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Pilot Evaluation Of Energy Savings From Residential Energy Demand Feedback Devices

Florida Solar Energy Center

Danny Parker
Florida Solar Energy Center, dparker@fsec.ucf.edu

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CONTRACT REPORT

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Submitted by:

Danny S. Parker
David Hoak
Jamie Cummings

Submitted to:

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1679 Clearlake Road, Cocoa, FL 32922-5703 • Phone: 321-638-1000 • Fax: 321-638-1010
www.fsec.ucf.edu

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Danny Parker, David Hoak and Jamie Cummings
Florida Solar Energy Center

ABSTRACT

Providing instantaneous feedback on household electrical demand has shown the promise to reduce energy consumption by 5-15%. This paper briefly reviews past research and describes a two year pilot evaluation of a low cost residential energy feedback system installed in twenty case study homes in Florida. Although not a statistical sample (the participants were self-selected), the study showed an average 7% reduction in energy use from feedback homes in the second year of monitoring after controlling for weather-related influences. A large identified advantage of the technology is that it provides better guidance on profitable areas to reduce household electrical demand—many of which may be unanticipated.

Introduction

It has long been known that occupant behavior has very large impacts on residential energy use (e.g., Socolow and Sonderegger, 1976). Indeed, experience would suggest that these influences are much larger than the impact of intrinsic differences in building materials and energy consuming appliances. Evidence for this comes from many sources, but here we highlight two examples. First is a study done by FSEC in the mid 1990s measuring the energy use in ten identical Habitat for Humanity all-electric homes built the year before monitoring in Homestead, Florida (Parker et al., 1996). Even though all homes had two or more occupants, with identical appliances and equipment, as shown in Figure 1, energy use varied by 2.6 to 1 from the highest to lowest consumer. Detailed measurement of the end-uses in the homes revealed that while the electrical consumption of appliances like refrigerators were remarkably similar, other uses such as air conditioning varied by 5:1 from the highest to lowest. Evaluation of interior temperature and operation showed that much of that difference was due to differing thermostat behavior.

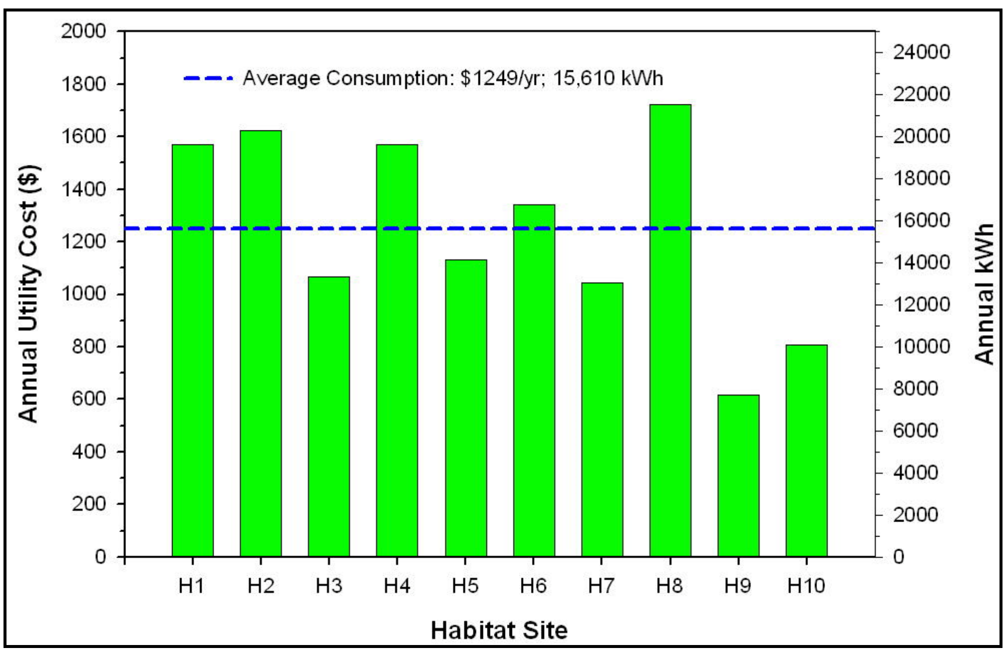

Figure 1. Variation in annual energy use in ten otherwise identical Habitat for Humanity homes in Homestead, FL (1994-1995).

A second study is of eleven very similar solar homes built in Sacramento, California under SMUD's solar homes program (SWA, 2005). This study evaluated the utility bills of the more efficient homes with solar features against other non-solar homes in the same community. As seen in Figure 2, the variation in annual energy use in the solar homes was tremendous. The most frugal home had negative utility cost (produced more solar electricity than it used), while the highest consuming solar home used near twice as much electricity as the average energy use of non-solar homes in the locality.

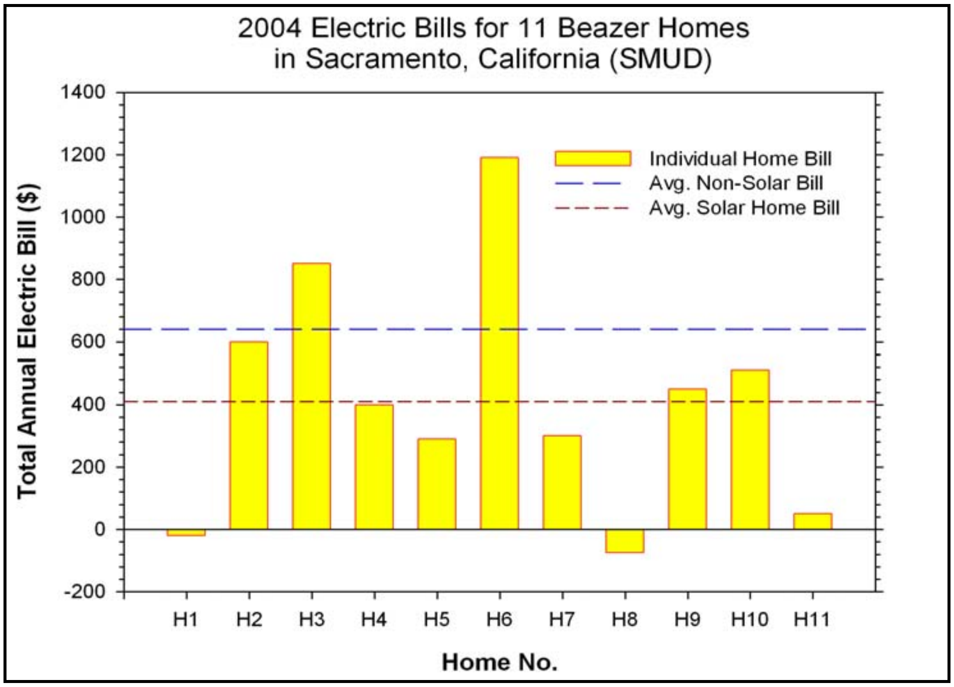

Figure 2. Variation in annyal energy use in eleven similar SMUD solar homes in Sacramento, CA (2004).

Both studies in very different part of the U.S. would suggest that motivating changes to occupant behavior has a powerful potential to achieve energy reductions. This particularly looks to be the case in more efficient homes with renewable energy features. Thus, it may be useful to examine ways in which providing more information to occupants on their immediate energy use might allow more effective home energy management strategies.

Unfortunately, most homes currently have no means to judge household energy use other than their monthly utility bill. However, this does not readily provide insight as to how, or where the energy is being used, given the long time delay between action and feedback.

Technology Summary

Due to advances in microelectronics and computing, energy feedback devices for home use are now commercially available and low in price. Models typically provide a small wall or desk mounted display that communicates the second-by-second electric power demand of the household. Most accumulate the data to show expected monthly utility costs or time related energy cost data. Some are now available for as little as $140. More detailed (and expensive) systems can report on disaggregated end uses. The *Whirlpool Corporation* has developed an advanced “Energy Monitor” system which provides information on household total electricity demand, as well as data from 14 separate circuits. The information is available on an LCD display showing current power use, demand profiles, history of past consumption and estimated energy bills. In one pilot project with monitoring, no impact was seen although the device was not fully functional. However, the project did show that over a five month period from April- August 2005, lighting and plug loads comprised 1300 kWh or 35% of total use (Griffiths, 2005).

However, the question remains as to whether the additional information is a benefit or liability ("valuable insight" vs. "too much information"). Commercially available models vary in terms of capability as summarized in our previous report. The two most popular devices currently, is the *PowerCost Monitor* (Mountain, 2006) and *The Energy Detective*. Both systems simplify installation by avoiding costly hard-wiring. The TED sends the energy demand signal over household wiring, whereas the *PowerCost Monitor* using a radio signal from the sending unit. However, the TED device does have two important advantages: 1) it has a resolution of 10W vs. 100W for the *PowerCost Monitor* which is quite important for evaluating energy use of small appliances, lighting and standby power and 2) real-time updates are also more frequent – every second for TED versus every 30 seconds for the *PowerCost Monitor*.

Past Studies

Past studies show that providing household energy feedback promises to reduce consumption, although evaluation of the impact of real-time energy information are spotty (Katzev and Johnson, 1986; Farhar and Fitzpatrick, 1989). An early study in Twin Rivers, NJ in the 1970's showed the promise of real-time energy displays to reduce energy use by 10-15% (Seligman and Darley, 1977; 1978). Other early studies showed similar savings (Palmer et al., 1977, McClelland and Cook, 1979). Potential savings also extend to non-electric fuels; Van Houwelingen and Van Raaij (1989) showed a 12% drop in natural gas consumption in Dutch homes provided with daily electric feed back. Bittle et al. (1979) showed similar beneficial results for electricity. A few studies could not reliably observe savings from energy-use feedback. For instance, in experiments in Canada and California, Hutton et al. (1986) showed uneven results with electricity savings of 5% in 92 Quebec homes compared with a control group, but minimal impact in the California sample. One recent study showing little potential was done on ten mostly low-income homes by researchers at Oberlin College (Allen and Janda, 2006) using *The Energy Detective* (TED). While occupants reported increased energy use awareness, the results showed no statistically significant energy reduction in any home. The tests were done over a limited three month monitoring period in ten homes who found it difficult to understand the energy monitor's displays. Regardless of a few projects with poor results, a compilation of available data on numerous real-time feedback studies (Darby, 2000) suggests an average 10-15% energy savings.

Recent Studies in Japan and Canada

There are a few larger scale studies of the impacts of real time energy-feedback. In one conducted by *Ontario Hydro* in Canada, Dobson and Griffin (1992) found that displays in 25 Canadian homes produced overall electricity savings of 13%, which largely persisted after the devices were removed.

Another intriguing evaluation of instantaneous electric demand feedback was conducted in Japan. This showed a 12% measured average total energy reduction from feedback in ten highly instrumented test homes (Ueno et al., 2005). The savings in electricity were even greater at 18% against those for natural gas (9%). Perhaps most interesting was that measured reductions in "other appliance" electricity use (largely miscellaneous electric loads) averaged 31%.

Most compelling, however, is a large and recent statistical study of 400 sites compared with a similarly sized control group conducted in Canada using the *PowerCost Monitor*. This project showed a 6.5% savings from providing instantaneous feedback to consumers (Mountain, 2006). Further, an average 7-10% savings was seen if device ownership was coupled with energy-reducing educational tips for the home owner.

Not only are these reductions potentially large as they comprise *all* end-uses, they may provide unique opportunities to realize goals for high-efficiency buildings. Reducing and shifting electrical demand is particularly important in Zero Energy Homes (ZEH), where it would be desirable to match solar electric PV output with household loads. There are parallels with hybrid automobiles, where evidence suggests that feedback from dash-mounted displays allows drivers of Toyota's *Prius* to improve their mileage as they learn from experience. As the physical efficiency attributes of buildings improves, there are decreasing returns to further investment in efficiency upgrades. Accordingly, behavioral changes may hold the best hope for reducing the remaining third of energy use in ZEH.

Energy Feedback Monitor

Our project was a two year pilot evaluation of the TED residential energy feedback system installed in twenty-two case study homes in Florida. The study consisted of an opportunity sample of households with the participants self-selected based on interest. Although the monitor sells for $140, there was no cost for the monitor or installation for the study participants.

However, several problems were encountered in analyzing the study results. One home could not obtain utility bill data for the period prior to the installation of the device. Another home experienced interference from home electronics which prevented the device from working (a problem that has largely been eliminated by the manufacturer). Two other homes did not yet have 12 months of post data when the analysis was complete. Finally, one further home was the author's own which was eliminated from the evaluation to reduce potential bias. This left a total of 17 participants in the final analysis group which had a full year of pre and post data and matching data periods within the large utility sample which comprised the control.

The participants in the study had *The Energy Detective* (TED) installed. This is a small 3.5 x 5" display unit which plugs into the wall and receives power line carrier signals from a sending unit installed in the central breaker panel. Output is available on a digital display as shown in Figure 3.

Figure 3. Free standing display of *The Energy Detective (TED)* feedback device. Display shows house is currently drawing 0.410 kW.

Some characteristics of *TED*:

1. Computes true power every second (kW) with a resolution 10 Watts. Energy use of the system itself was measured at 0.8 Watts. We found the device could be easily installed in 30 minutes.
2. Sends signals on instantaneous electric power over house wiring by power line carrier so that the display device can be installed in any room and simply plugged into the wall. This significantly simplifies installation and set-up.
3. Shows both instantaneous and cumulative electric power for the month. Also records daily and monthly peak electrical demand. Can also be configured to show cumulative $/hr.
4. The unit maintains its programming and cumulative data in non-volatile memory. Thus, no problems are encountered with power interruption.

One objective of our earlier investigation was to develop a protocol and educational element to help homeowners or auditors for Zero Energy homes use the feedback information to effectively inventory all (Parker, et.al, 2006). This was accomplished in each of the study homes. The developed method, which evaluates all loads on a given circuit breaker, was completely described in our previous report.

Based on our experience, we found such a protocol could potentially be a powerful means to reduce household energy use. Although the protocol was performed on each home in the study, occupants were not advised as to what measures might be considered and were left to their own decision making. Using such information as an audit tool educational element might be considered for a follow-on study.

Two-Million Home Control Group

Within the study we had 17 monitors with a full year of data on which to analyze. Understanding the need to establish a control group with which to compare our limited opportunity sample, we approached the largest Florida utility, *Florida Power and Light Company (FPL)* and asked if it might be possible to obtain long term billing histories for all single family customers who are not seasonal residents.

The utility agreed to help, providing five year average data on average energy use in the over 2 million single family homes in their service territory. These homes represent roughly 2% of the entire U.S. residential building stock and a third of all residential dwelling units of all types in the State of Florida.

The advantage of using this data was that it would allow a control group for both the pre and post periods for each participant that would intrinsically adjust for natural changes due to appliance saturation and behavior as well as responses to monthly weather conditions. Figure 4 shows the average electricity use in the two million customers over a five year period stretching from September 2002 to August of 2007. One can see on the data, the superposition of a moving 12-month average of electrical consumption which takes out the seasonal variation in energy use. This arithmetic mean, shown as yellow triangles, shows that electricity use in year round occupied single family residences slowly declined over the measurement period.

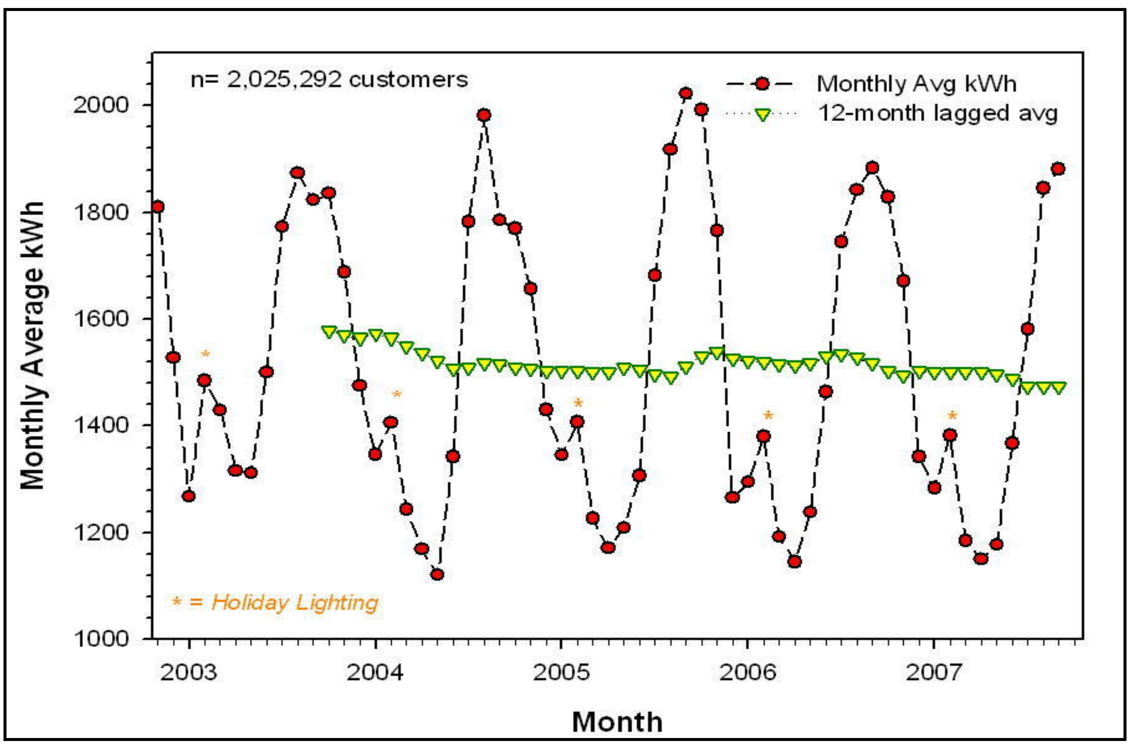

Figure 4. Measured average five year monthly electricity consumption in all *Florida and Light Company* single-family non-seasonal homes

Annual consumption averaged 18,948 kWh in the first year, slowly declining to 17,688 kWh in the last year. Analysis of the data when compared to weather data from West Palm Beach (perhaps the geographic account-weighted center of the FPL service territory) revealed that most of the decline in consumption is coming from slowly dropping heating degree days (HDD) during Florida's mild winter over the five year period. Figure 5 repeats the plot of average monthly electricity use with the relevant heating and cooling degree days from the previous month superimposed on the data. The weather influence is graphically apparent.

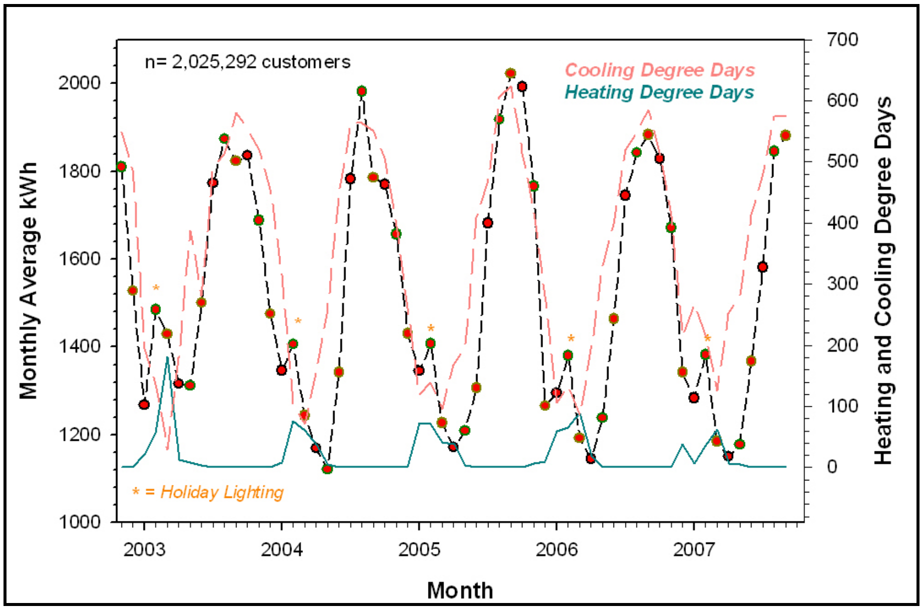

Figure 5. Monthly electricity use in FPL single family homes over 5 years with heating and cooling degree days.

A simple multiple-regression model including heating and cooling degree days for the current and previous month and a dummy variable for Christmas explained 88% of the variation in measured average electricity consumption:

```
. regress kwh cdd_lag hdd_lag holiday hdd cdd

      Source |       SS       df       MS              Number of obs =      60
-------------+------------------------------           F(  5,    53) =   87.91
       Model |  3790310.97     5  758062.195           Prob > F      =  0.0000
    Residual |  457029.941    53  8623.20643           R-squared     =  0.8924
-------------+------------------------------           Adj R-squared =  0.8822
       Total |  4247340.92    58  73230.0158           Root MSE      =  92.861

------------------------------------------------------------------------------
         kwh |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
     cdd_lag |   1.401425   .1484902     9.44   0.000     1.103592    1.699259
     hdd_lag |   3.204404    .573337     5.59   0.000     2.054436    4.354373
     holiday |    159.071   47.77327     3.33   0.002     63.24993     254.892
         hdd |    1.92612   .5573796     3.46   0.001     .8081584    3.044082
         cdd |   .7993953    .138172     5.79   0.000     .5222574    1.076533
       _cons |   628.3914   60.39217    10.41   0.000       507.26    749.5227
------------------------------------------------------------------------------
```

All coefficients were statistically significant at better than a 99% level. Note that holiday lighting (holiday), is very evident both in the graphical presentation of the data and the statistical model, being estimated at approximately 160 kWh for the month of December. Note also the relatively larger coefficients for heating degree days which is a likely result of the fact that many Florida homes are heated with electric resistance heat whereas air conditioners meeting excessive cooling degree days (CDD) have an efficiency greater than unity. We did try adding a variable to see if energy consumption was changing over time after controlling for weather and holidays. However, even though an added variable (elapsed months) was slightly negative, it was not statistically significant, indicating that most of the change in electricity consumption was weather related.

The advantage of using this very large data source was that we could then have it serve as the control group for comparison of how the non-experiment population's consumption varied over the specific pre and post period for each individual site. Generally, most sites saw a natural, weather-related reduction from the pre and post period (the variation was -4.0% to + 2.5%) with an average drop of 1.9% for the overall group of 17. This was computed for each individual site.

Evaluation Results

Table 1 shows the overall results from the year pre and post in the 17 homes, both with and without the control group weather correction. Note that pre-installation consumption averaged 18,396 kWh/year–virtually identical to the 18,201 kWh seen in FPL's two million home control group from May 2005 - April 2006.

Table 1
Energy Use Pre and Post Installation of Feedback Monitors

Site	Install Date	Before Installation	After Installation	Reduction (%)	Weather Change* (%)	Raw Savings (kWh)	Normalized Savings (kWh)	Normalized Savings (%)
C1	May-06	49.9 kWh	52.1 kWh	-4.4%	1.36%	-2.2 kWh	-2.9 kWh	-5.9%
C2	Feb-06	41.3 kWh	41.3 kWh	-0.2%	1.20%	-0.1 kWh	-0.6 kWh	-1.4%
C3	May-06	39.9 kWh	38.1 kWh	4.4%	1.36%	1.8 kWh	1.2 kWh	3.1%
F1	May-06	51.4 kWh	50.0 kWh	2.6%	1.36%	1.3 kWh	0.6 kWh	1.2%
F2	May-06	113.3 kWh	92.2 kWh	18.6%	1.36%	21.1 kWh	19.5 kWh	17.5%
H1	Apr-06	39.7 kWh	37.9 kWh	-0.2%	0.88%	-0.1 kWh	-0.4 kWh	-1.1%
H2	May-06	30.2 kWh	27.1 kWh	10.3%	1.36%	3.1 kWh	2.7 kWh	9.1%
H3	Feb-06	40.8 kWh	36.7 kWh	10.0%	1.20%	4.1 kWh	3.6 kWh	8.9%
H4	Dec-06	76.0 KWh	66.4 kWh	12.6%	1.87%	9.6 kWh	8.2 kWh	10.9%
K1	Jul-06	43.8 kWh	44.3 kWh	-1.2%	3.95%	-0.5 kWh	-2.3 kWh	-5.4%
M1	May-06	18.3 kWh	19.1 kWh	-4.5%	1.36%	-0.8 kWh	-1.1 kWh	-5.9%
M2	Jun-06	32.8 kWh	31.2 kWh	5.0%	2.73%	1.7 kWh	0.8 kWh	2.4%
M3	May-06	45.6 kWh	38.3 kWh	16.1%	1.36%	7.4 kWh	6.7 kWh	15.0%
P1**	Jul-05	18.5 kWh	13.7 kWh	26.1%	-2.51%	4.8 kWh	5.3 kWh	27.9%
S1	Aug-06	26.0 kWh	27.4 kWh	-5.6%	3.56%	-1.4 kWh	-2.4 kWh	-9.5%
S2	May-06	31.8 kWh	28.9 kWh	8.9%	1.36%	2.8kWh	2.4 kWh	7.7%
T1	Aug-06	138.4 kWh	114.1 kWh	17.5%	3.56%	24.3 kWh	19.3 kWh	14.5%
V1	May-06	38.8 kWh	32.7 kWh	15.7%	1.36%	6.1 kWh	5.6 kWh	14.5%
Overall		**50.4 kWh**	**45.8 kWh**	**9.1%**	**1.80%**	**4.6 kWh**	**3.7 kWh**	**7.4%**

* Average % energy use reduction for FPL customers in the same time period as each participant in the study, according to their TED
** Author's home; not included in overall averages

Our analysis showed that average electricity use in the overall group declined in the year after the installation of the energy monitor. However, as expected, the specific change varied substantially from one site to another. The average raw reduction was 9.1% or 4.6 kWh/day. We did complete a detailed analysis for each project participant which is given in Appendix A.

When corrected to the control group (which often had weather related reductions in the post period) we saw the average savings from the energy feedback monitors of 3.7 kWh/day or 7.4%. However, as shown in Figure 6, this varied considerably from one home to another, ranging from an energy *increase* of 9.5% to a savings of 27.9%. Eleven homes showed savings while six homes showed energy use increases. The absolute value of the weather-adjusted savings varied from -2.9 to 19.5 kWh/day.

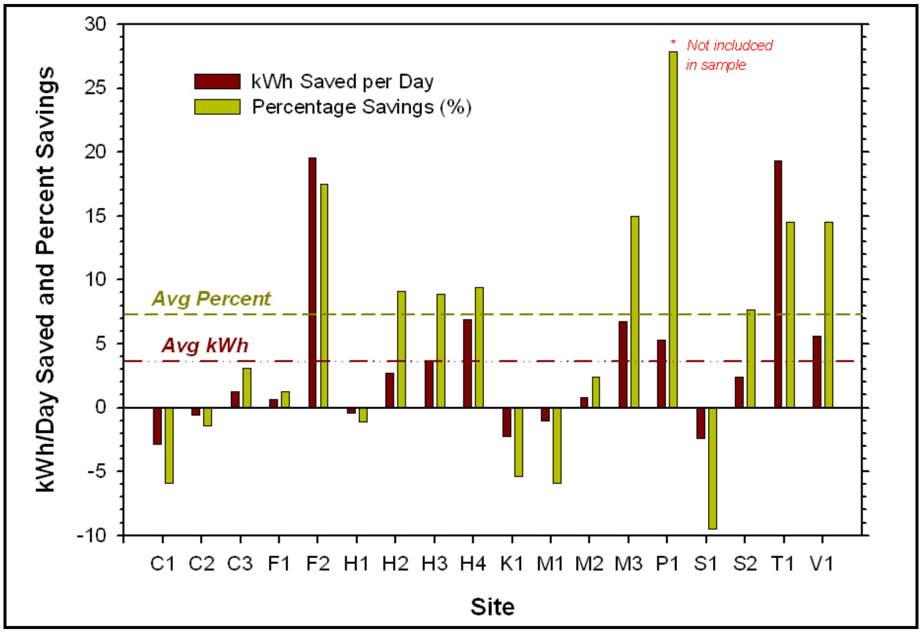

Figure 6. Measured daily electricity savings in kWh and percent by site.

Generally, the homes with the largest consumption also experienced the largest savings. Notably, the two homes with the largest pre-monitor installation use also achieved the largest savings in the post period. Based on exit interviews with the occupants, these two household paid close attention to the monitors and used what they learned to make overt changes in household appliances as well as scheduling for some equipment. This included large changes to household lighting, reduction of pool-pump hours and replacement of an aging AC system in one. This may mean that energy feedback monitors would have special value for utilities in homes with high bill complaints. It also may indicate that the economics of feedback will be most persuasive, for interested, but high energy consumers.

Findings from Survey

A short one page survey was sent to the homeowners at the end of the study. Of the 17 with complete utility data, 14 filled out and returned the survey. The short survey instrument is included in Appendix B.

We found that the monitor was most commonly placed in the kitchen, although the degree with which the household paid attention to the device varied considerably. Several respondents indicated looking at the display several times a day, but others reported disinterest and one considered the device an eyesore. Generally, most respondents indicated that their primary interest in using the device was in saving money; the second most common response to this question was interest in helping the environment.

In terms of how the device was used, responses again varied from “very interested and useful” to “total apathy.” Interestingly, those most interested in the device also uniformly reported making considerable changes to their energy using equipment or their schedules. Not surprisingly, we found that these responses correlated strongly to observed energy savings in the second year.

For instance, of the five respondents who reported both considerable interest in the device as well as considerable changes made in equipment or schedules, savings averaged 9.2 kWh/day or 13.3% versus a savings 1.0 kWh/Day and 2.6% reduction in the other less interested and less motivated respondents.

Although a very limited sample, this study seems to indicate that interest and motivation were large factors in whether having the feedback device made a difference in energy use. Thus, consumers worried about high bills or otherwise interested in really lowering their energy use could be the best candidates for using the technology. What is not clear from the evaluation is how the timing of the savings would impact utility peak demand or the motivational factors that generate interest in the first place. One clue, however, is that the major motivation mentioned by participants was saving money, coupled with the fact that generally those saving most had the highest utility bills.

Future Research

Energy feedback and our understanding of its impact on energy use is evolving with experience and display technology. Not only are behavioral influences of feedback largely un-researched in recent years, but information is also lacking on the impact on time-of-day demand. Also, occupant interest in energy feedback will likely be influenced by the relative price of energy (see Hayes and Cone, 1977; Battalio et al., 1979; Winett et al., 1979)—another area where available research information is dated. Little, too, is known about the degree to which feedback display design itself determines the magnitude of reduction, although the available information would suggest that bold, vivid displays are best (Winett and Kagel, 1984). The overall user-interface design for feedback displays is another area to be further refined.

Another potentially critical topic is the potential interaction with critical utility pricing signals (Stein 2004; Mitchell-Jackson, 2005). Most studies have confined themselves to the impact of time-of-day electricity pricing, rather than the question of how such pricing might influence energy use when combined with real-time energy data (Wood et. al., 2004). Information is also lacking on behavioral persistence. Finally, the use of feedback systems as a tool for building diagnostics and occupant education, such as suggested by Harrigan and Kempton (1995), has not been effectively evaluated.

The potential seems particularly attractive for low energy buildings with solar photovoltaics (PV). For instance in the pioneering Livermore ZEH in California, the occupants who were previously not interested in their low energy house, found a provided energy feedback meter a powerful motivator to reduce consumption to better match the output of the solar electric system (Springer, 2005). Parallel research in Great Britain underscores the potential of feedback in grid-connected PV homes (Keirstead, 2005).

Conclusions

Earlier research dating from the 1970s have shown that providing effective feedback from appliance use decisions can be a powerful means to impact energy use. Until recently, however, few methods have existed for households to gauge influences on household electricity use. Fortunately, a series of low cost energy monitors are now becoming available which allow consumers to obtain such information. Recent evaluations in Canada and Japan suggest a typical range of energy savings from providing feedback of 5-15%. Moreover, feedback has potential to reduce miscellaneous energy use which is otherwise difficult to accomplish. An important advantage of the technology is that it provides good guidance on profitable areas to reduce household electrical demand.

Within the paper, we performed a pilot evaluation of a low cost monitoring systems in 22 case study homes of which 17 homes had one year pre and post data. Although not a statistical sample (the participants were self-selected), the study showed an average 7.4% reduction in energy use (3.7 kWh/day) from feedback in homes in the second year of monitoring after controlling for weather-related influences. A large identified advantage of the technology is that it provides better guidance on profitable areas to reduce household electrical demand—many of which may be unanticipated.

Savings from owning the device appeared roughly correlated with pre-installation consumption levels – those using most energy appeared to save most from using the monitors. Moreover, exit survey results clearly showed that those expressing large interest in the monitor and those saying they were motivated to cut energy use were much more successful at achieving energy reductions than the remainder of the group.

Acknowledgments

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References

Allen, D. and Kathryn B. Janda. 2006. "The Effects of Household Characteristics and Energy Use Consciousness on the Effectiveness of Real-Time Energy Use Feedback: A Pilot Study," Proceedings of the American Council for an Energy-Efficient Economy 2006 Summer Study. Volume 7, "Human and Social Dimensions of Energy Use, ACEEE: Washington DC

Battalio, Raymond C., John H. Kagel, Robin C. Winkler and Richard A. Winett 1979. "Residential Electricity Demand: An Experimental Study," *Review of Economics and Statistics*, 61 (2), pp. 180-189.

Bittle, Ronald G., Robert Valesano and Greg Thaler, 1979. "The Effects of Daily Cost Feedback on Residental Electricity Consumption," *Behavior Modification*, 3 (April), pp. 187-202.

Darby, Sarah, 2000, "Making it obvious: designing feedback into energy consumption," Proceedings, 2nd International Conference on Energy Efficiency in Household Appliances and Lighting. Italian Association of Energy Economists, Naples, 2000.

Dobson, John K., and J.D. Anthony Griffin. 1992. "Conservation Effect of Immediate Electricity Cost Feedback on Residential Consumption Behavior," ACEEE 1992 Summer Study on Energy Efficiency in Buildings, American Council for an Energy Efficient Economy, Washington D.C.

Farhar, B. Fitzpatrick, C, 1989. Effects of Feedback on Residential Electricity Consumption: A Literature Review, SERI/TR-254-3386, Solar Energy Research Institute, Golden, CO.

Griffiths, Dianne, 2005. "CARB Research Highlights East," Building America presentation, *Steven Winter and Associates*, 17 October 2005.

Harrigan, M., W. Kempton, et al. (1995). Empowering Customer Energy Choices: A Review of Personal Interaction and Feedback in Energy Efficiency Programs, Washington, DC, Alliance to Save Energy.

Hayes, Steven C. and John D. Cone, 1977. "Reducing Residential Electrical Energy Use: Payments, Information and Feedback," *Journal of Applied Behavior Analysis*, 10, p. 425.

Hutton, R. Bruce, Mauser, Gary A, Filiatrault, Pierre and Ahtola, Olli T, 1986. "Effects of Cost Related Feedback on Consumer Knowledge and Consumption Behavior: A Field Experimental Approach," Journal of Consumer Research, Vo. 13, p. 327.

Katzev, R. D. and T. R. Johnson (1986). Promoting Energy Conservation: An Analysis of Behavioral Research, Boulder, Westview Press.

Keirstead, J., (2005). "Household Behavioral Responses to PV-System Monitoring Devices," in Proceedings of World Renewable Energy Congress, 23 - 27 May 2005, Aberdeen, Scotland.

Lutzenhiser, Loren. 1990. Explaining Consumption: The Promises and Limitations of Energy and Behavior Research, ACEEE 1990 Summer Study on Energy Efficiency in Buildings, American Council for an Energy Efficient Economy, Washington D.C.

McClelland, Lou and Stuart W. Cook, 1979. "Energy Conservation Effects of Continuous In-Home Feedback in All-Electric Homes," *Journal of Environmental Systems*, 9 (2), p. 169.

Mitchell-Jackson, Jennifer, 2005. "The Behavioral Effects of Enhanced Energy Information: An Evaluation of the Statewide California Information Display Pilot," Proceedings of the 2005 International Energy Program Evaluation Conference, August 17-19, 2005, New York, NY.

Mountain, Dean, 2006. The Impact of Real Time Energy Feedback on Residential Electricity Consumption: The Hydro One Pilot, McMaster University, Ontario, March 2006.

Palmer, Michael H., Margaret E. Lloyd and Kenneth E. Lloyd, 1977. "An Experimental Analysis of Electricity Conservation Procedures," *Journal of Applied Behavior Analysis*, 10, p. 665.

Parker, Danny, Hoak, David, Meier, Alan, Brown, Richard, 2006. "How Much Energy are we Using: the Potential For Energy Demand Feedback Devices, Proceedings of the American Council for an Energy-Efficient Economy 2006 Summer Study, ACEEE: Washington DC.

Parker, D., Mazzara, M., Sherwin, J., 1996. "Monitored Energy Use Patterns In Low-Income Housing In A Hot And Humid Climate," Proceedings of the Tenth Symposium on Improving Building Systems in Hot Humid Climates, Ft. Worth, TX, p. 316.

Seligman, Clive and Darley, John .M. (1977). "Feedback as a Means of Decreasing Residential Energy Consumption," Journal of Applied Psychology, 62, p. 363.

Seligman, Clive and Darley, John.M. and Becker, Lawrence J. (1978). "Behavioral Approaches to Residential Energy Conservation," in Saving Energy in the Home: Princeton's Experiments at Twin Rivers, Ballinger Publishing Co., Cambridge, MA.

Socolow, R. and Sonderegger, R., 1976. The Twin Rivers Program on Energy Conservation in Housing: Four Year Summary Report, *Center for Environmental Studies*, Princeton, August, 1976.

Springer, David, "Personal communication regarding Livermore Zero Energy Home," November 2005, Davis Energy Group, Davis, CA.

Stein, Lynn F., 2004. California Information Display Pilot Technology Assessment, Final Report, prepared for Southern California Edison, Primen, Inc., Boulder, CO, 21 December 2004.

SWA, 2005, "Cutting the Power," CARB News, Consortium for Advanced Residential Buildings, *Stephen Winter and Associates*, Vol. 8, No. 9, November 2005.

Ueno, T., Inada, R., Saeki, O and Tsuji, K. "Effectiveness of Displaying Energy Consumption Data in Residential Houses," ECEEE 2005 Summer Study on Energy Efficiency in Buildings, Vol. 6, European Council for an Energy Efficient Economy, Brussels, p. 1289.

Van Houwelingen, Jeannet and Fred W. Van Raaij, 1989. "The Effect of Goal Setting and Daily Electronic Feedback on In-Home Energy Use," Journal of Consumer Research, Vol. 16, June.

Winett, Richard A. and John H. Kagel, 1984. "Effects of Information Presentation Format on Resource Use in Field Settings," Journal of Consumer Research, 11 (September), p. 655.

Winett, Richard A., Michael S. Neale and H. Cannon Grier, 1979. "Effects of Self-Monitoring and Feedback on Residential Electricity Consumption," Journal of Applied Behavior Analysis, 12 (Summer), p. 173.

Appendix A

Survey Instrument

Energy Feedback Followup Survey

Dear Energy Feedback Study participants. This a very short survey of those involved in the project to allow us to gauge how using the TED energy display worked out for you over the last year. Please respond to the email in context so we can tally the results. Thank you.

1) What room was the TED display located?
- a) kitchen
- b) living room
- c) dining room
- d) bedroom
- e) study
- f) hid it in the utility room/garage
- g) other ____________

2) How often did someone in the house examine the display?
- a) Several times a day
- b) Once a day
- c) Every few days
- d) Once a week
- e) Scarcely noticed it blinking at night

3) What was the response from members of your household to the device (check as many as apply)
- a) Thought it was interesting, and very useful to our attempts to control energy use
- b) Thought it was nifty at first, but we quickly lost interest
- c) Couldn't care less
- d) Never knew it was there
- e) Thought it was an eyesore and wanted to get rid of it

4) When you looked at the display, what information did you examine?
- a) Instantaneous power demand (kW)
- b) Accumulated daily power use (kWh)
- c) Energy cost data
- d) Looked at the various types of displays
- e) Was all Geek Greek to me
- f) Never looked at the numbers

5) Which choice best characterizes your interest in the display?
- a) Not interested at all; ignored it
- b) Some interest
- c) Considerable interest, but didn't know what do do with the information
- d) Very interested; used the display to understand energy using equipment
- e) Very interested and used the display to make changes in habits and/or energy using equipment

6) Did you change any energy using equipment during the time the display was in use in your home?
- a) No; no real changes
- b) Changes in household equipment and appliances, but none attributable to the device
- c) Yes, some change in habits
- d) Yes, made some changes to equipment
- e) Yes, made considerable change to both habits and equipment

7) What was the biggest limitation of the device?

a) Being more attractive or attention getting
b) Ineffective at displaying meaningful information
c) Not knowing where the loads were coming from that I was seeing
d) Not knowing what to do about what I was seeing
e) General household apathy about the display

8) What would be your Number 1 motivation to reduce energy use?

a) Save money
b) Help with the environment
c) Set a household example

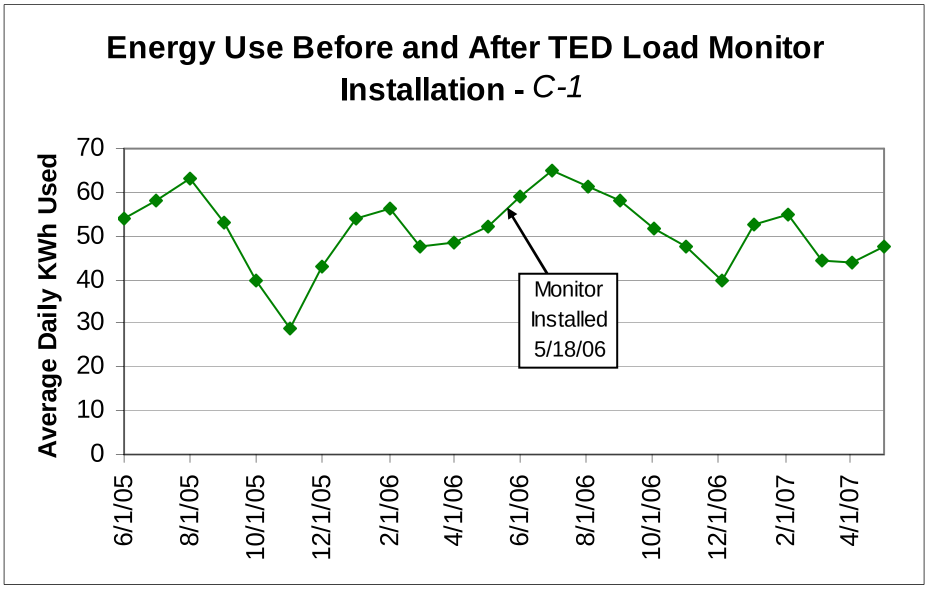
9) Please fill in the following:

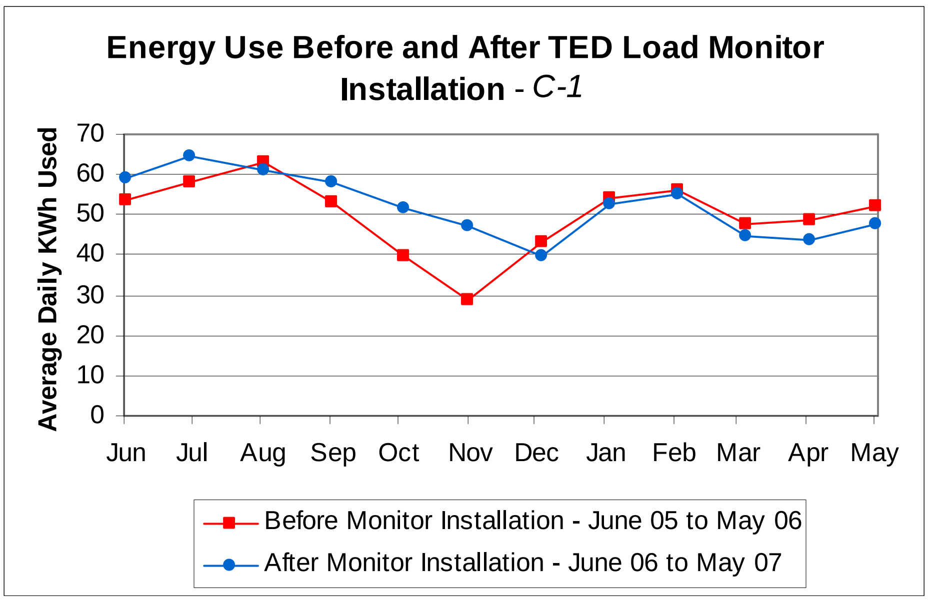
a) Years at current address______
b) Avg hours per weekday that house is occupied______
c) Number of people in household_______
d) Number of children in household______
e) Conditioned floorspace of home_______

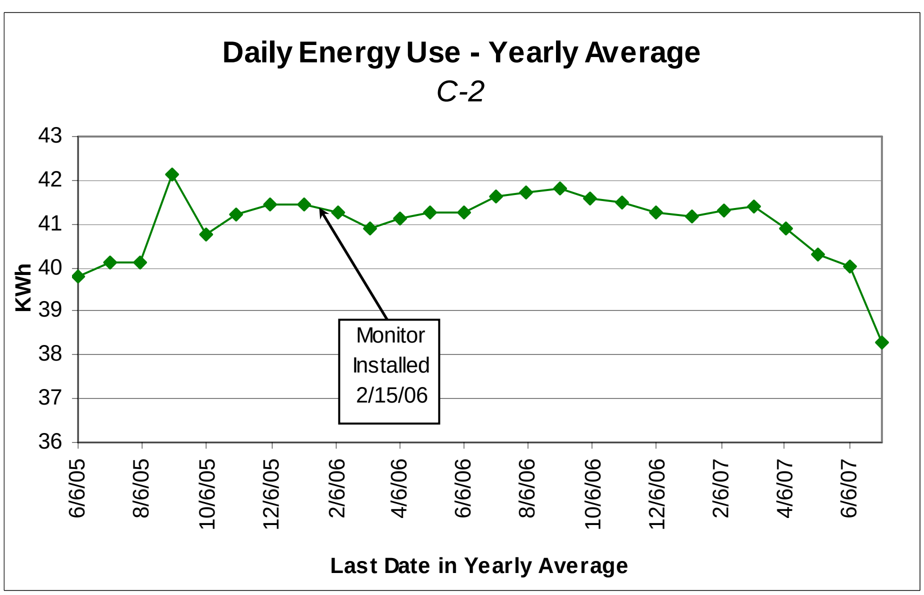
10) What other information would you like to convey to us about your experiences using the TED feedback display?

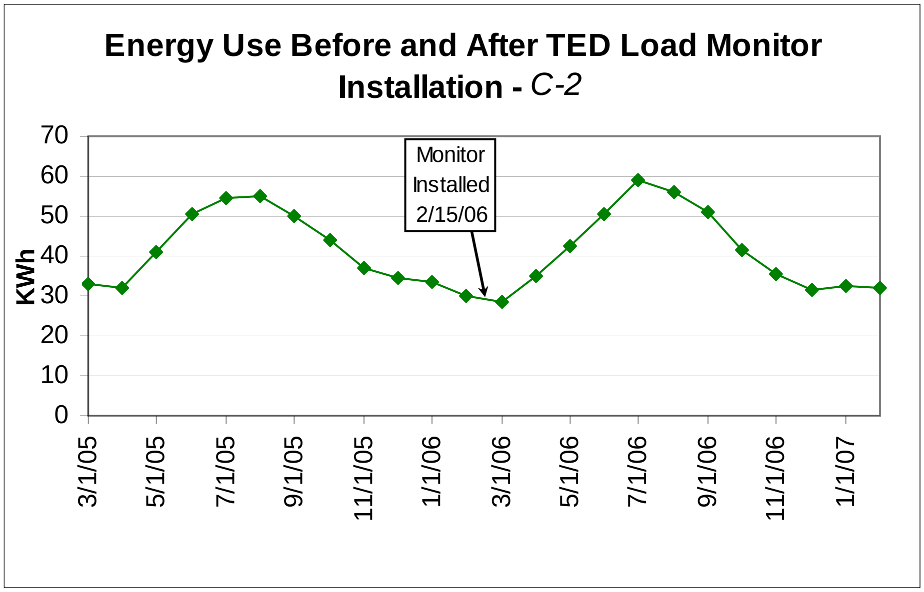
Appendix B

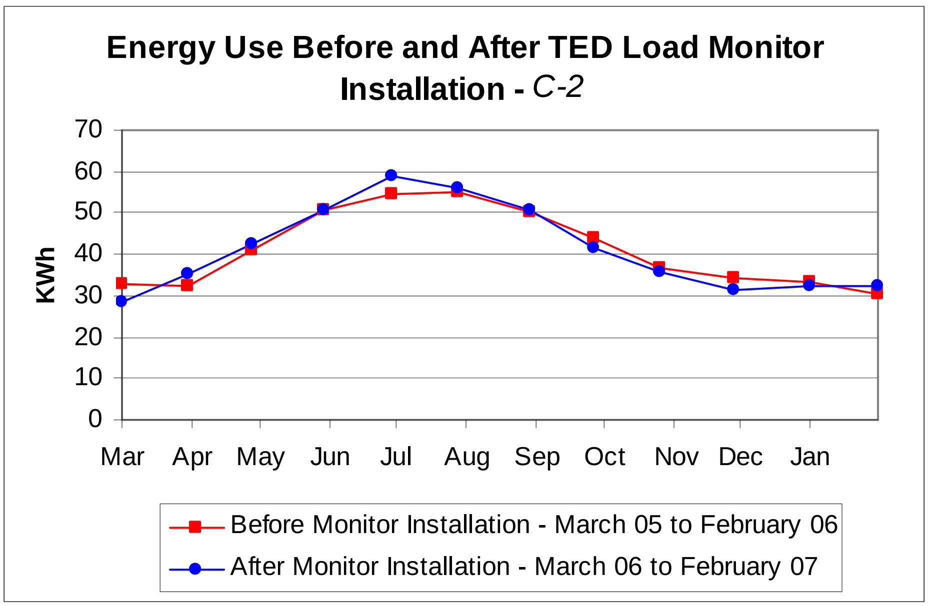
Analysis Plots for Individual Sites

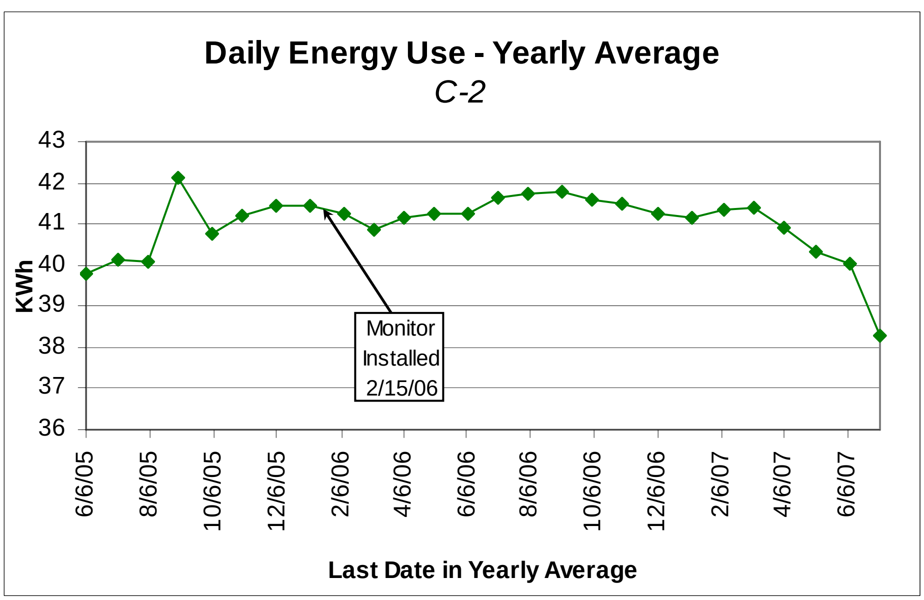

Energy Use Before and After TED Load Monitor Installation - C-1
Average Daily KWh Used
70
60
50
40
30
20
10
0
6/1/05
8/1/05
10/1/05
12/1/05
2/1/06
4/1/06
6/1/06
8/1/06
10/1/06
12/1/06
2/1/07
4/1/07
Monitor Installed 5/18/06

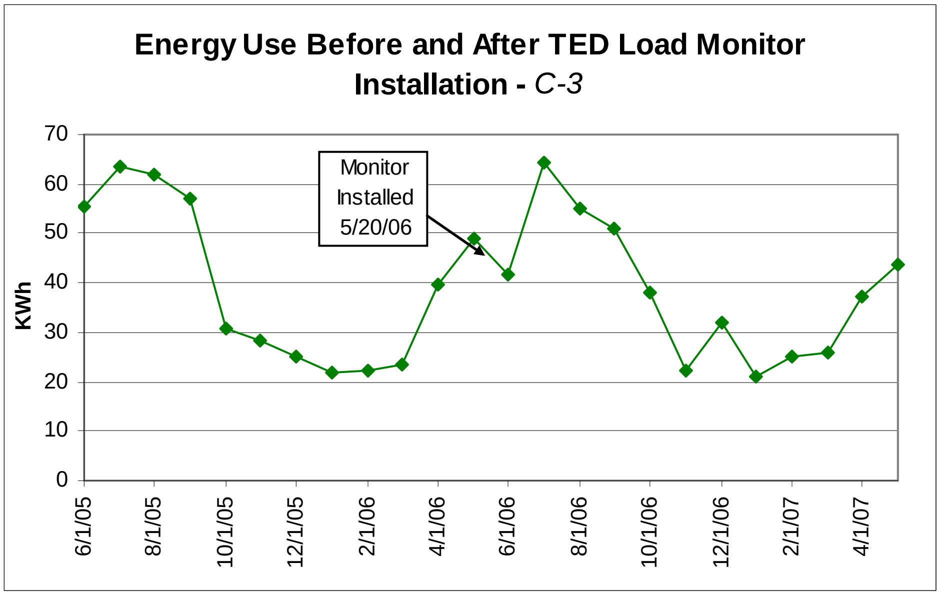

Energy Use Before and After TED Load Monitor Installation - C-1
Average Daily KWh Used
70
60
50
40
30
20
10
0
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Before Monitor Installation - June 05 to May 06
After Monitor Installation - June 06 to May 07

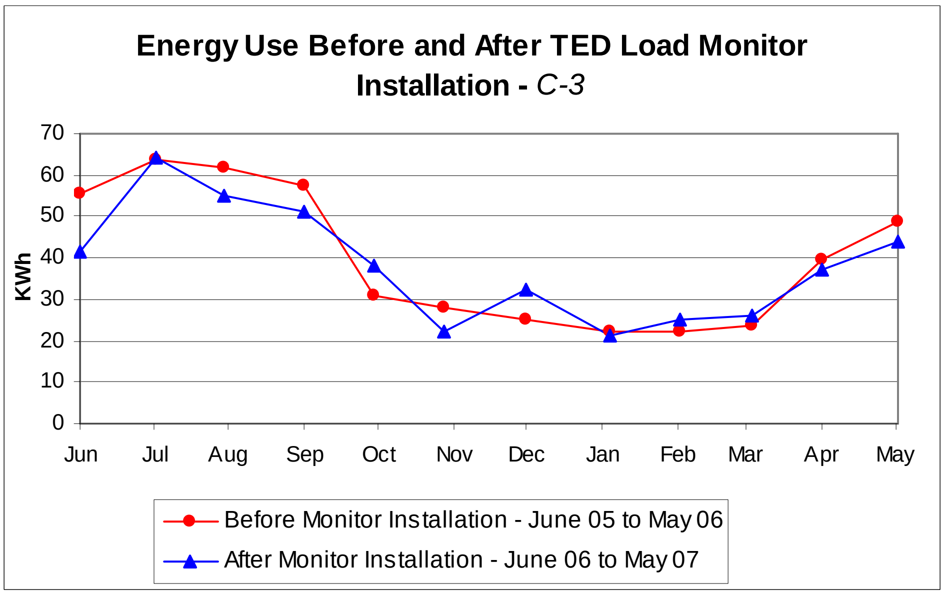

Daily Energy Use - Yearly Average
C-2
KWh
43
42
41
40
39
38
37
36
6/6/05
8/6/05
10/6/05
12/6/05
2/6/06
4/6/06
6/6/06
8/6/06
10/6/06
12/6/06
2/6/07
4/6/07
6/6/07
Monitor Installed 2/15/06
Last Date in Yearly Average

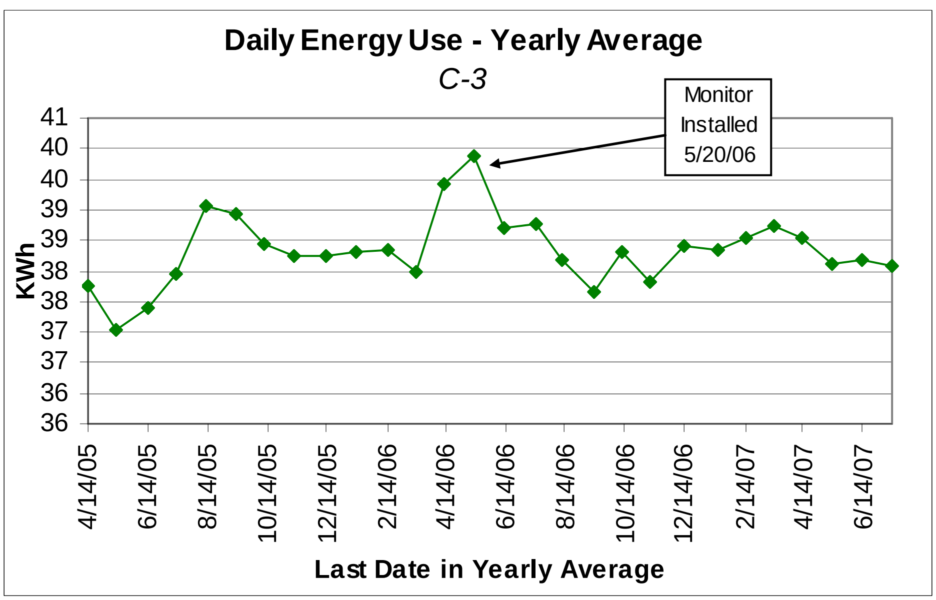

Energy Use Before and After TED Load Monitor Installation - C-2
Monitor Installed 2/15/06
KWh
0
10
20
30
40
50
60
70
3/1/05
5/1/05
7/1/05
9/1/05
11/1/05
1/1/06
3/1/06
5/1/06
7/1/06
9/1/06
11/1/06
1/1/07

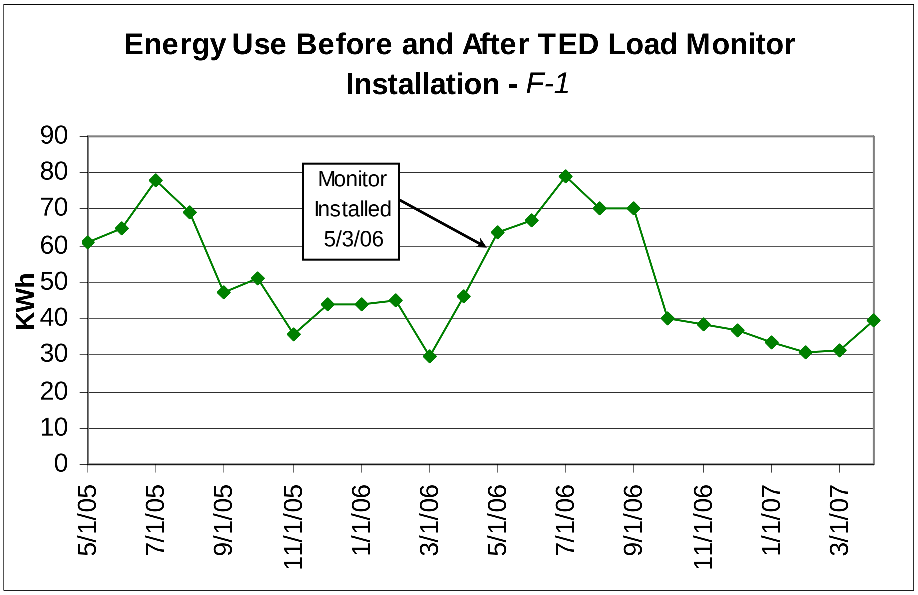

Energy Use Before and After TED Load Monitor Installation - C-2
KWh
0
10
20
30
40
50
60
70
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Before Monitor Installation - March 05 to February 06
After Monitor Installation - March 06 to February 07

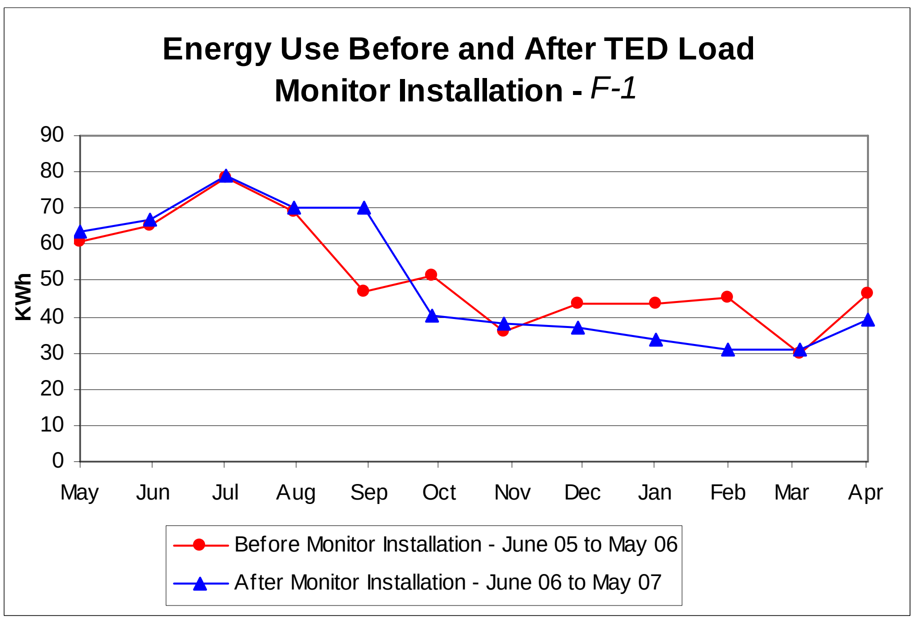

Daily Energy Use - Yearly Average
C-2
KWh
36
37
38
39
40
41
42
43
Monitor Installed 2/15/06
6/6/05
8/6/05
10/6/05
12/6/05
2/6/06
4/6/06
6/6/06
8/6/06
10/6/06
12/6/06
2/6/07
4/6/07
6/6/07
Last Date in Yearly Average

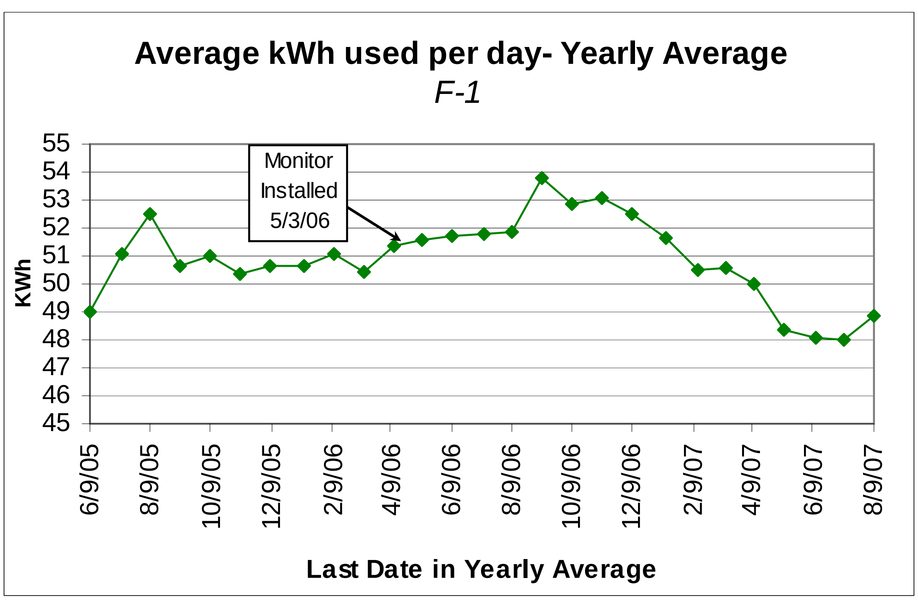

Energy Use Before and After TED Load Monitor Installation - C-3
Monitor Installed 5/20/06
KWh
70
60
50
40
30
20
10
0
6/1/05
8/1/05
10/1/05
12/1/05
2/1/06
4/1/06
6/1/06
8/1/06
10/1/06
12/1/06
2/1/07
4/1/07

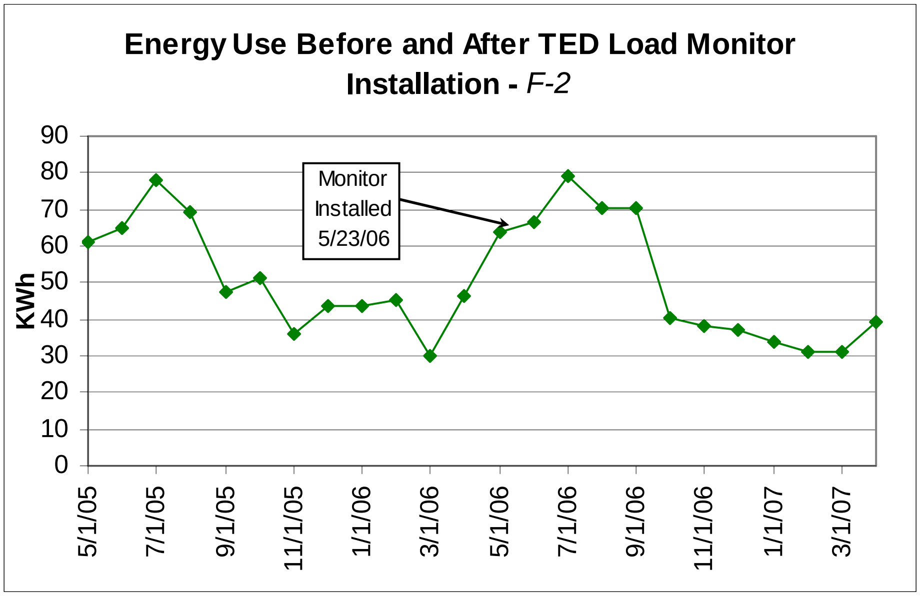

Energy Use Before and After TED Load Monitor Installation - C-3
KWh
70
60
50
40
30
20
10
0
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Before Monitor Installation - June 05 to May 06
After Monitor Installation - June 06 to May 07

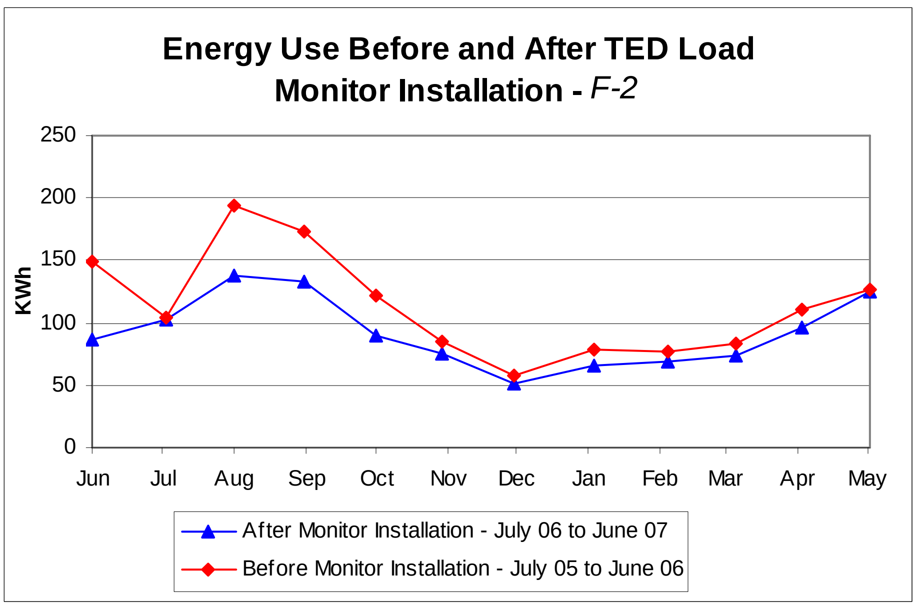

Daily Energy Use - Yearly Average
C-3
Monitor Installed 5/20/06
KWh
41
40
40
39
39
38
38
37
37
36
36
4/14/05
6/14/05
8/14/05
10/14/05
12/14/05
2/14/06
4/14/06
6/14/06
8/14/06
10/14/06
12/14/06
2/14/07
4/14/07
6/14/07
Last Date in Yearly Average

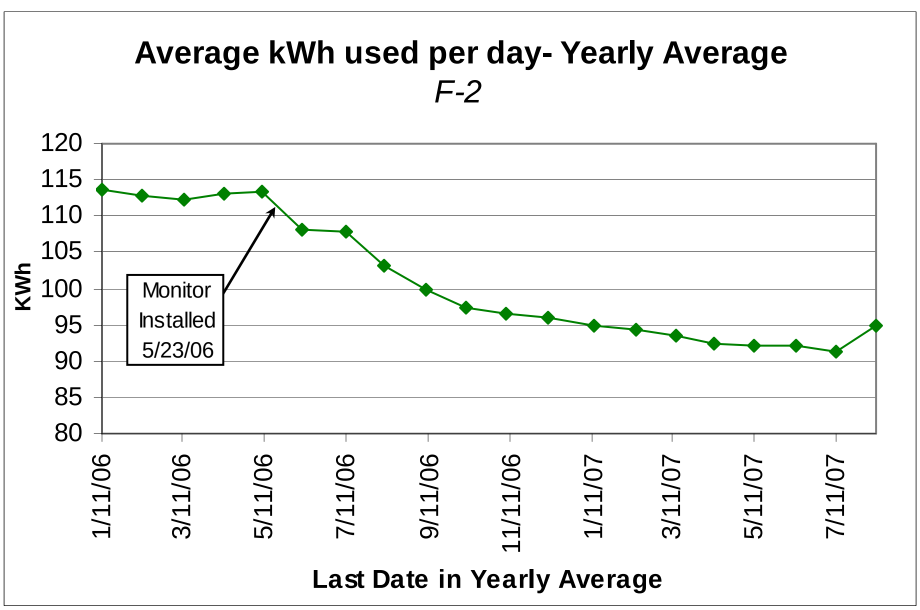

Energy Use Before and After TED Load Monitor Installation - F-1
KWh
Monitor Installed 5/3/06
5/1/05
7/1/05
9/1/05
11/1/05
1/1/06
3/1/06
5/1/06
7/1/06
9/1/06
11/1/06
1/1/07
3/1/07

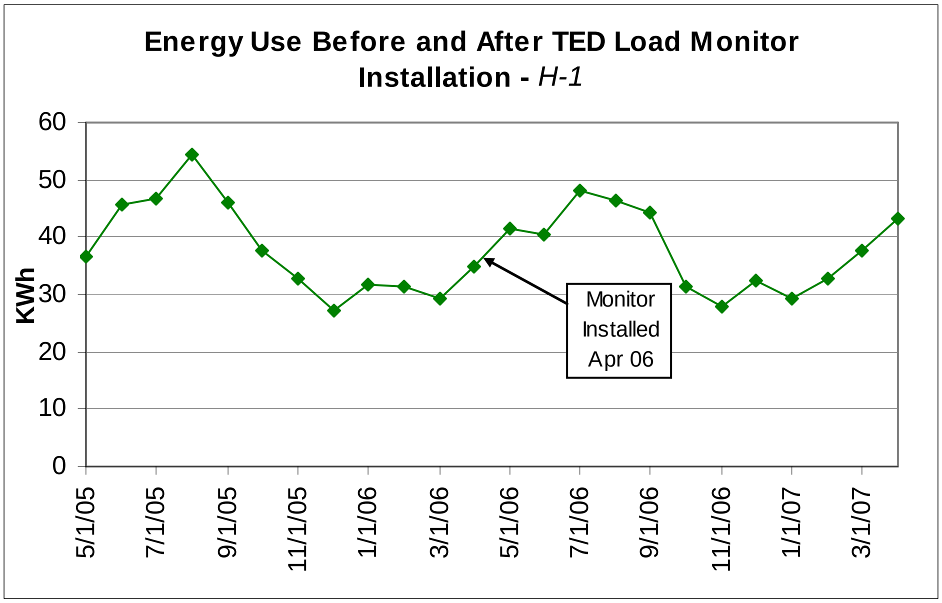

Energy Use Before and After TED Load Monitor Installation - F-1
KWh
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
Before Monitor Installation - June 05 to May 06
After Monitor Installation - June 06 to May 07

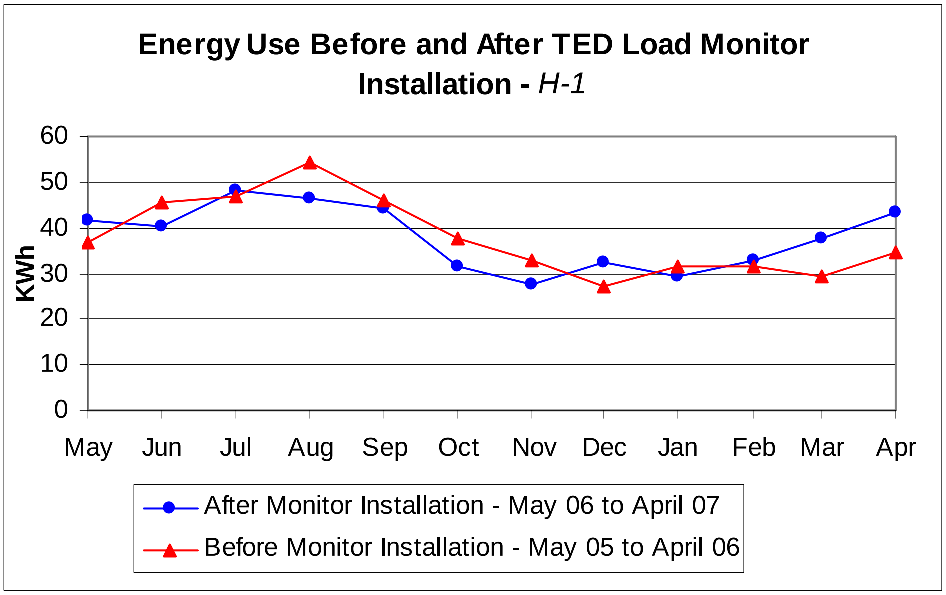

Average kWh used per day- Yearly Average F-1
KWh
Monitor Installed 5/3/06
6/9/05
8/9/05
10/9/05
12/9/05
2/9/06
4/9/06
6/9/06
8/9/06
10/9/06
12/9/06
2/9/07
4/9/07
6/9/07
8/9/07
Last Date in Yearly Average

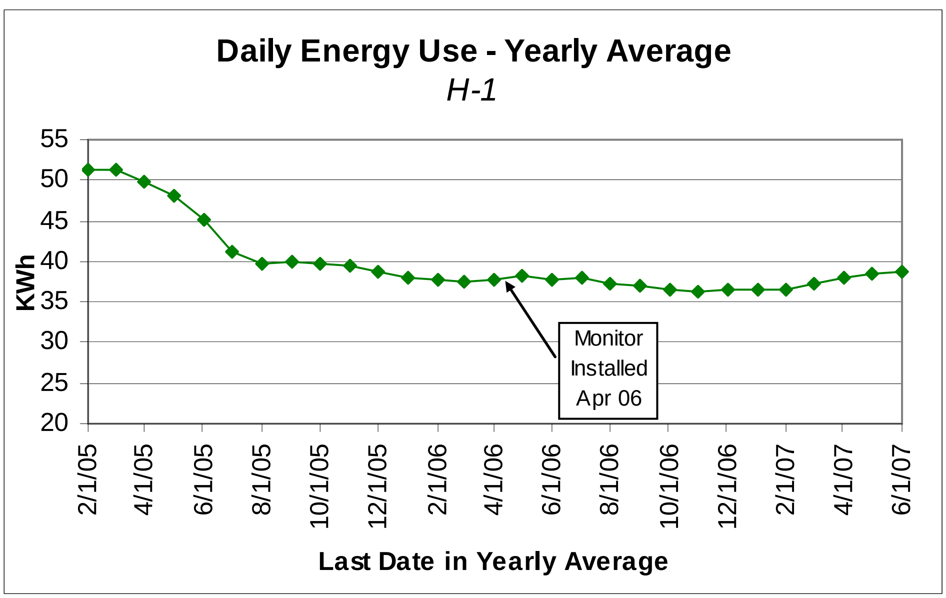

Energy Use Before and After TED Load Monitor Installation - F-2
KWh
90
80
70
60
50
40
30
20
10
0
Monitor Installed 5/23/06
5/1/05
7/1/05
9/1/05
11/1/05
1/1/06
3/1/06
5/1/06
7/1/06
9/1/06
11/1/06
1/1/07
3/1/07

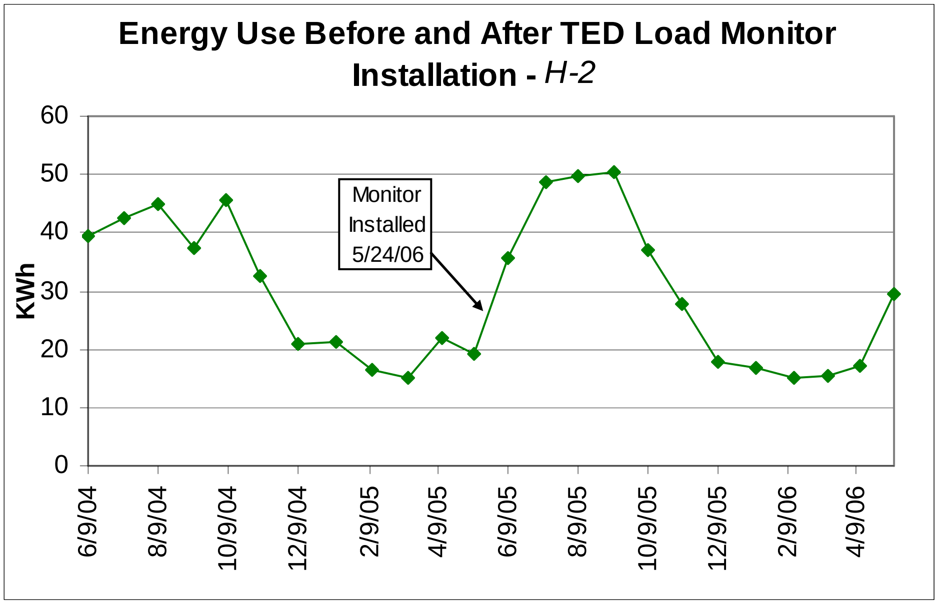

Energy Use Before and After TED Load Monitor Installation - F-2
KWh
250
200
150
100
50
0
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
After Monitor Installation - July 06 to June 07
Before Monitor Installation - July 05 to June 06


Average kWh used per day- Yearly Average F-2
KWh
120
115
110
105
100
95
90
85
80
Monitor Installed 5/23/06
1/11/06
3/11/06
5/11/06
7/11/06
9/11/06
11/11/06
1/11/07
3/11/07
5/11/07
7/11/07
Last Date in Yearly Average

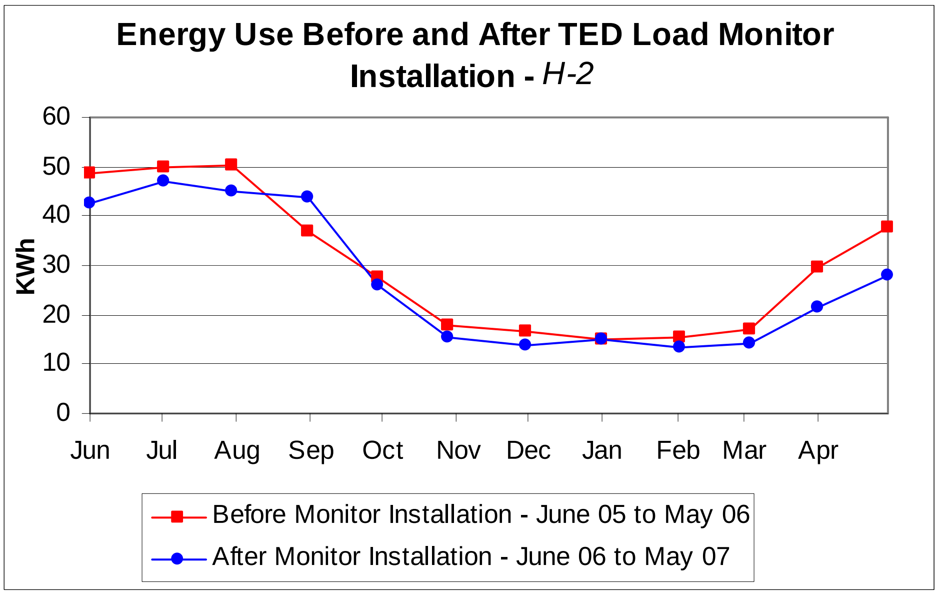

Energy Use Before and After TED Load Monitor Installation - H-1
KWh
60
50
40
30
20
10
0
5/1/05
7/1/05
9/1/05
11/1/05
1/1/06
3/1/06
5/1/06
7/1/06
9/1/06
11/1/06
1/1/07
3/1/07
Monitor Installed Apr 06


Energy Use Before and After TED Load Monitor Installation - H-1
KWh
60
50
40
30
20
10
0
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
After Monitor Installation - May 06 to April 07
Before Monitor Installation - May 05 to April 06

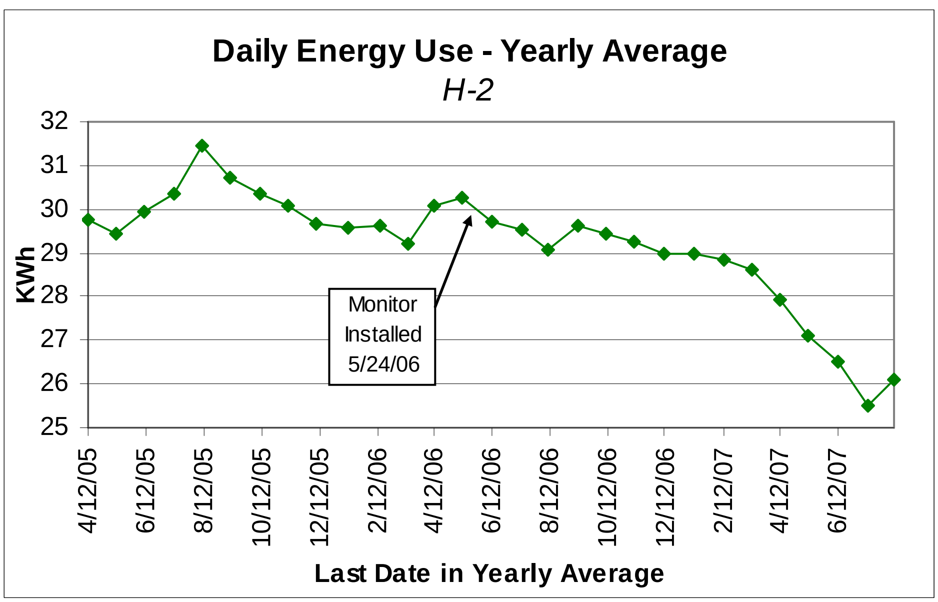

Daily Energy Use - Yearly Average
H-1
KWh
55
50
45
40
35
30
25
20
2/1/05
4/1/05
6/1/05
8/1/05
10/1/05
12/1/05
2/1/06
4/1/06
6/1/06
8/1/06
10/1/06
12/1/06
2/1/07
4/1/07
6/1/07
Monitor Installed Apr 06
Last Date in Yearly Average



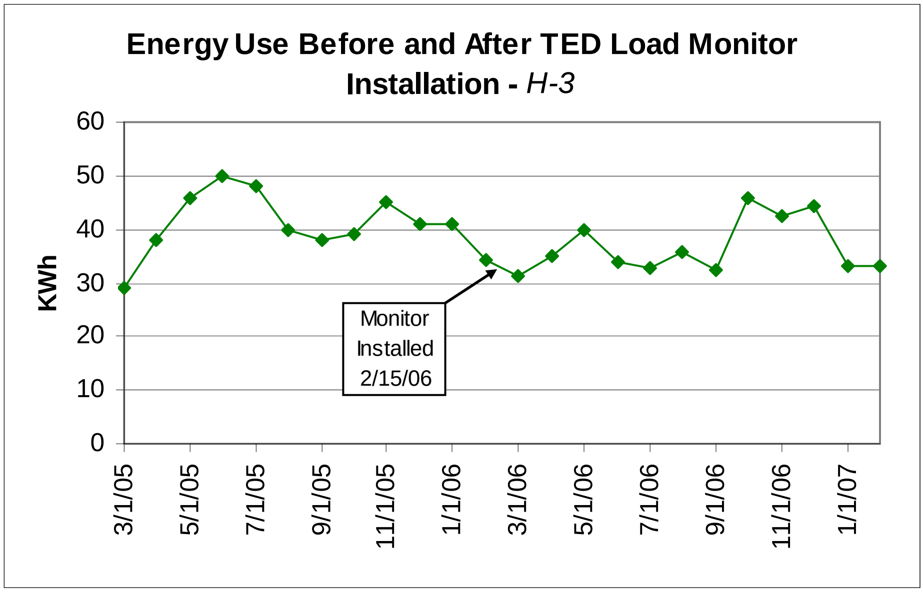
Energy Use Before and After TED Load Monitor Installation - H-2
KWh
60
50
40
30
20
10
0
Monitor Installed 5/24/06
6/9/04
8/9/04
10/9/04
12/9/04
2/9/05
4/9/05
6/9/05
8/9/05
10/9/05
12/9/05
2/9/06
4/9/06

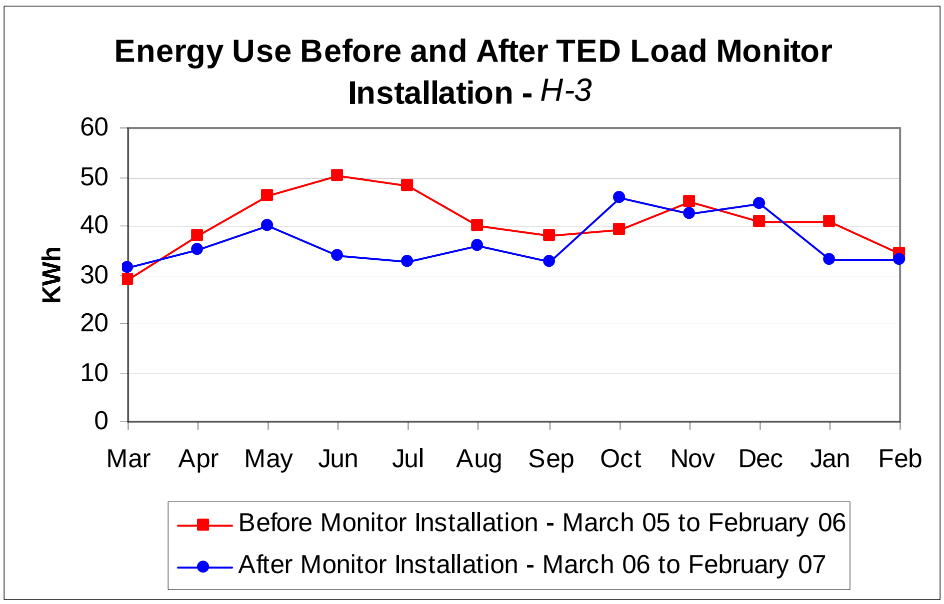


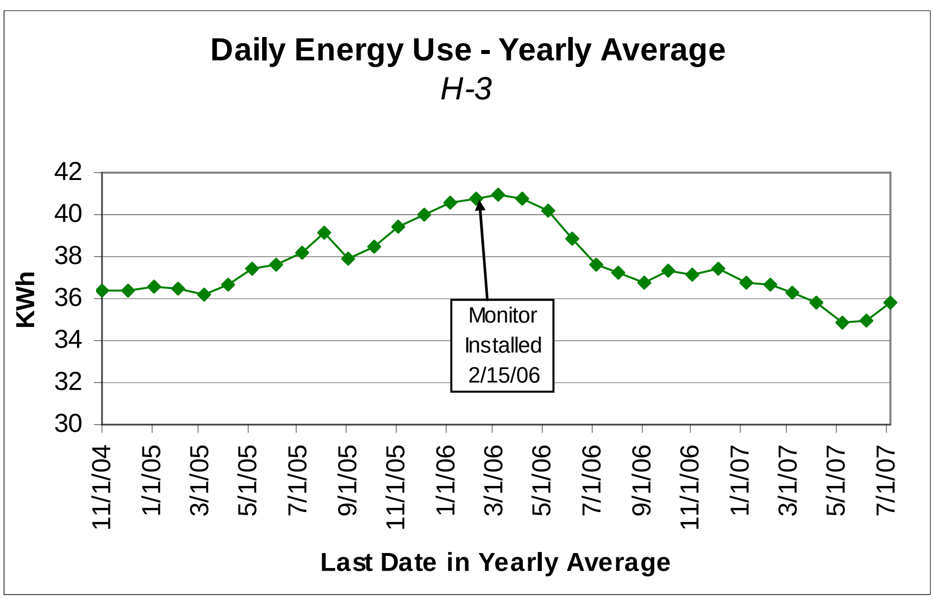
Energy Use Before and After TED Load Monitor Installation - H-2
KWh
60
50
40
30
20
10
0
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
Before Monitor Installation - June 05 to May 06
After Monitor Installation - June 06 to May 07

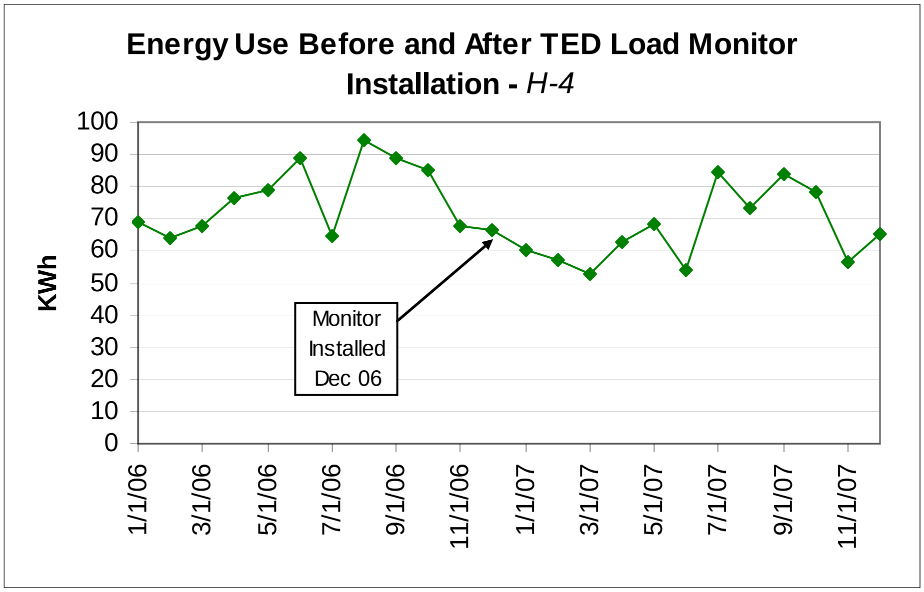


Daily Energy Use - Yearly Average
H-2
KWh
32
31
30
29
28
27
26
25
Monitor Installed 5/24/06
4/12/05
6/12/05
8/12/05
10/12/05
12/12/05
2/12/06
4/12/06
6/12/06
8/12/06
10/12/06
12/12/06
2/12/07
4/12/07
6/12/07
Last Date in Yearly Average

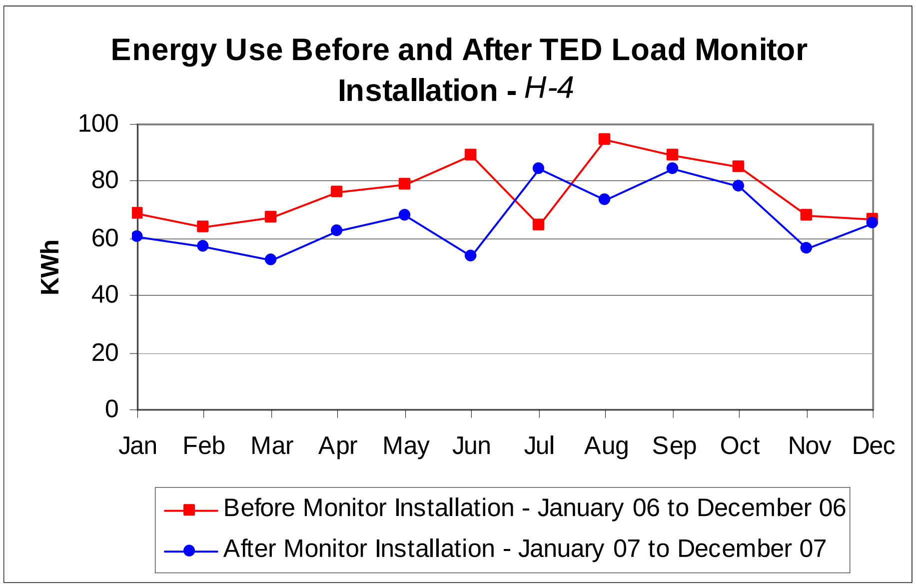

Energy Use Before and After TED Load Monitor Installation - H-3
KWh
60
50
40
30
20
10
0
Monitor Installed 2/15/06
3/1/05
5/1/05
7/1/05
9/1/05
11/1/05
1/1/06
3/1/06
5/1/06
7/1/06
9/1/06
11/1/06
1/1/07


Energy Use Before and After TED Load Monitor Installation - H-3
KWh
60
50
40
30
20
10
0
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Before Monitor Installation - March 05 to February 06
After Monitor Installation - March 06 to February 07

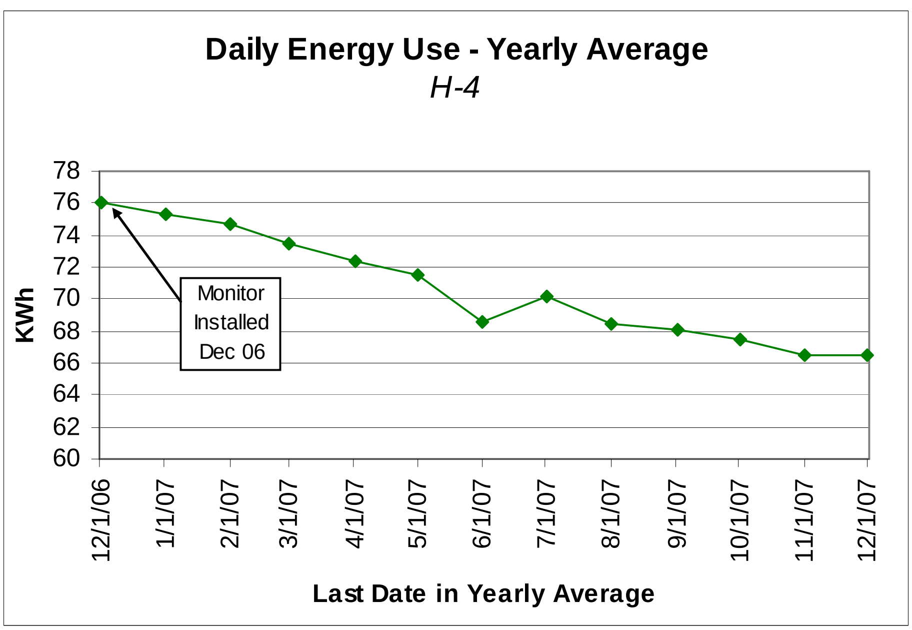

Daily Energy Use - Yearly Average
H-3
KWh
42
40
38
36
34
32
30
Monitor Installed 2/15/06
11/1/04
1/1/05
3/1/05
5/1/05
7/1/05
9/1/05
11/1/05
1/1/06
3/1/06
5/1/06
7/1/06
9/1/06
11/1/06
1/1/07
3/1/07
5/1/07
7/1/07
Last Date in Yearly Average



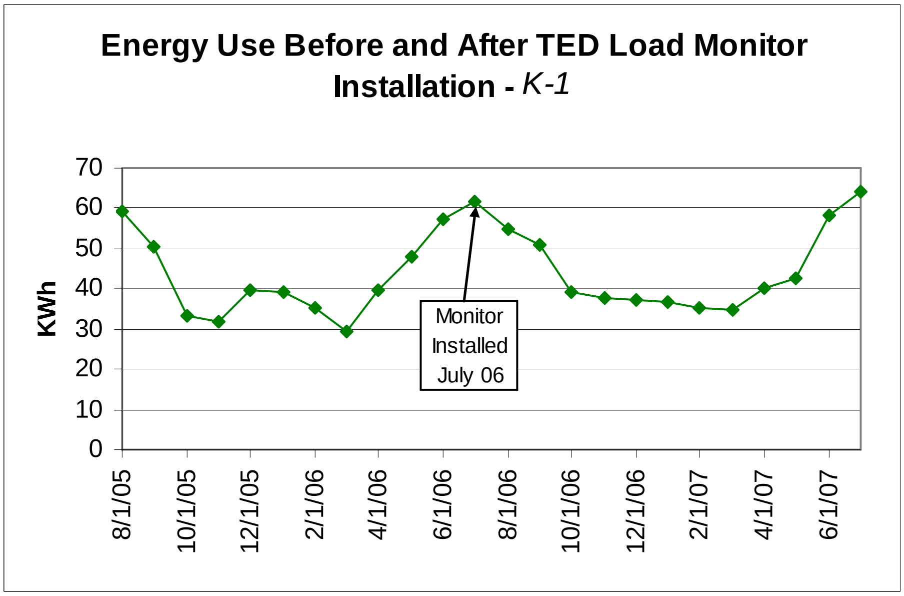
Energy Use Before and After TED Load Monitor Installation - H-4
KWh
100
90
80
70
60
50
40
30
20
10
0
Monitor Installed Dec 06
1/1/06
3/1/06
5/1/06
7/1/06
9/1/06
11/1/06
1/1/07
3/1/07
5/1/07
7/1/07
9/1/07
11/1/07

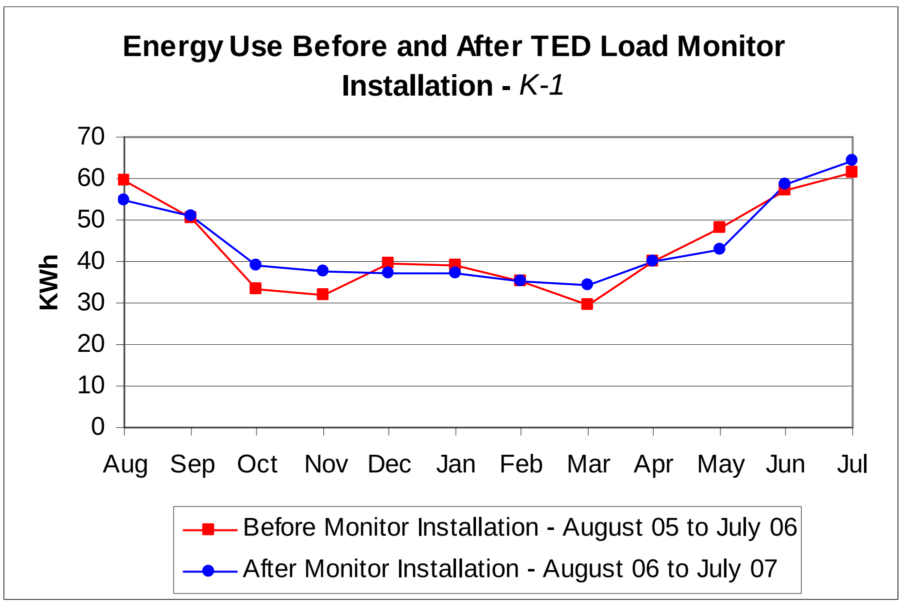


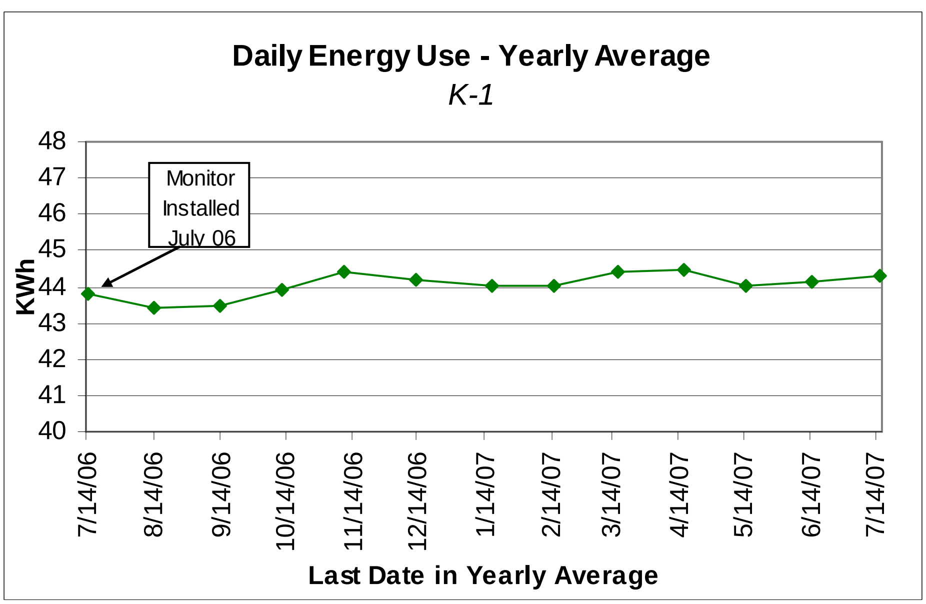
Energy Use Before and After TED Load Monitor Installation - H-4
KWh
100
80
60
40
20
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Before Monitor Installation - January 06 to December 06
After Monitor Installation - January 07 to December 07

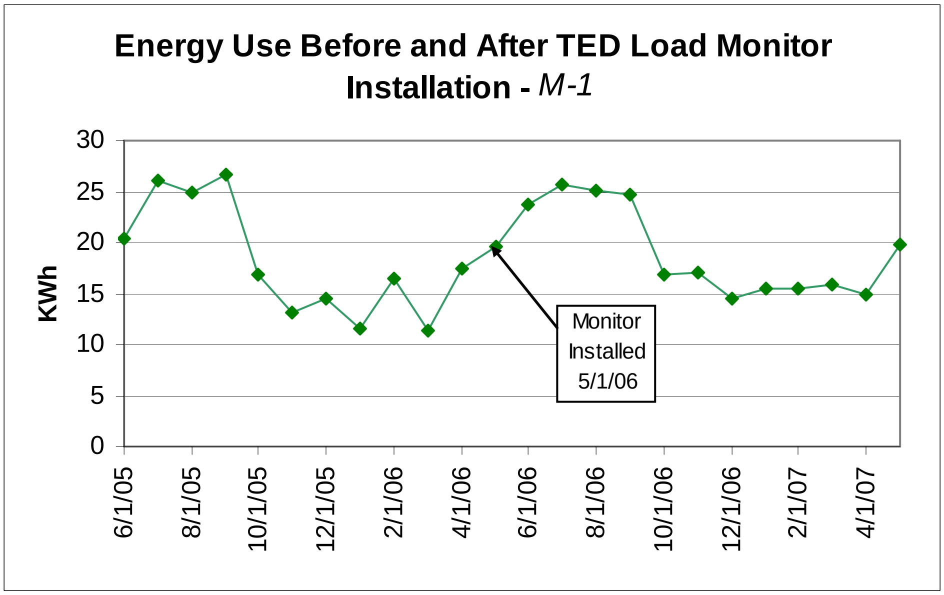


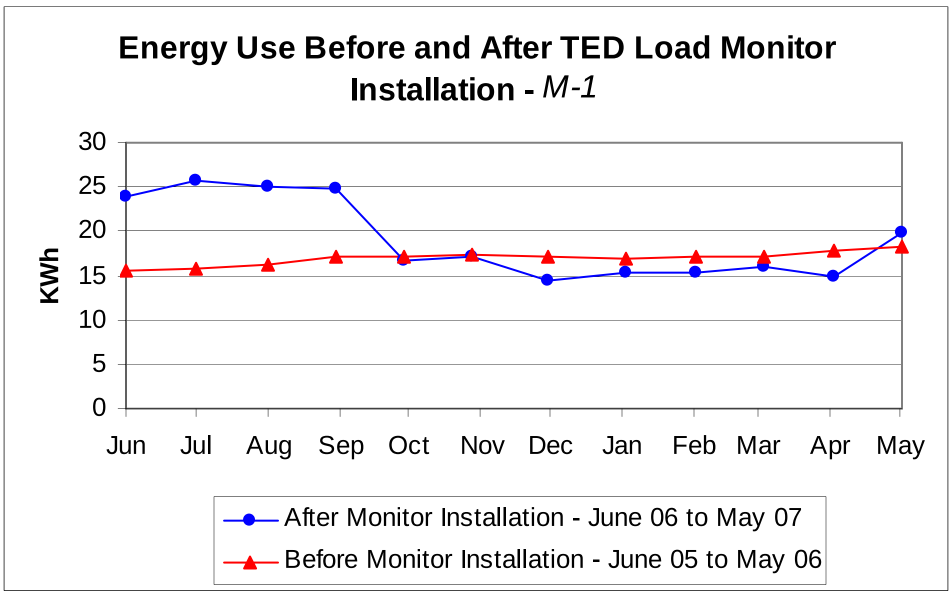
Daily Energy Use - Yearly Average
H-4
KWh
78
76
74
72
70
68
66
64
62
60
Monitor Installed Dec 06
12/1/06
1/1/07
2/1/07
3/1/07
4/1/07
5/1/07
6/1/07
7/1/07
8/1/07
9/1/07
10/1/07
11/1/07
12/1/07
Last Date in Yearly Average

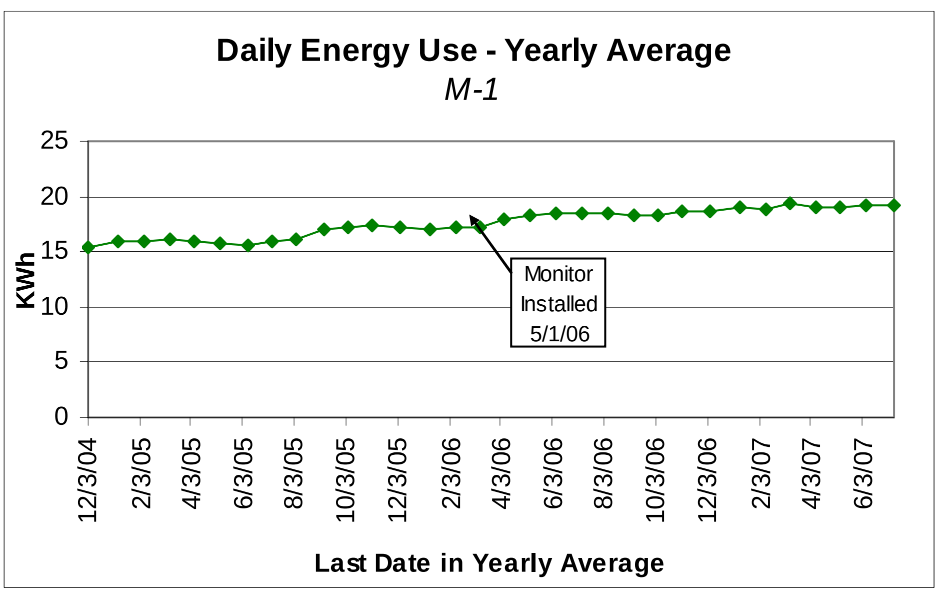

Energy Use Before and After TED Load Monitor Installation - K-1
KWh
70
60
50
40
30
20
10
0
Monitor Installed July 06
8/1/05
10/1/05
12/1/05
2/1/06
4/1/06
6/1/06
8/1/06
10/1/06
12/1/06
2/1/07
4/1/07
6/1/07

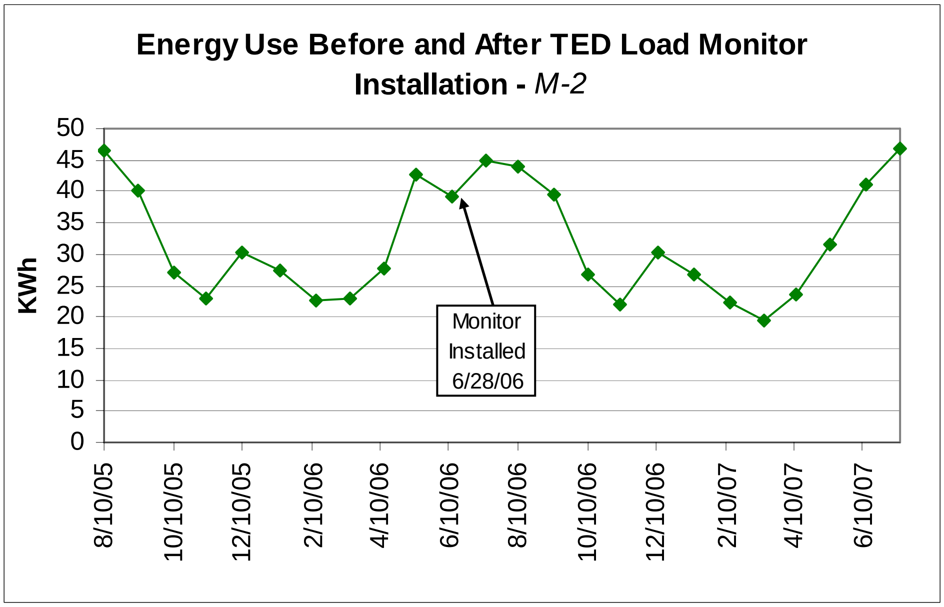

Energy Use Before and After TED Load Monitor Installation - K-1
KWh
70
60
50
40
30
20
10
0
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Before Monitor Installation - August 05 to July 06
After Monitor Installation - August 06 to July 07

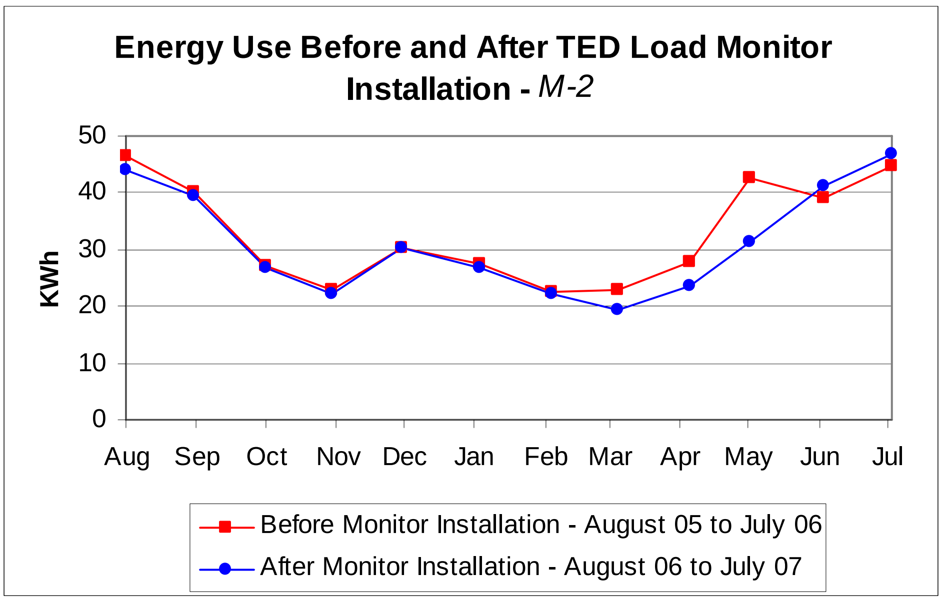

Daily Energy Use - Yearly Average
K-1
KWh
48
47
46
45
44
43
42
41
40
Monitor Installed July 06
7/14/06
8/14/06
9/14/06
10/14/06
11/14/06
12/14/06
1/14/07
2/14/07
3/14/07
4/14/07
5/14/07
6/14/07
7/14/07
Last Date in Yearly Average

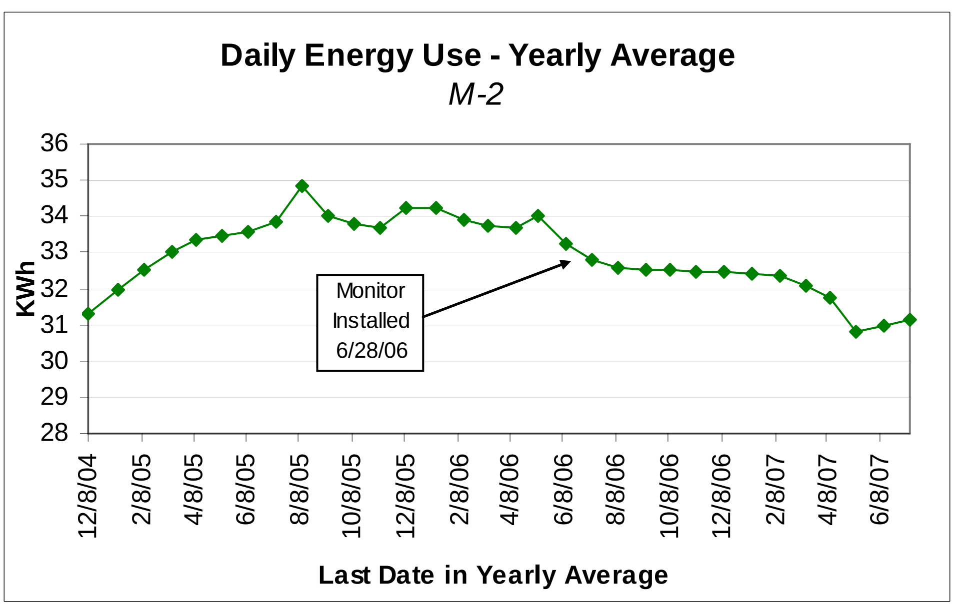

Energy Use Before and After TED Load Monitor Installation - M-1
KWh
30
25
20
15
10
5
0
6/1/05
8/1/05
10/1/05
12/1/05
2/1/06
4/1/06
6/1/06
8/1/06
10/1/06
12/1/06
2/1/07
4/1/07
Monitor Installed 5/1/06

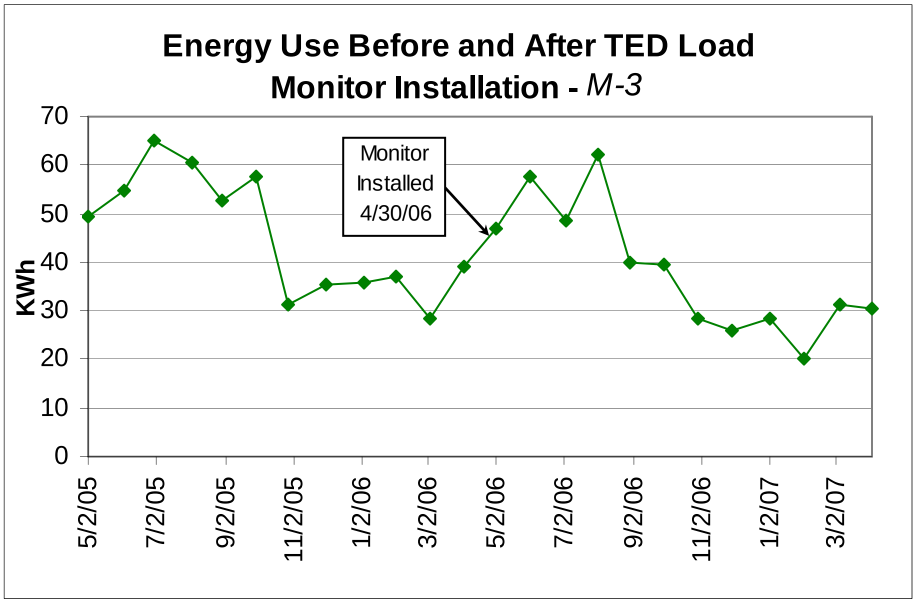

Energy Use Before and After TED Load Monitor Installation - M-1
KWh
30
25
20
15
10
5
0
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
After Monitor Installation - June 06 to May 07
Before Monitor Installation - June 05 to May 06

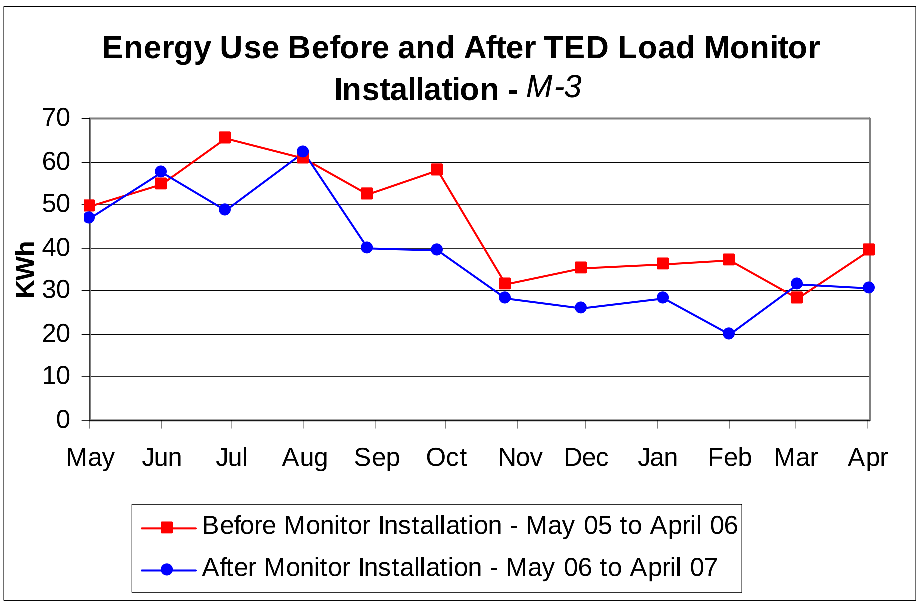

Daily Energy Use - Yearly Average
M-1
KWh
25
20
15
10
5
0
12/3/04
2/3/05
4/3/05
6/3/05
8/3/05
10/3/05
12/3/05
2/3/06
4/3/06
6/3/06
8/3/06
10/3/06
12/3/06
2/3/07
4/3/07
6/3/07
Monitor Installed 5/1/06
Last Date in Yearly Average

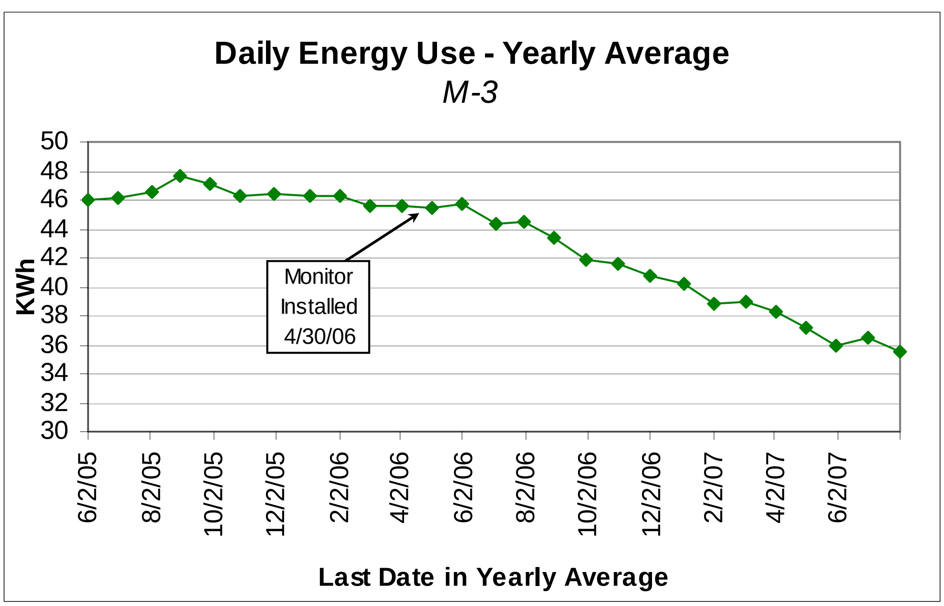

Energy Use Before and After TED Load Monitor Installation - M-2
KWh
50
45
40
35
30
25
20
15
10
5
0
Monitor Installed 6/28/06
8/10/05
10/10/05
12/10/05
2/10/06
4/10/06
6/10/06
8/10/06
10/10/06
12/10/06
2/10/07
4/10/07
6/10/07

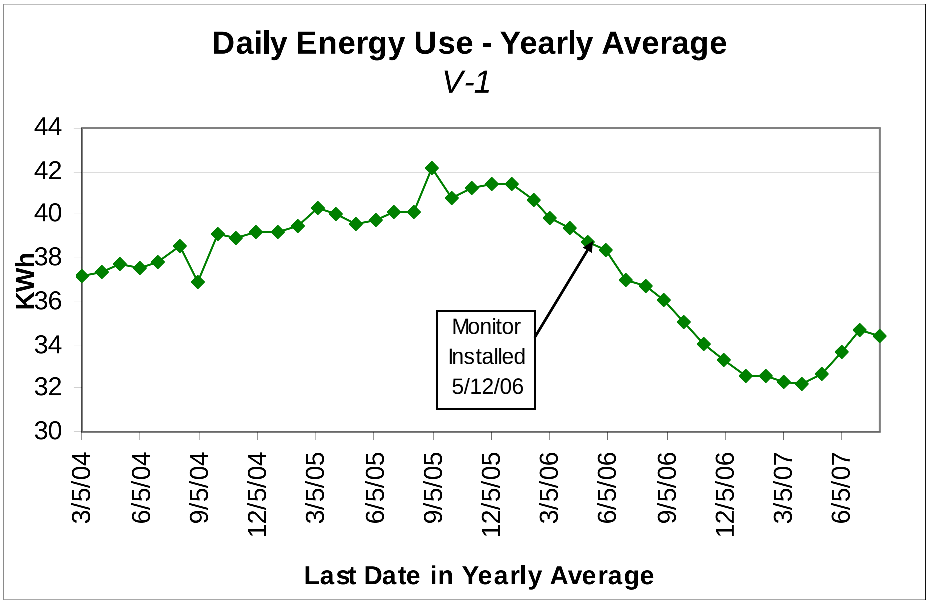

Energy Use Before and After TED Load Monitor Installation - M-2
KWh
50
40
30
20
10
0
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Before Monitor Installation - August 05 to July 06
After Monitor Installation - August 06 to July 07

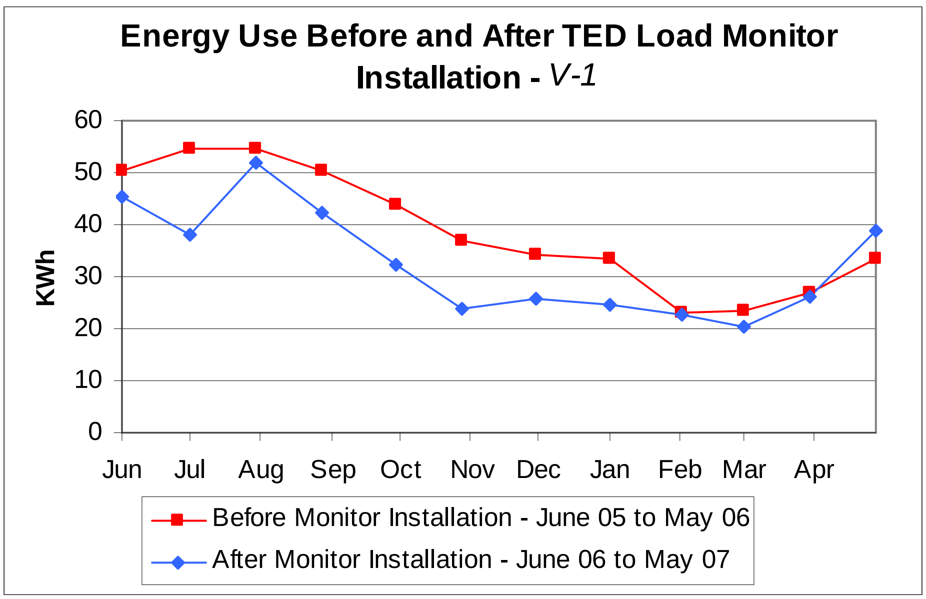

Daily Energy Use - Yearly Average
M-2
KWh
36
35
34
33
32
31
30
29
28
Monitor Installed 6/28/06
12/8/04
2/8/05
4/8/05
6/8/05
8/8/05
10/8/05
12/8/05
2/8/06
4/8/06
6/8/06
8/8/06
10/8/06
12/8/06
2/8/07
4/8/07
6/8/07
Last Date in Yearly Average

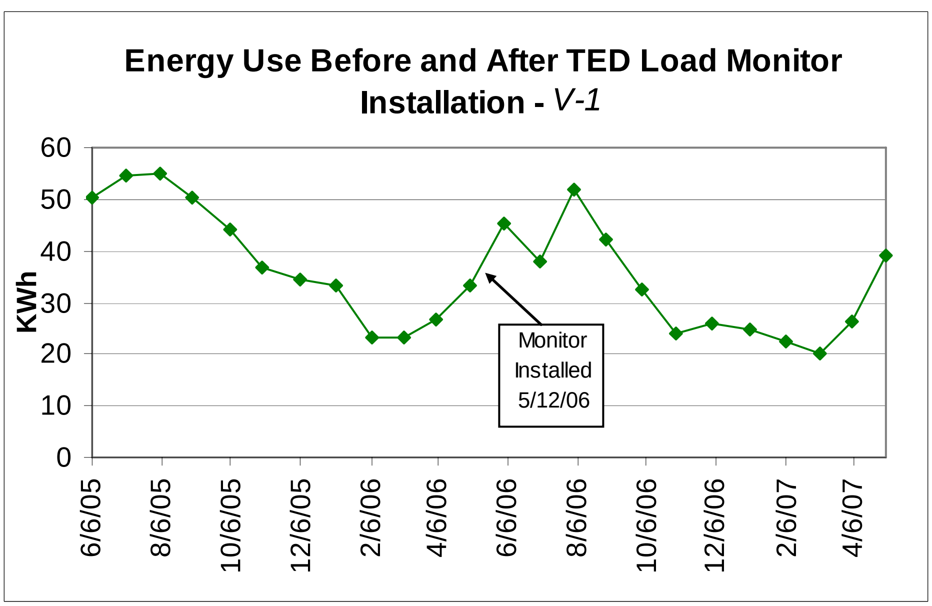

Energy Use Before and After TED Load Monitor Installation - M-3
KWh
70
60
50
40
30
20
10
0
Monitor Installed 4/30/06
5/2/05
7/2/05
9/2/05
11/2/05
1/2/06
3/2/06
5/2/06
7/2/06
9/2/06
11/2/06
1/2/07
3/2/07


Energy Use Before and After TED Load Monitor Installation - M-3
KWh
70
60
50
40
30
20
10
0
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
Before Monitor Installation - May 05 to April 06
After Monitor Installation - May 06 to April 07


Daily Energy Use - Yearly Average
M-3
KWh
50
48
46
44
42
40
38
36
34
32
30
Monitor Installed 4/30/06
6/2/05
8/2/05
10/2/05
12/2/05
2/2/06
4/2/06
6/2/06
8/2/06
10/2/06
12/2/06
2/2/07
4/2/07
6/2/07
Last Date in Yearly Average


Daily Energy Use - Yearly Average
V-1
KWh
44
42
40
38
36
34
32
30
Monitor Installed 5/12/06
3/5/04
6/5/04
9/5/04
12/5/04
3/5/05
6/5/05
9/5/05
12/5/05
3/5/06
6/5/06
9/5/06
12/5/06
3/5/07
6/5/07
Last Date in Yearly Average


Energy Use Before and After TED Load Monitor Installation - V-1
KWh
60
50
40
30
20
10
0
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
Before Monitor Installation - June 05 to May 06
After Monitor Installation - June 06 to May 07


Energy Use Before and After TED Load Monitor Installation - V-1
KWh
60
50
40
30
20
10
0
Monitor Installed 5/12/06
6/6/05
8/6/05
10/6/05
12/6/05
2/6/06
4/6/06
6/6/06
8/6/06
10/6/06
12/6/06
2/6/07
4/6/07