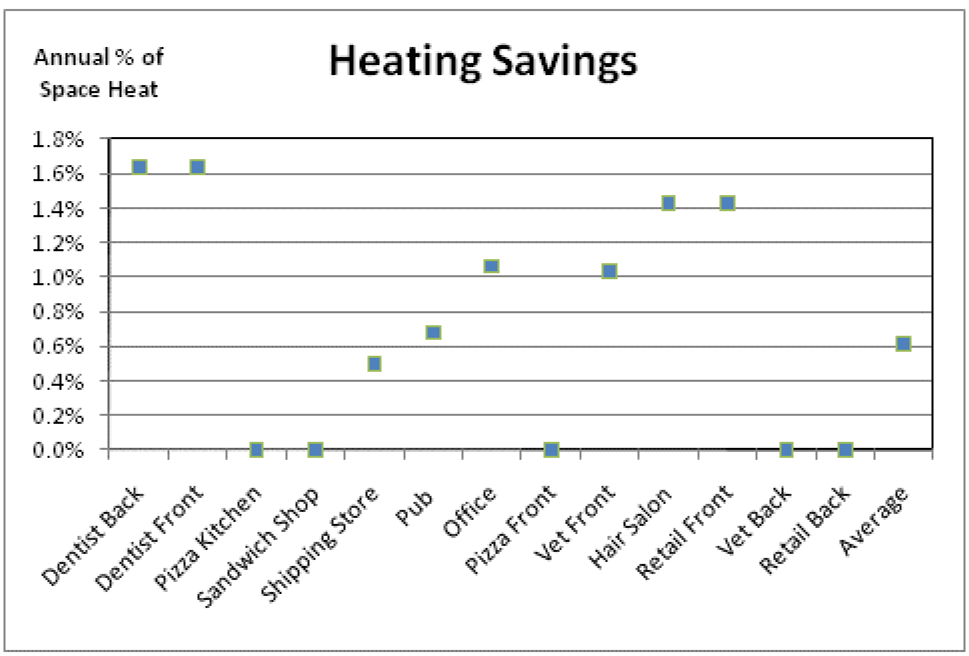

Figure 6. Estimated Heating Savings

Table 2. Estimated Natural Gas Savings

Cases	Therm	% of SH
Dentist Back	1.9	1.6%
Dentist Front	2.9	1.6%
Pizza Kitchen	0.0	0.0%
Sandwich Shop	0.0	0.0%
Shipping Store	1.1	0.5%
Pub	5.7	0.7%
Office	0.8	1.1%
Pizza Front	0.0	0.0%
Vet Front	7.4	1.0%
Hair Salon	7.1	1.4%
Retail Front	4.2	1.4%
Vet Back	0.0	0.0%
Retail Back	0.0	0.0%
Average	2.4	0.6%
All units	2.5	0.6%

As shown in Figure 6, those cases with a gas impact were computed to be about 1% on an annual basis. The lower savings occur in spaces with a relatively high amount of internal gain. Those cases with high internal gains are assigned zero impact. Table 2 shows that savings averaged 2.4 therms or 0.6% space heat savings, including those cases with no savings.

Program cost effectiveness in shown in Table 3. The cost of the HVAC tune-up is estimated at $1685. This includes equipment and labor by the contractor but does not include the cost of administration and verification. Overall, the program results for all 15 units result in a Benefit to Cost Ratio (BCR) of 1.22. This indicates that he program offering is cost effective. (Source: BES-EB Workbook v05.xls.)

Table 3. Program Cost Effectiveness

Cases studied	Average KWh Savings		Average Therm Savings	
13 Directly monitored	2,145	38%	2.4	0.6%
15 Including all units	2,074	37%	2.5	0.6%

Unit cost	$1,685
PV of electricity	$0.980
PV of Gas	$7.872
PV of Benefits	$2,052
BCR	1.22

CONCLUSIONS

- Savings averaged 2,074 annual kWh or 37% of HVAC consumption.
- The savings were due to a variety of treatment measures. Most important were proper scheduling and programming of night setback and the addition or repair of economizers. Repair of air leaks and cleaning coils were also of benefit. The verification methodology does not allow savings to be isolated to specific treatments.
- For about one third of the cases, the tune-up repairs did not result in savings. This is a small amount of "dry holes" and it is probably not necessary to attempt to screen out such cases prior to treatment.
- Before the repairs, most of the systems exhibited problems. Outside air intakes were disabled which meant that no ventilation was occurring in most of the businesses. Those units that had economizers did not have two-stage wiring so the economizers were ineffectual.
- While we were not able to directly measure gas impact, we compute small gas savings averaging 2.4 annual therms. The savings are due to lockout of outside air during morning warm-up and are accomplished by the new programmable controls.
- Unit cost averaged $1,685 for labor and materials (without counting administrative expense). The estimated Benefit Cost Ratio is 1.22 indicating that a cost-effective service was provided.

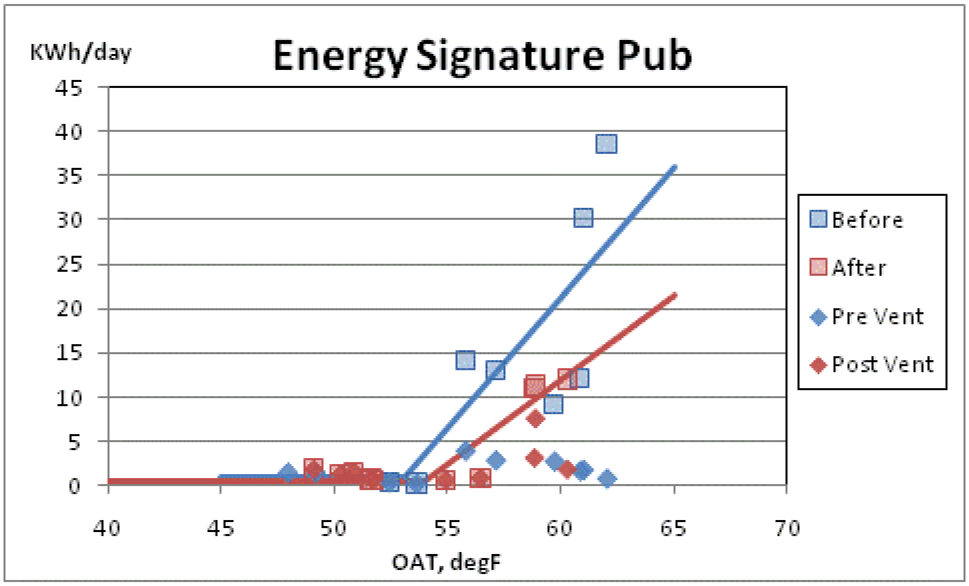

Figure 7. Energy Signature -- Pub

The RTU, together with an identical twin, served the dining area. There were no barriers between the two units so we assumed the same performance for both. The kitchen was served by large exhaust hoods. Makeup air for the kitchen was supplied through a non-functioning evaporative cooler so one expects that these are separate areas for HVAC. These units were greasy and benefited from coil cleaning. We also observed, but did not quantify, a reduction in air leakage. The units already had economizers but they were ineffective due to a lack of 2-stage controls. The treatment included new economizer sensors, with changeover set to 63 degrees and new thermostats with 2-stage controls. Scheduling was improved with night setback.

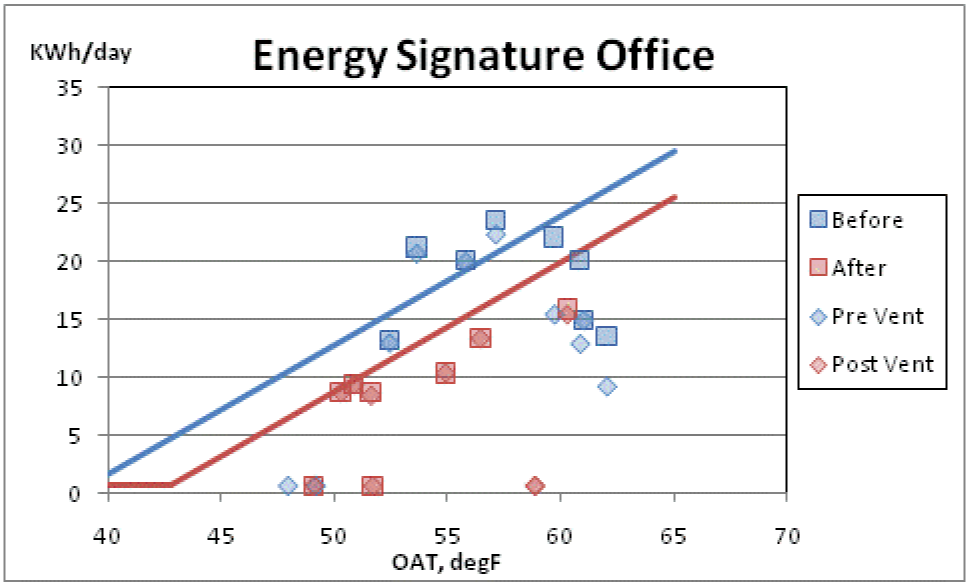

Figure 8. Energy Signature – Office

The RTU, together with an identical twin, served the same area. There were no barriers between the two units so we assumed the same performance for both. The office was occupied five days a week and had fairly high internal gains due to desktop computers. We also observed, but did not quantify, a reduction in air leakage. The treatment included new economizers, with changeover set to 63 degrees and new thermostats with 2-stage controls. Scheduling was improved with night setback.

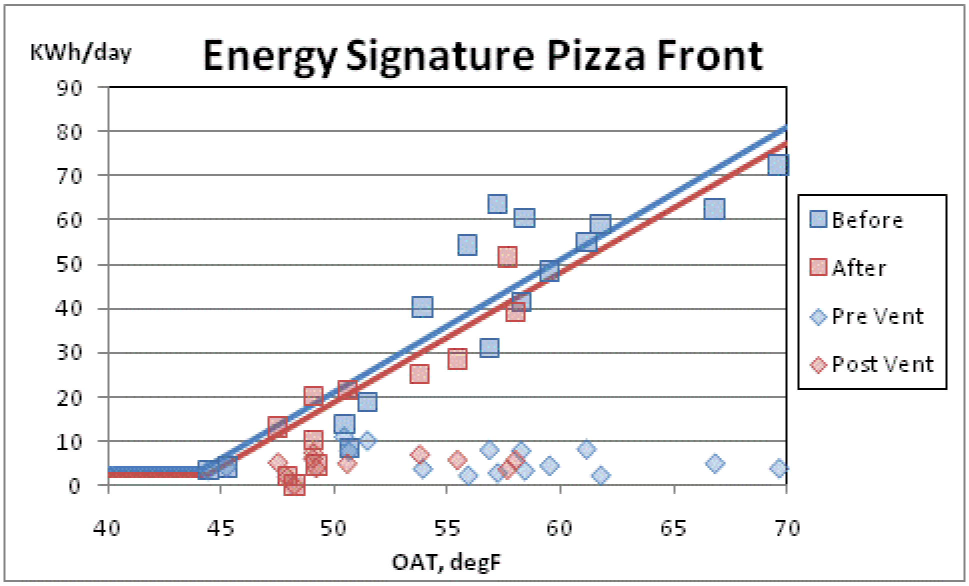

Figure 9. Energy Signature -- Pizza Front

This unit served the front counter for a take-out pizza restaurant. Makeup air is supplied through a non-functioning evaporative cooler so the HVAC system is probably isolated from the kitchen exhaust. This is an older unit and an economizer was not added.

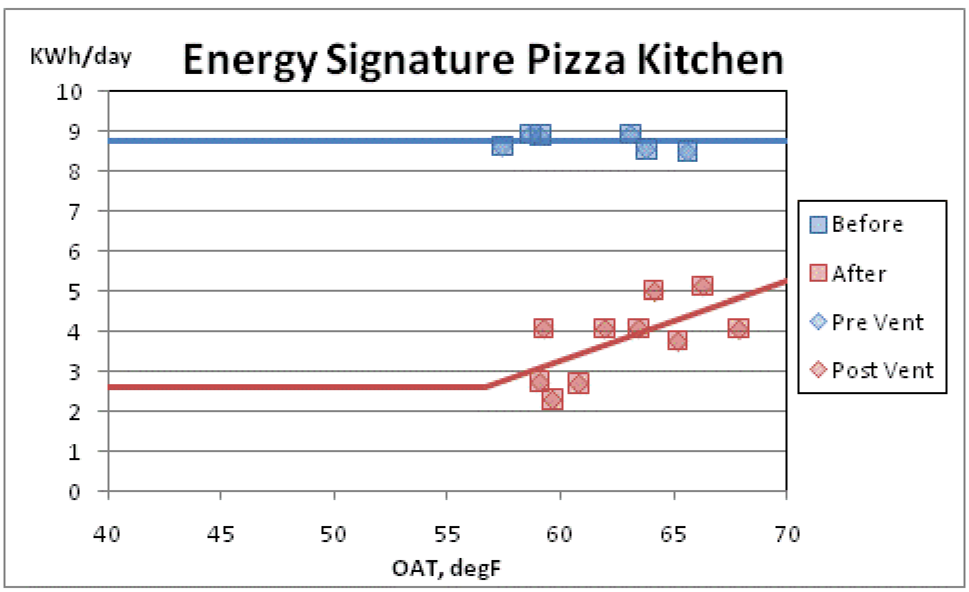

Figure 10. Energy Signature -- Pizza Kitchen

This unit served the kitchen in the same establishment. The supply is located next to a large exhaust hood over the ovens so much of the conditioned air is likely to be exhausted. Coil cleaning was important for this unit due to extensive flour dust. The treatment included new economizers, with changeover set to 63 degrees and new thermostats with 2-stage controls. Scheduling was improved for both units with setback for night and unoccupied days. This store is typically open on Sundays but closed on Mondays.

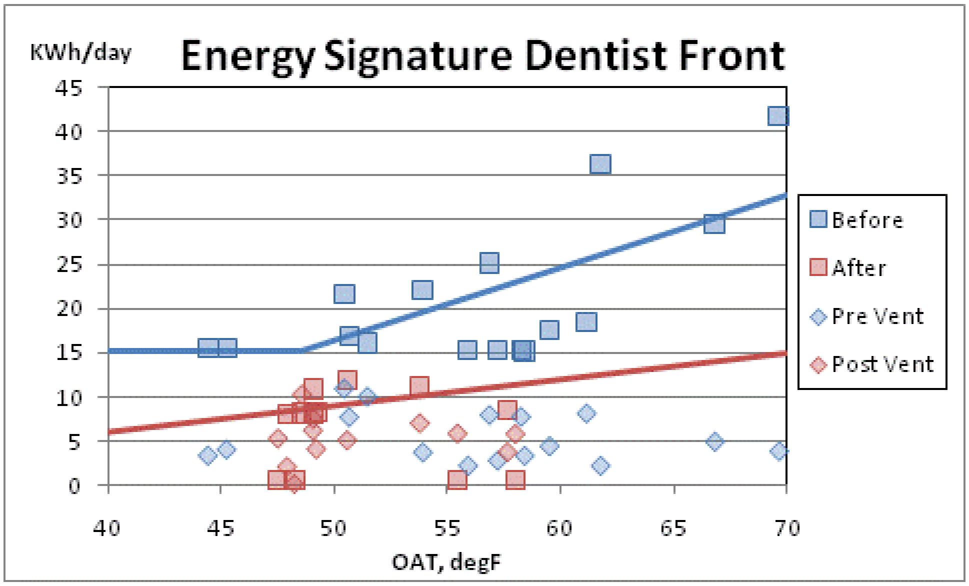

Figure 11. Energy Signature -- Dentist Front

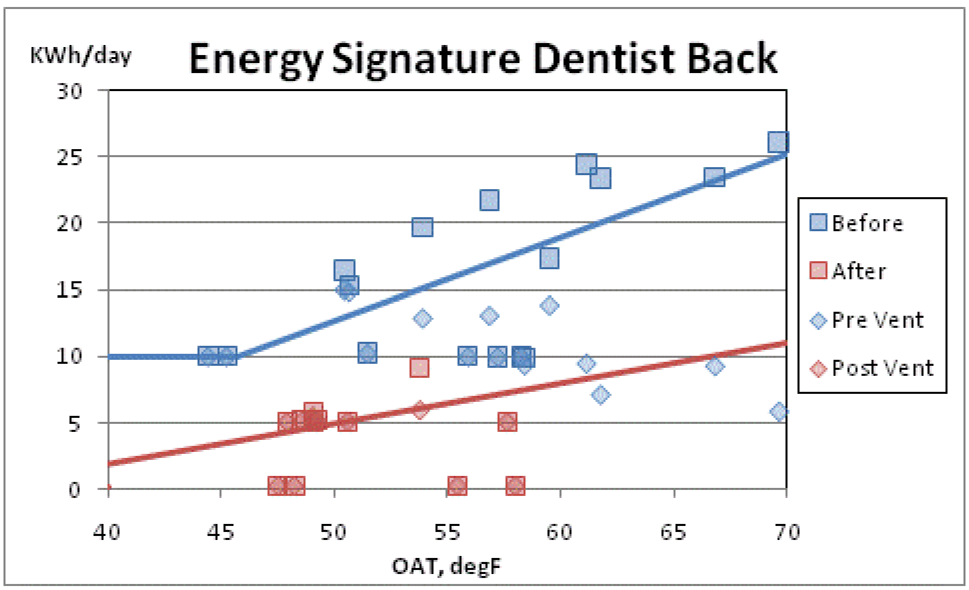

Figure 12. Energy Signature -- Dentist Back

These are identical units serving the front and back area of a dentist office. The treatment included new economizers, with changeover set to 63 degrees and new thermostats with 2-stage controls. Scheduling was improved for both units with setback for night and unoccupied days.

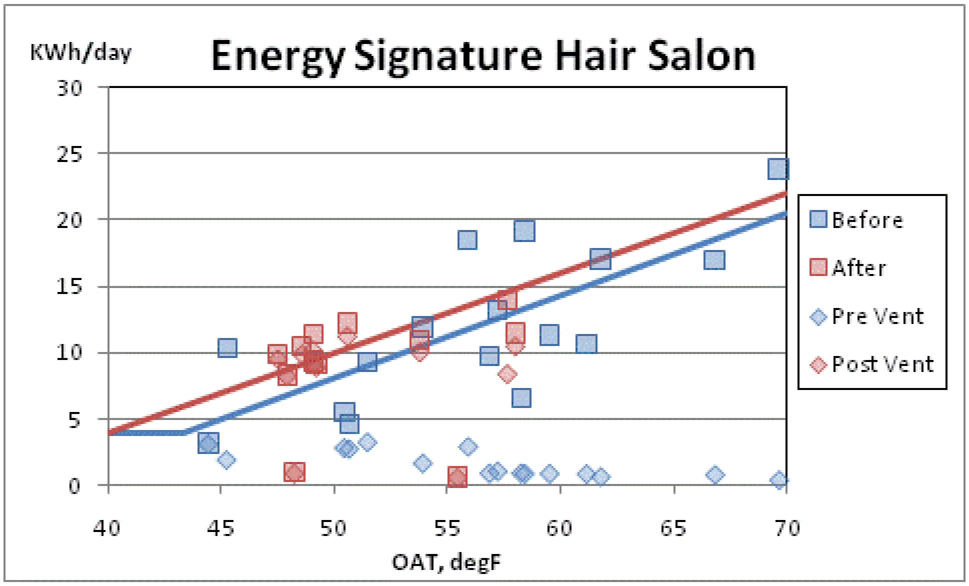

Figure 13. Energy Signature -- Hair Salon

This business needed careful consideration of HVAC requirements. Due to the chemicals used, occupants were concerned about the amount of ventilation air. This was the only unit that had an operating outside air inlet. Even so, they were observed during the study to frequently open the front door in order to get more air. Similarly, they were observed to manually adjust heating and cooling prior to the retrofit. Occupant behavior afterward suggests that they were content with the program scheduling. The treatment included a new economizer, with changeover set to 63 degrees and new thermostat with 2-stage controls. Savings appear to be slightly negative due to increased amount of ventilation with the new scheduling.

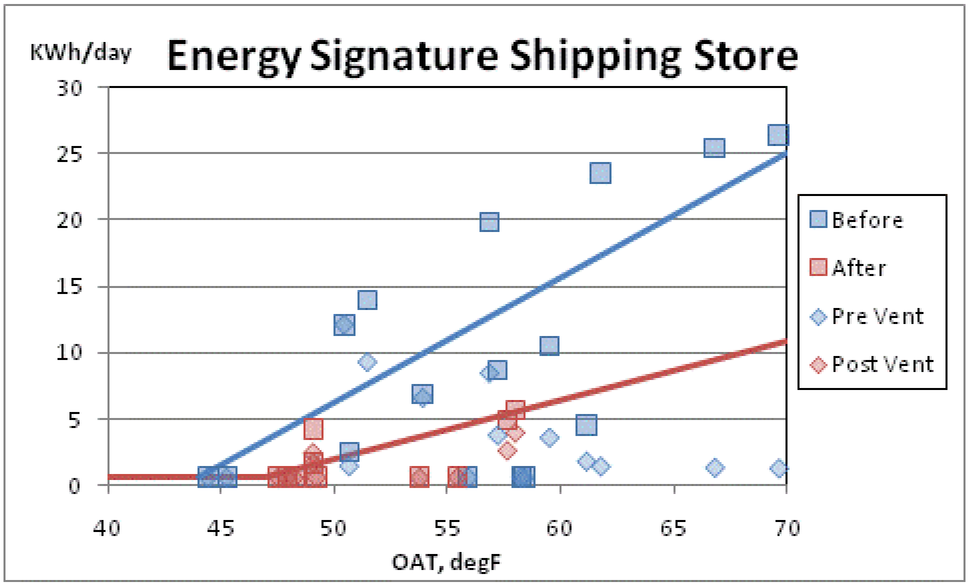

Figure 14. Energy Signature -- Shipping Store

This business provided shipping service and mailboxes. The supply air was located in the front foyer near the mailboxes and was observed to be delivering excessively cold air prior to retrofit. The treatment included a new economizer, with changeover set to 63 degrees and new thermostat with 2-stage controls. Scheduling was improved with setback for night.

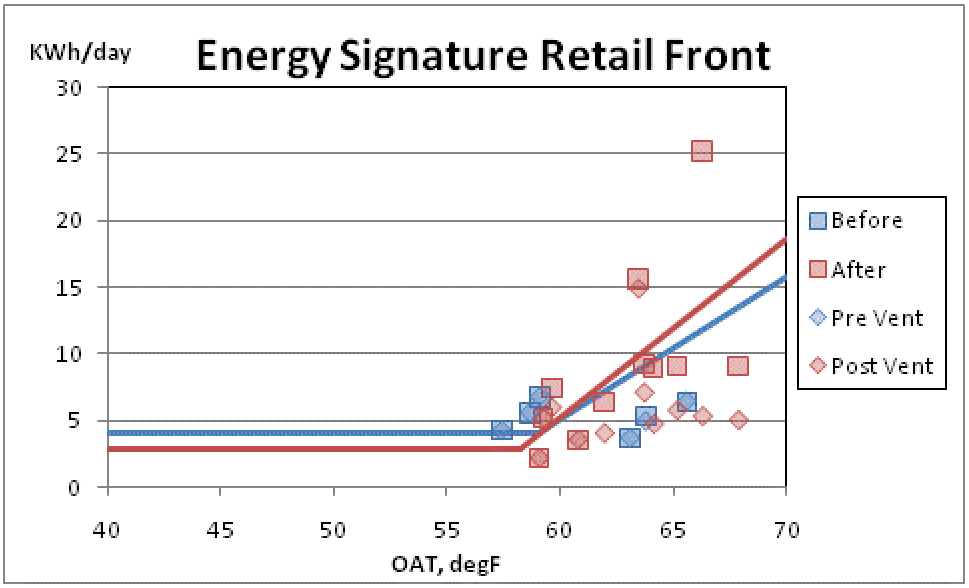

Figure 15. Energy Signature -- Retail Front

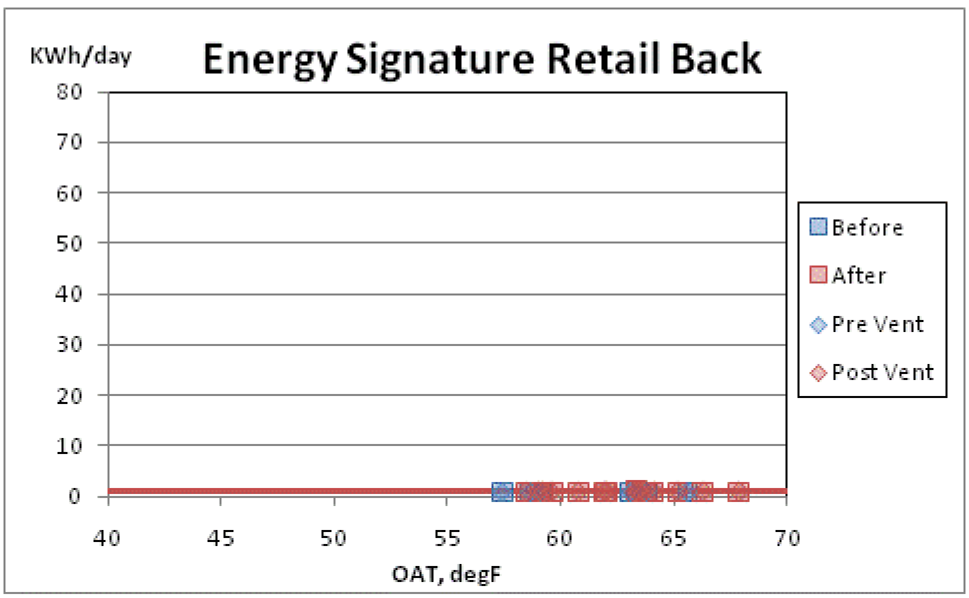

Figure 16. Energy Signature -- Retail Back

The front unit was the only one that had a functioning economizer prior to the retrofit. This unit served the store area with high ceilings. The treatment included new economizer sensors, with changeover set to 63 degrees and new thermostat. Scheduling added setback for night but without effective savings. The back unit served a stockroom and rarely operated. This was apparent prior to retrofit so the back unit was untreated other than coil cleaning and general checkout.

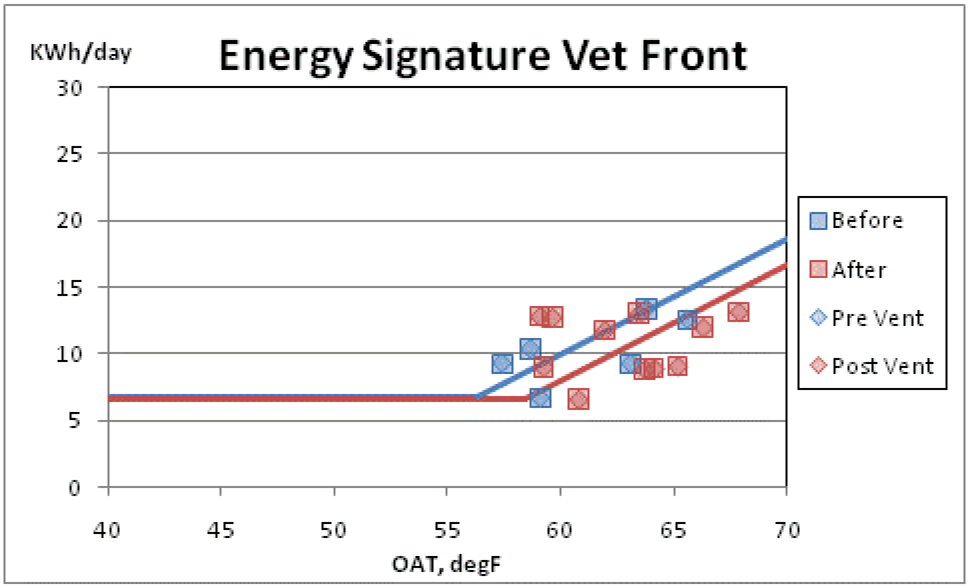

Figure 17. Energy Signature -- Vet Front

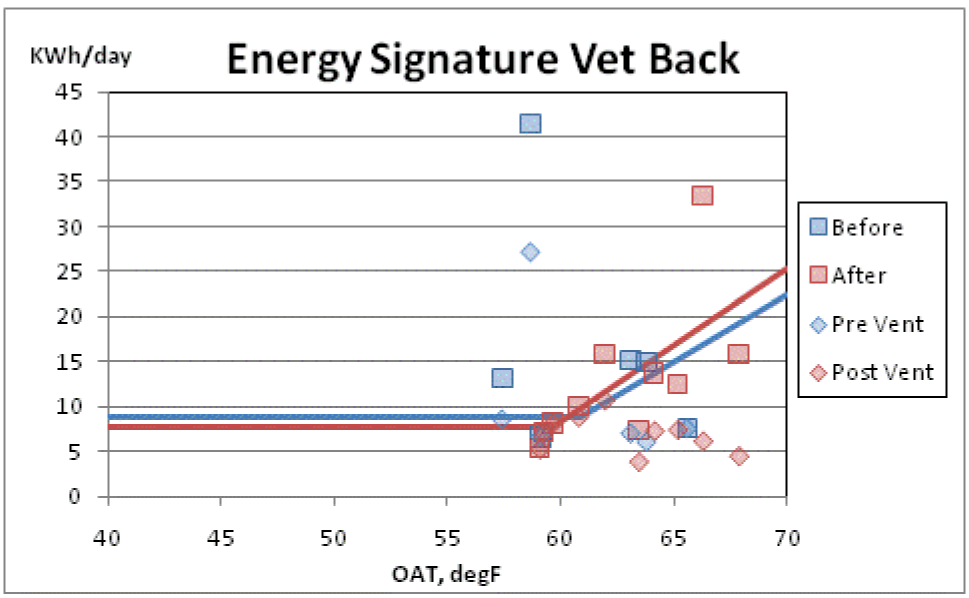

Figure 18. Energy Signature -- Vet Back

The front area of the veterinary office was served by a large unit with a non-functioning economizer. The back area included kennels for animals and was fully conditioned although often unoccupied. The treatment included new economizer sensors, with changeover set to 63 degrees and new thermostat for both units. This provided modest savings in the front area. The occupant did not want night setback for the back area so there were no effective savings in that area.

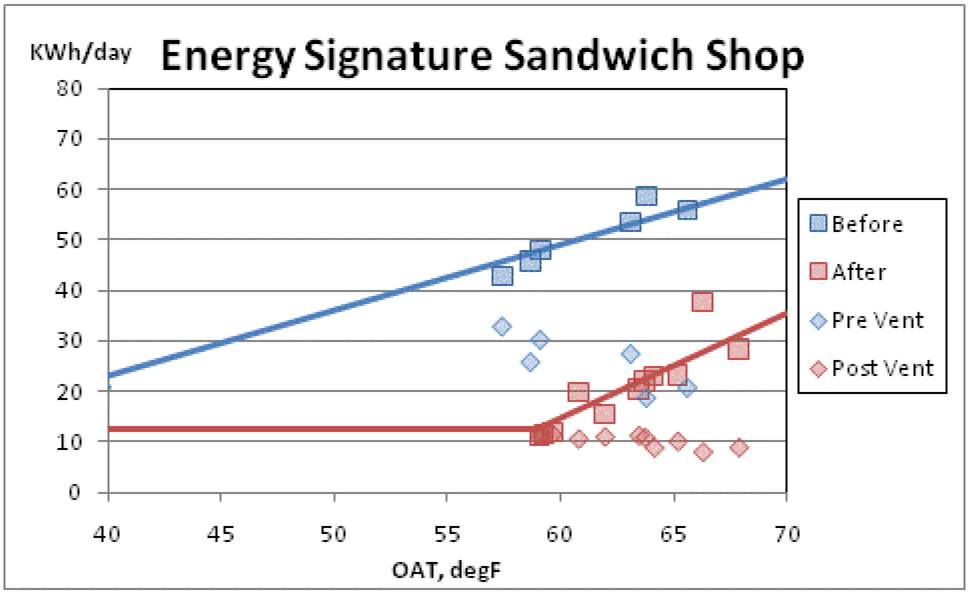

Figure 19. Energy Signature -- Sandwich Shop

This same figure was used in Figure 1to demonstrate a successful case. There are significant internal gains from ovens so the air conditioning was observed to be in almost constant use. The treatment included new economizer sensors, with changeover set to 63 degrees and new thermostat. Scheduling was improved with setback for night and weekends.