Advanced Energy
909 Capability Drive, Suite 2100
Raleigh, NC 27606-3870
919 857-9000 | advancedenergy.org

Home Energy Monitor Report

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This document was prepared by Advanced Energy.

Primary Investigator / Author
Shawn Fitzpatrick
Matt Murray

Organizations
Progress Energy
Dominion Power
Duke Energy
NCEMC

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Advanced Energy

909 Capability Drive

Suite 2100

Raleigh, NC 27606

License Number: F-1192

NORTH CAROLINA PROFESSIONAL SEAL 030978 ENGINEER SHAWN A. FITZPATRICK

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Executive Summary

The present work evaluated three home energy monitoring devices and two web-based energy use interfaces. While the TED 5000-C unit was found to be the most complicated unit to install, its installation complexity allowed it to achieve greater metering accuracy due to its ability to measure true power. The Blueline PowerCost unit's installation was the simplest of all units evaluated. The PowerCost unit was found to give reasonable tabletop reading accuracy over the short-term. However, due to intermittent, spurious energy readings, the PowerCost Microsoft Hohm reporting system was found to have poor long-term energy usage metering accuracy. The CurrentCost ENVI's tabletop display power reading accuracy was generally found to be in disagreement with other evaluated units. The CurrentCost Google PowerMeter system was found to overstate energy usage over extended monitoring periods. The TED 5000-C hardware kit was found capable of reporting long-term energy usage within ±2.5 percent. The PowerCost and CurrentCost units were substantially less accurate. Both web-interfaces (Google PowerMeter and Microsoft Hohm) appeared to be susceptible to data loss and processing errors. For example, although the TED 5000-C hardware accuracy was quite high, the TED 5000-C Google PowerMeter interface's maximum monthly deviation from utility billing data was found to be approximately 14 percent.

Background

On Feb 18, 2010 a meeting was held with representatives from Advanced Energy, Dominion Power, Duke Energy, North Carolina's Electric Co-operatives and Progress Energy in order to discuss items of interest to test at the ETTC during 2010. A list was generated and votes were taken from all interested parties. One of the top items of interest was having ETTC to look into assessing the effectiveness of home energy monitoring devices.

The current project is focused on understanding the real-world issues associated with the installation and operation of home energy monitoring equipment. This type of equipment is meant to allow the home owner to see their instantaneous power demand and their energy usage history via tabletop display units and/or web-based interfaces. Homeowners can use this information to detect energy usage trends and identify potential energy waste. One of the key features of a home energy monitoring device that was of interest to verify was the ability of the device to make information regarding home energy use available online, which allowed a customer to view their home energy use and use history online from anywhere. Two such services are Google PowerMeter (www.google.com/powermeter) and Microsoft Hohm (www.microsoft-hohm.com).

In the present report findings regarding the installation and use of three different home energy monitoring systems are presented. The three systems where installed on a test house and were used simultaneously. The test home was a 900 ft^2, single-story home with two bedrooms and one bathroom. The home has had numerous energy efficiency upgrades and had very low energy consumption as a result. Measurement performance and installation complexity will be reviewed for the various home energy monitoring devices. Comparisons to the utility meter will be presented. Also, direct comparisons of the measurement accuracy of the three home energy monitoring units will be presented.

TED 5000 Home Energy Monitor

The Energy Detective (TED) device is a commercially available home energy monitoring device that is meant to allow home owners to monitor their home's power consumption in real-time. It also allows users to setup an account with Google PowerMeter to provide historical usage information so that home owners can detect trends in their energy usage and identify potential waste. TED has two types of units available for purchase: the TED1000 and the TED 5000. The TED 1000 unit was the original home energy monitoring unit available from TED. The TED 5000 unit is an updated version of TED's home energy monitor that allows the home owner to access their historical energy use via the internet using Google PowerMeter's service. The TED 5000 was the only unit made by TED evaluated in this report.

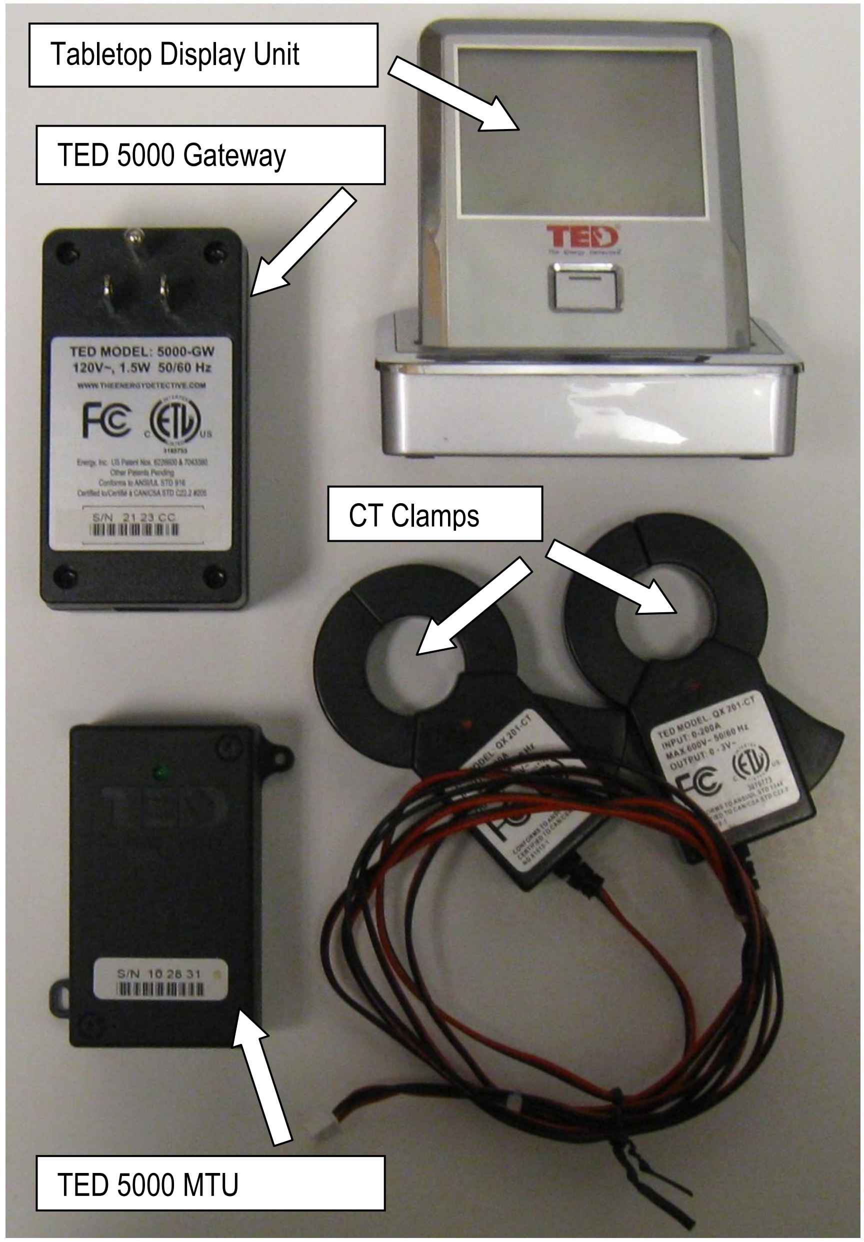
The TED 5000-C energy monitoring kit comes with hardware that must be installed in the living space and the electrical panel of the house being monitored. This hardware includes:

- **Current transformers and voltage taps** – This equipment is coupled to the measured home's main electrical service lines in order to measure the current and voltage present on the lines feeding the home's electrical panel.
- **MTU** – The measurement and transmitting unit (MTU) receives measurement signals from the CT's and voltage taps and converts these readings into digital encoded signals that it sends to the Gateway unit via the home's electrical wiring. The MTU is powered by the electrical lines that it is measuring.
- **Gateway** – This device plugs into a normal wall outlet in the home near an internet connection and receives measurement information sent over the home's electrical wiring by the MTU. The gateway then stores this data internally while sending real-time electrical usage data to the tabletop display unit via wireless link. In addition, the gateway unit can be connected to the home's internet connection via Ethernet cable. This makes TED's energy usage information available to the home owner via internet services such as Google PowerMeter. The gateway unit can internally store up to 10 years of monthly data, two years of daily data, 90 days of hourly data, 48 hours of minute-by-minute data and one hour of second-by-second data.
- **Tabletop Display** – The display unit receives data from the gateway wirelessly and can display instantaneous power draw information as well as cumulative energy use information. The display unit is powered and charged by a base unit that plugs into a wall outlet.[1]

[1] One issue noticed early in the evaluation period for the TED 5000-C is that the "Multipanel" display gives units of power in kWh when it should be given in kW.

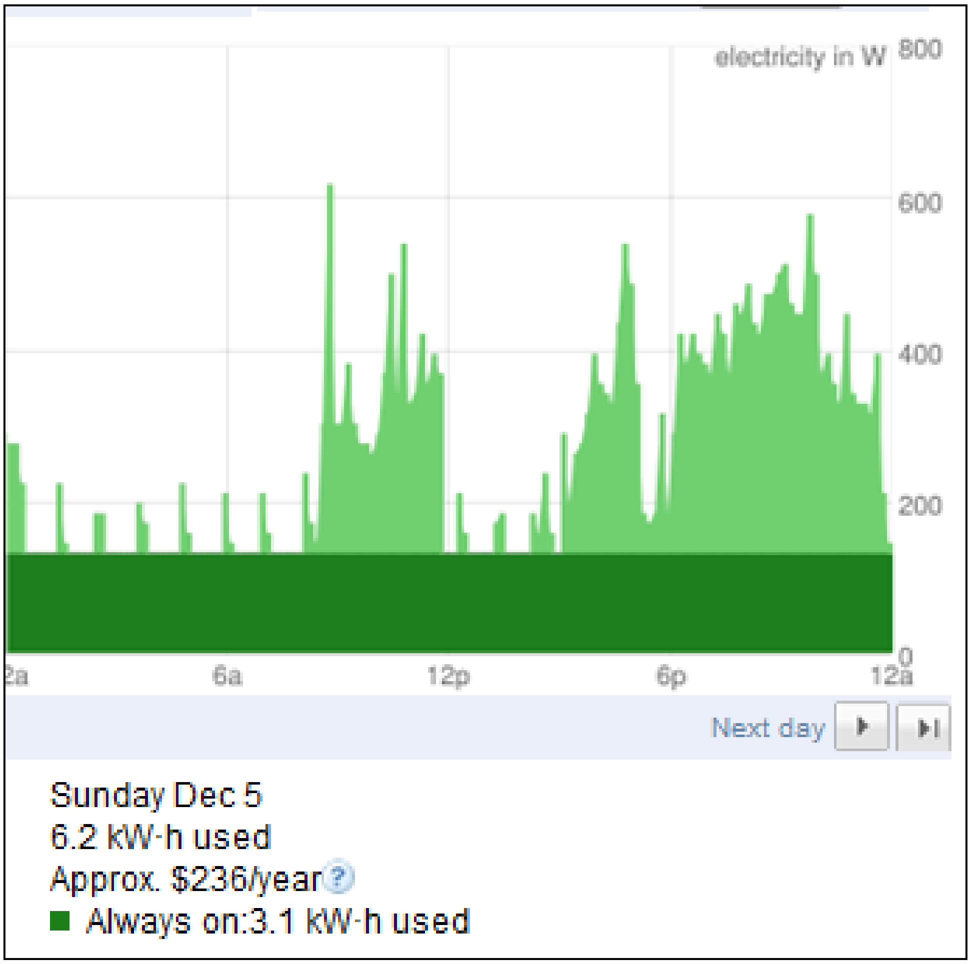
A picture of the TED 5000-C kit's hardware can be seen in Figure 1. The TED system can support more than one set of measurements CT's and MTU's if needed.

Figure 1 – TED 5000-C Kit Hardware



The TED system allows home energy use to be uploaded to the Google PowerMeter service for on-line display. A screen shot of example output from the Google PowerMeter service can be seen in Figure 2. Historical energy usage can be viewed via the online interface or downloaded for post-processing using standard data analysis software. The output in Figure 2 shows the periods of maximum power draw throughout a given day, the energy use for the day, the estimated energy cost for the home per year and the baseline always-on home electrical load for the day. Some missing data and corrupt data were found in the Google PowerMeter displayed data.

Figure 2 – TED 5000-C Data from Google PowerMeter's Web-Interface



TED 5000 Installation

Installation of the TED 5000-C unit requires the installer to access the inside of the monitored home's electrical panel. Electrical connections must be made to the home's main electrical service lines in order to measure line voltage. Current transformers must also be clamped around the home's main electrical service lines. Working inside an electrical panel should only be done by a qualified individual. As such, there is some knowledge and experience required to safely install the TED 5000 unit. For the present work, the TED 5000-C's installation instructions were studied and the installation proceeded much as expected. The installation instructions were found to be adequate to allow someone with reasonable electrical experience to accomplish the task of connecting the device to the electrical panel.

The TED system ships with dedicated PC-based software known as “Footprints.” This software is installed on the user’s computer and allows the status of the TED system to be viewed in real time. The Footprints software also allows the user to configure the system with information pertinent to the home’s electrical configuration and energy cost rate schedule. The menu system in the Footprints software was found to be intuitive and rather uncomplicated. The software is comprised of a “dashboard” display that gives an instantaneous overview of the parameters being monitored in the home’s electrical system. A screenshot showing the “dashboard” view from the Footprints software can be seen in Figure 3. The Footprints software also allows the homeowner to monitor their energy usage history. This functionality will be the focus of later discussions in the present report.

Figure 3 – TED “Footprints” Software PC Dashboard Display

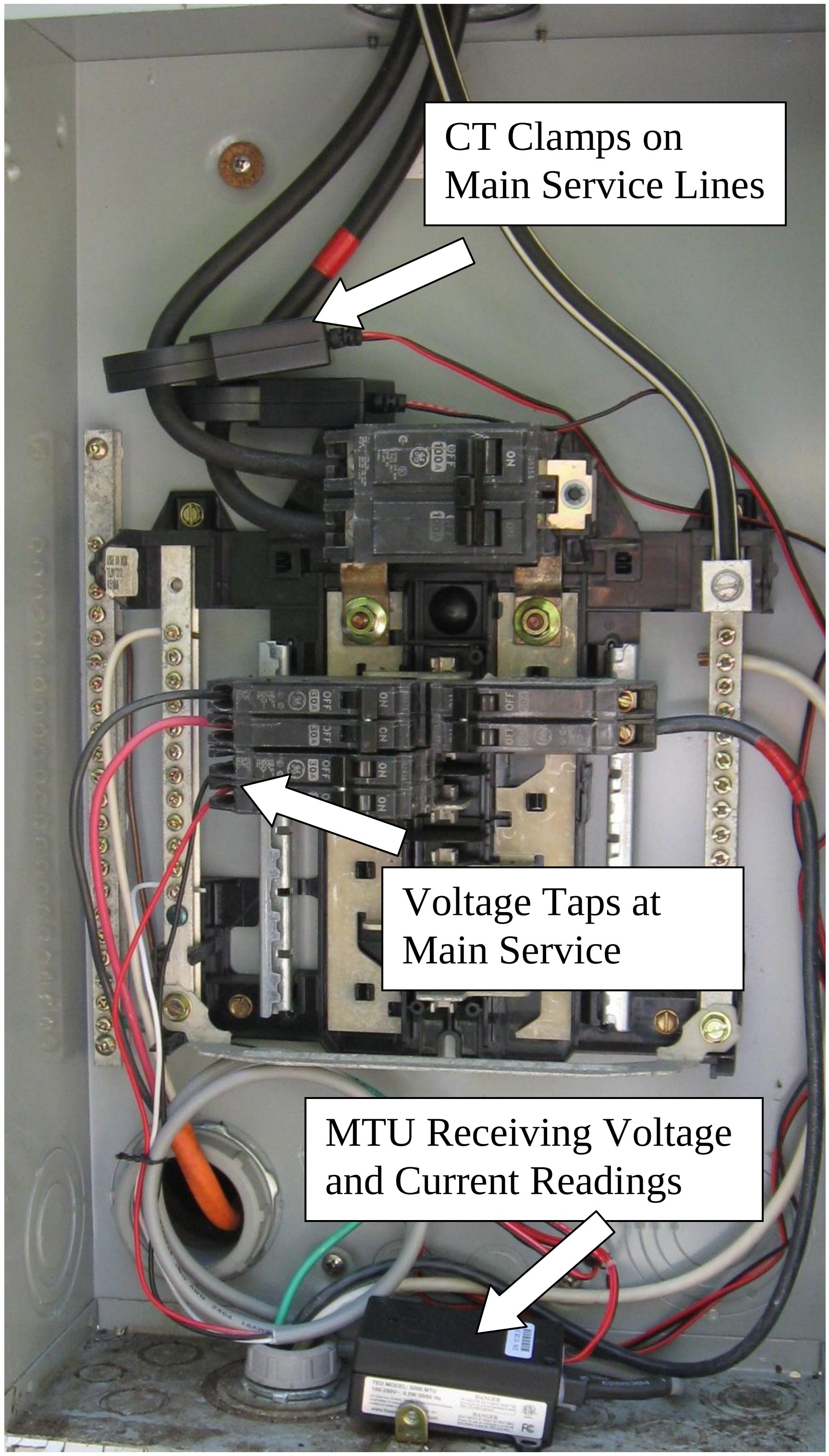
The settings used in the particular installation used for this study can be found in Table 1.

Table 1

Energy Cost Details Used During TED 5000 Installation	
Setting Type	Setting Value
Basic Customer Charge	$6.75 /month
Summer Energy Charge (July – Oct)	10.57 ¢/kWh (10.887 ¢/kWh with tax)
Winter Energy Charge (Nov – June)	9.57 ¢/kWh (9.857 ¢/kWh with tax)
REPS Adjustment	65 ¢/month

The electrical installation of the TED 5000-C unit is the most complex of all the units tested in this study. It requires accessing the inside of the home's electrical panel and making connections to line voltage leads as well as CT-clamp connections on the main service lines. This increase in installation complexity gives TED access to more information regarding the true power consumed by the monitored home. Details of the power panel connections can be seen in Figure 4. The use of power-line communication from the MTU in the electrical panel to the Gateway unit inside the home requires that the Gateway unit be plugged into an outlet connected to the same phase as the MTU unit in the electrical panel.

Figure 4 – TED 5000-C Installation



Blueline PowerCost Home Energy Monitor

The Blueline PowerCost home energy monitor differs from other units investigated in this study in that it does not make any direct measurements of the monitored home's current or voltage. Instead, it reads pulses generated by the home's utility meter that correspond to a given amount of energy consumed by the home. The unit's sub-components communicate wirelessly with each other and the home's wireless router using WiFi (IEEE 802.11). In addition to the included tabletop display unit, the PowerCost device supports a web-based interface where the home owner can view consumption history and energy statistics on-line. At the time the PowerCost unit was purchased and installed for this study only Microsoft Hohm was configured to work with the unit. Since that time, the PowerCost unit has been configured to work with Google PowerMeter's web interface as well. A picture of the Blueline PowerCost kit's hardware can be seen in Figure 5.

The Blueline PowerCost energy monitoring kit comes with hardware that must be installed in the living space and on the exterior of the utility electrical meter of the house being monitored. This hardware includes:

- **Optical Meter Sensor** – This optical sensor is configured to either read light pulses from newer digital meters or disk rotations from older analog meters without requiring any electrical connection to the meters. The sensor is clamped to the exterior of the meter and counts meter pulses/rotations to determine the energy being used by the monitored residence. This information is then relayed to the gateway unit and the table top display unit wirelessly. The meter sensor is powered by two AA batteries.
- **Gateway** – This device is powered by a normal wall outlet in the home and receives measurement information from the meter sensor wirelessly. The gateway unit is capable of relaying the measured energy information to a home internet router via a WiFi wireless interface. This capability makes Blueline's energy usage information available to the home owner via internet services such as Microsoft Hohm and Google PowerMeter. The gateway is powered by a wall outlet.
- **Tabletop Display** – The display unit receives data from the meter sensor wirelessly and can display instantaneous power draw information as well as cumulative energy use information. It is powered by two AA batteries.

The Microsoft Hohm web-site provides historical usage data for different intervals of time (years, months, days, hours and minutes). For years and months it also provides the capability for the user to make comparisons of home energy use with average outdoor temperature. In addition to usage information, the Microsoft Hohm website allows users to input detailed information regarding their homes and then provides an assessment of the relative energy efficiency of the monitored home referenced to other homes of similar age, size and condition. The site also advises users on ways that they can improve their energy efficiency. An example of the type of data available via the Microsoft Hohm web interface can be seen in Figure 6. The grayed-out portions of the chart indicate intervals of missing data.

Figure 5 – Blueline PowerCost Monitor Kit Hardware

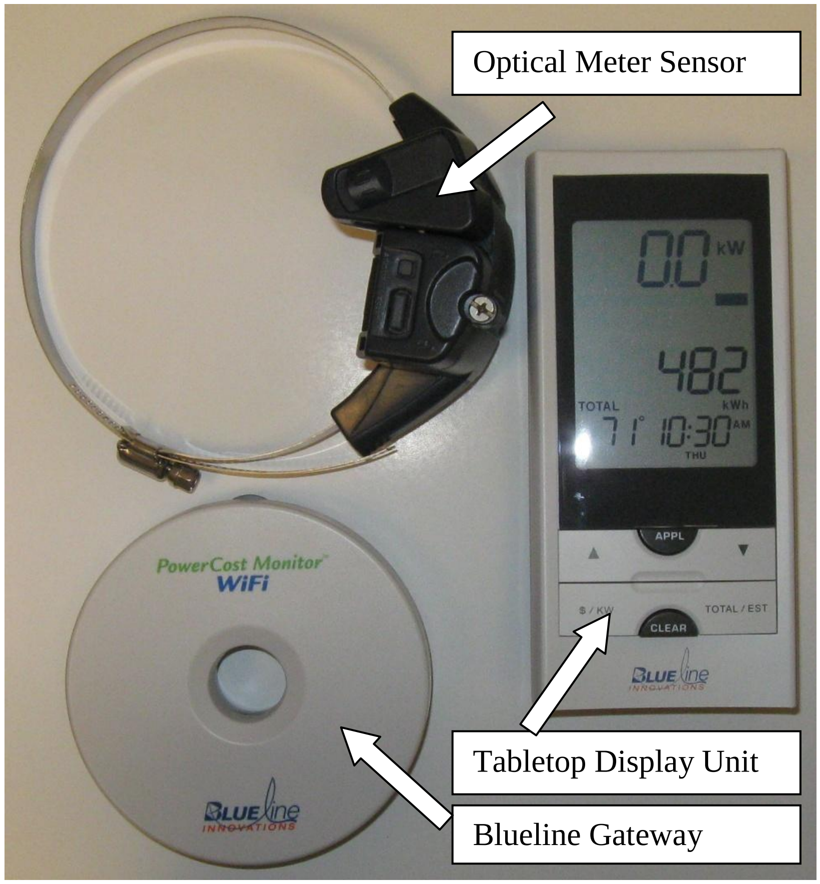
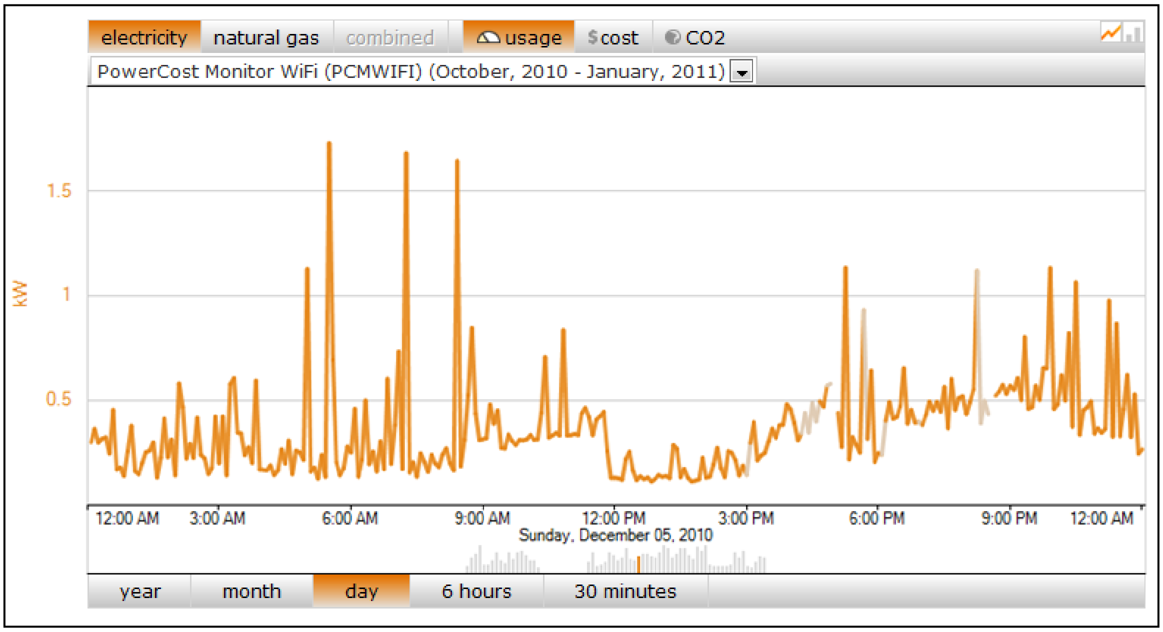


Figure 6 – Blueline PowerCost Data from Microsoft Hohm Web-Interface



Blueline PowerCost Installation

The installation of the PowerCost unit is the simplest of all units tested in this study. It does not require the home owner to access the inside of their electrical panel at all. The optical sensing unit is fastened to the outside of the meter with a band clamp as can be seen in Figure 7. The use of wireless communication by all system components makes installation possible without any cable connections.

Figure 7 – Blueline PowerCost Installation

CurrentCost ENVI Home Energy Monitor

The CurrentCost ENVI home energy monitor measures electrical current on the main service lines to the monitored home and assumes nominal line voltage and power factor in order to calculate power draw. This makes connecting the meter to the power panel substantially simpler than in the case of the TED 5000. However, the simplifying assumption for voltage and power factor does not allow the unit to measure true power. The unit's sub-components communicate wirelessly with each other using a short range device band at 433 MHz. In addition to the included tabletop display unit, the CurrentCost ENVI interfaces with Google PowerMeter's online service. A picture of the CurrentCost kit's hardware can be seen in Figure 8.

The CurrentCost ENVI energy monitoring kit comes with hardware that must be installed in the living space and in the main electrical service panel of the house being monitored. This hardware includes:

- **Current transformers** – The CTs are clamped around the main electrical service lines in order to measure the current supplying the home.
- **Transmitter** – This unit is installed in the electrical panel and the outputs from the CTs are connected to it. The transmitter reads the signals from the CTs, calculates estimated power and relays this information to the tabletop display unit wirelessly. The transmitter is powered by two D size batteries.
- **Gateway** – This device is powered by a normal wall outlet in the home and receives measurement information from the tabletop display unit through a short Ethernet cable. The gateway unit is capable of relaying the measured energy information to a home internet router via an Ethernet connection. This allows CurrentCost energy usage information to be available to the home owner via Google PowerMeter.
- **Tabletop Display** – The display unit receives data from the transmitter wirelessly and can display instantaneous power draw information as well as cumulative energy use information. The display unit is powered by the gateway through the short Ethernet cable connecting the two.

The CurrentCost ENVI display unit can store up to seven years of historical energy usage data. An example of the CurrentCost ENVI data available via Google PowerMeter can be seen in Figure 9. Areas with missing data are evident in the screen shot shown in Figure 9.

Figure 8 – CurrentCost ENVI Kit Hardware

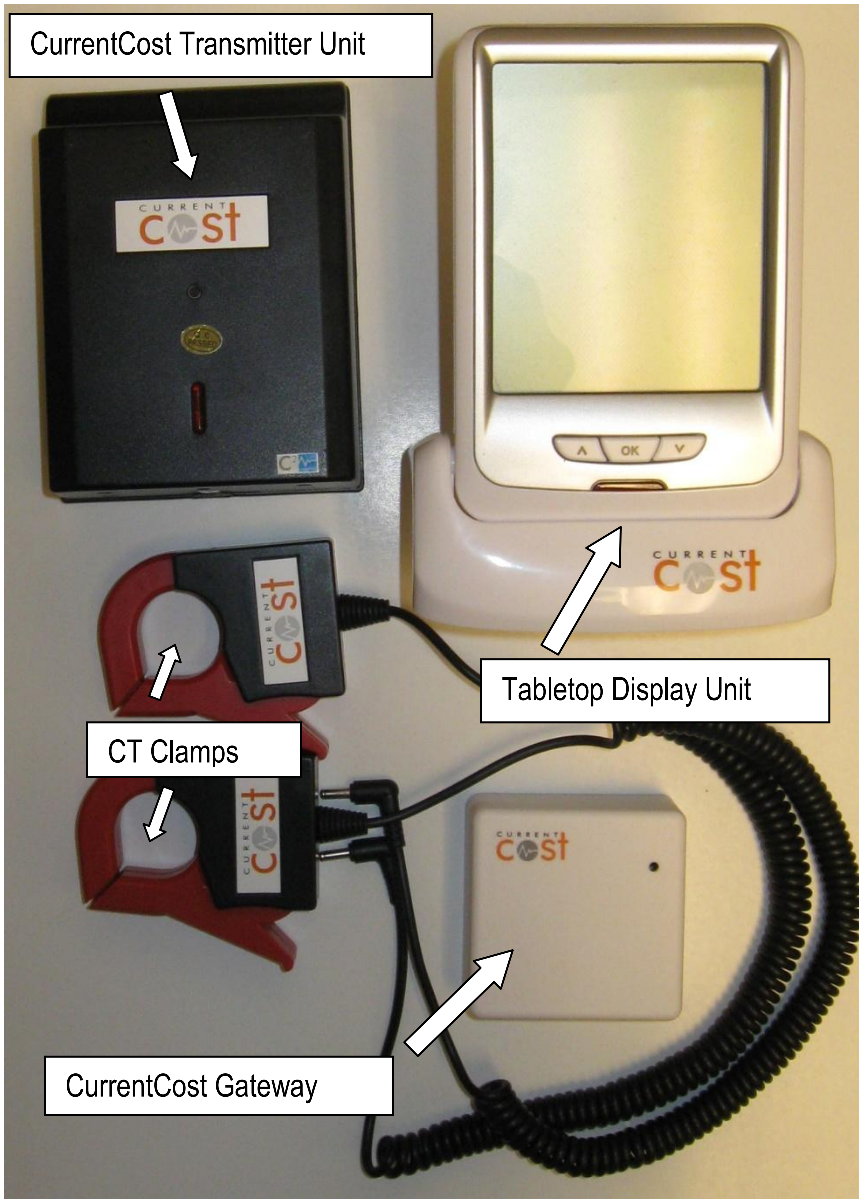
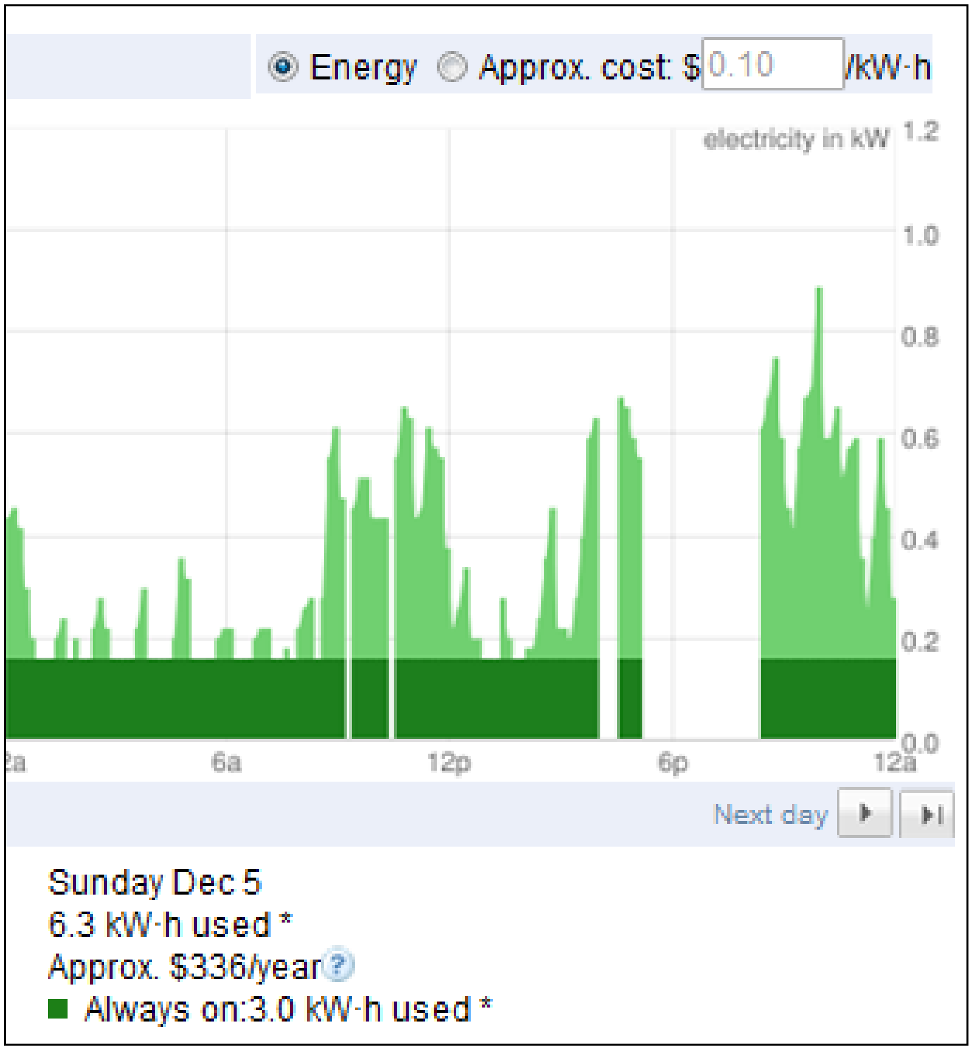


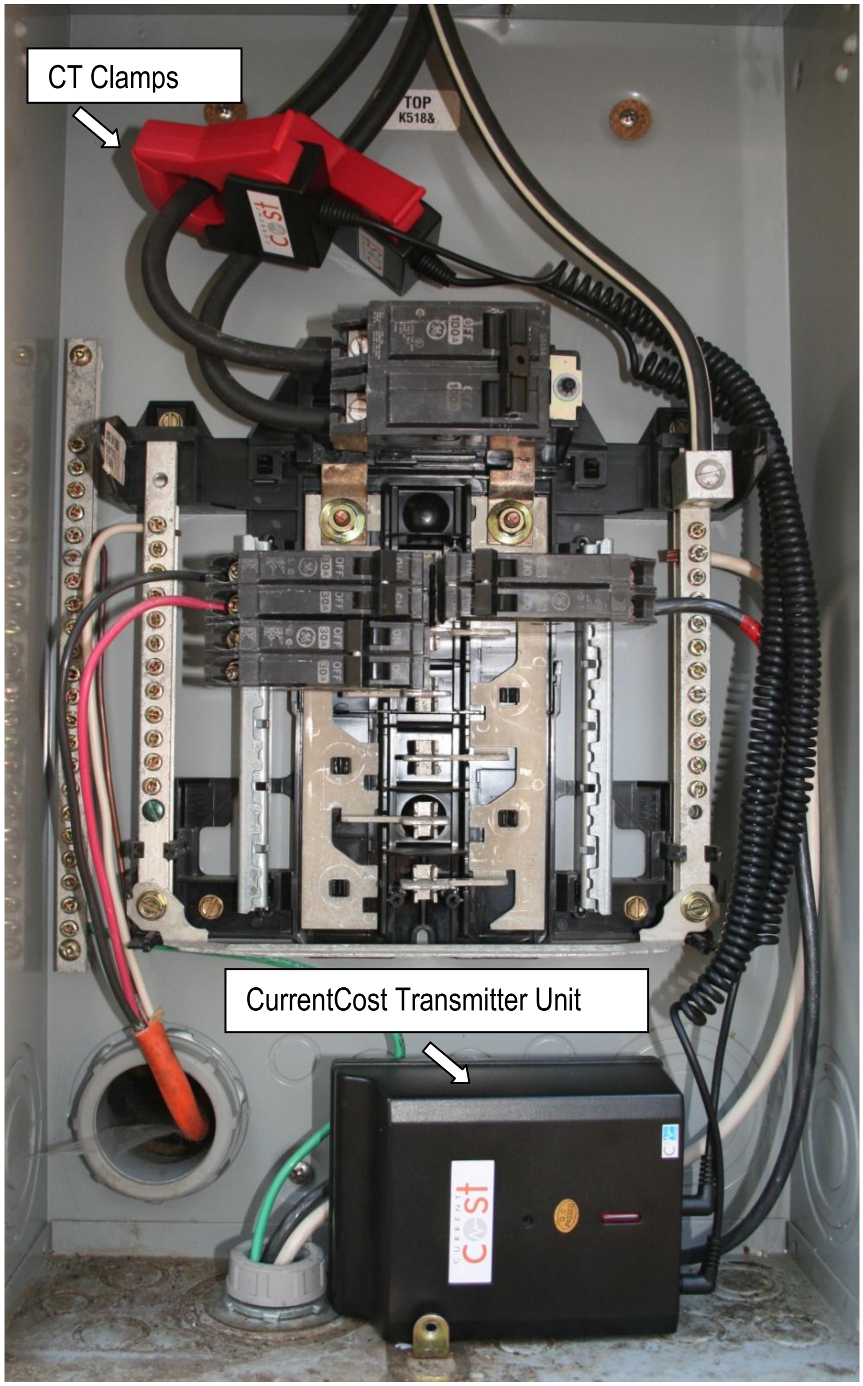
Figure 9 – CurrentCost Data from Google PowerMeter's Web-Interface



CurrentCost ENVI Installation

As with the installation of the TED 5000-C unit, the CurrentCost unit's installation requires the installer to access the inside of the monitored home's main electrical panel. No voltage connections are required but current transformers must be clamped around the home's main electrical service lines. Some knowledge and experience are required to safely install the CurrentCost ENVI unit. The installation instructions were found to be adequate to allow someone with reasonable electrical experience to accomplish the task of connecting the device to the electrical panel. The CurrentCost transmitter unit and the current transformer clamps can be seen in the installation picture of the ENVI unit in Figure 10.

Figure 10 – CurrentCost ENVI Installation



Performance Monitoring

When assessing the monitoring capability of the various systems tested in this report it was of interest to see how they corresponded to one another in real-time. All three units evaluated in this report were used to monitor the test house contemporaneously. Simultaneous readings for all three display units can be seen in Figures 11 and 12. Significant deviations between the units' readings are apparent at low and high home power draws.

Typically, as seen in Figures 11 and 12, the CurrentCost device was found to read higher than the others at low power and lower than the others at high power. Routine observation of all three units, by the homeowner, showed that the TED unit and the PowerCost unit consistently registered very similar values for instantaneous power draw. It was noticed that there was a definitive lag in the readings displayed by the PowerCost unit between home appliances being activated and corresponding readings being displayed on the unit. This is expected. Whereas the TED unit updates every second and the CurrentCost unit updates roughly every twelve seconds, the PowerCost unit updates approximately every 30 seconds. The delayed response of the PowerCost unit is due to its need to sum pulses over an extended period of time to achieve reasonable power draw measurement accuracy.

Figure 11 – Low Power tabletop Display Unit Output Comparisons

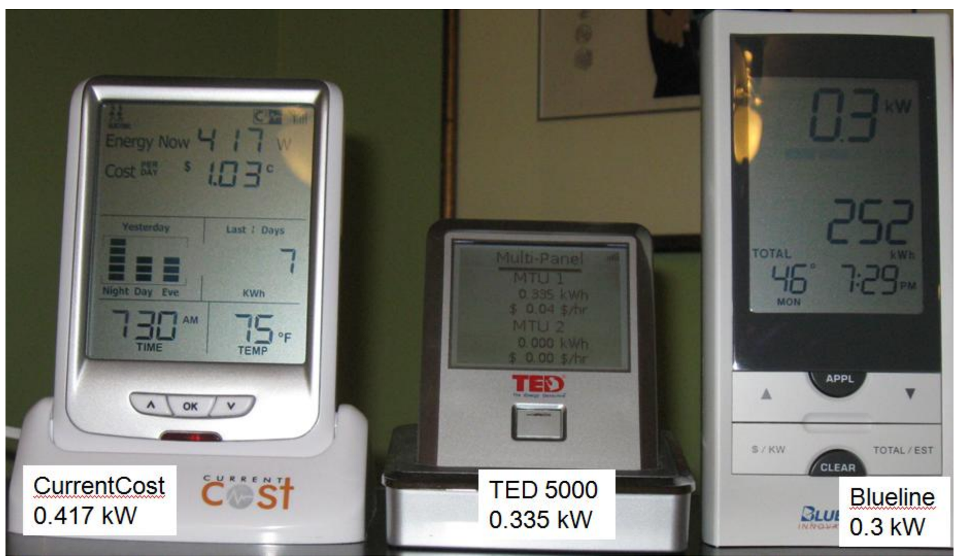


Figure 12 – High Power Tabletop Display Unit Output Comparisons

The absolute metering accuracy of the three units evaluated is this study is of specific interest in this report. When evaluating unit accuracy here the utility meter is considered to be the authoritative meter from which accurate readings can be obtained.

The TED unit was the first unit to be obtained for testing during the present study. Consequently there is much more data collected from this device than from either the CurrentCost or PowerCost home energy monitors. Because of the much larger data collection history with the TED unit it was of particular interest to compare the TED data to the utility billing data for the home being monitored during this study. As the TED unit has an on-line interface (Google PowerMeter) as well as a local PC-based interface (Footprints) from which data can be downloaded it was thought instructive to include both sets of data in the comparison between TED and the utility meter. Figure 13 shows this comparison for all complete months in which data was recorded.

It can also be seen in Figure 13 that the Footprints data closely matches the utility meter data for all recorded months. In general the Google PowerMeter data tends to be consistently lower than the utility meter data month after month. In Figure 14, the percent difference for the two comparisons can be seen, along with the percent of time the Google PowerMeter was found to be missing data each month. The two months with the largest discrepancies between the Google PowerMeter data and the utility meter data also happen to be the two months with the largest percent of missing data (down time). The relationship between down time and metering error is not absolute however, as other months appear to have less correlation between the two parameters. In general it is quite clear, from Figures 13 and 14, that the TED Footprints data is a good overall representation of the utility meter usage data. According to the TED-5000 documentation the unit is capable of accuracy within 2% of the true value of parameters of interest. Based on the Footprints data collected here this statement of accuracy appears to be well founded.

Figure 13 – Comparisons of Metered Energy (TED vs. Utility Meter)

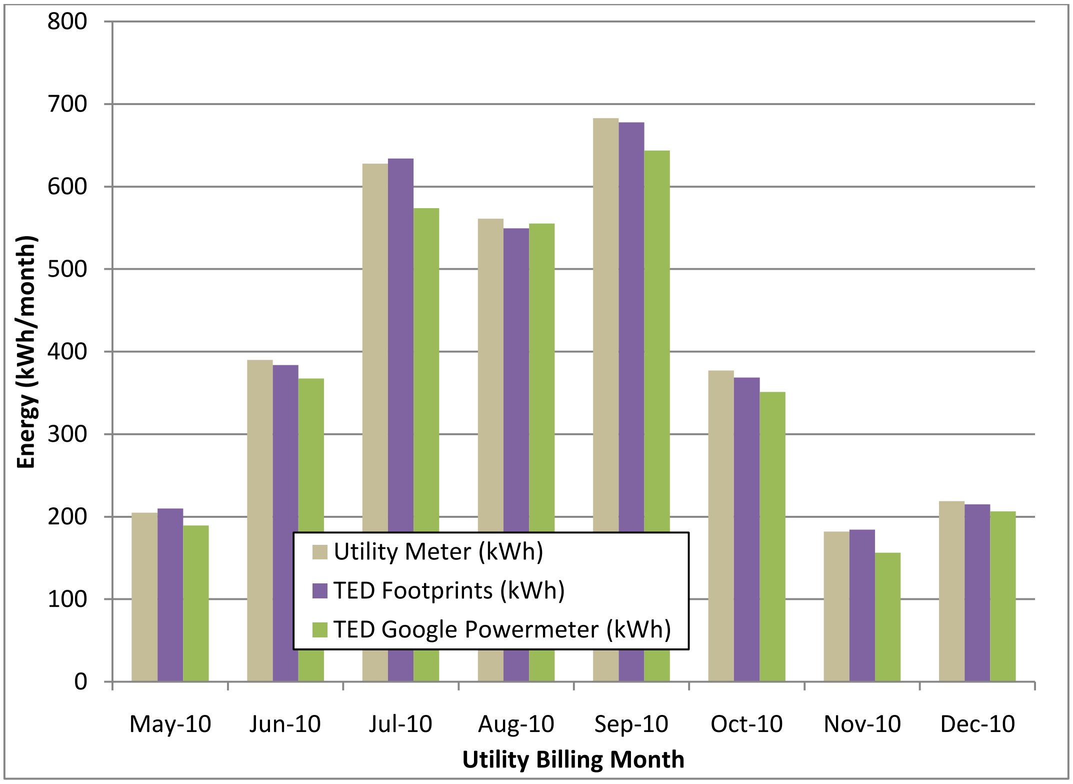
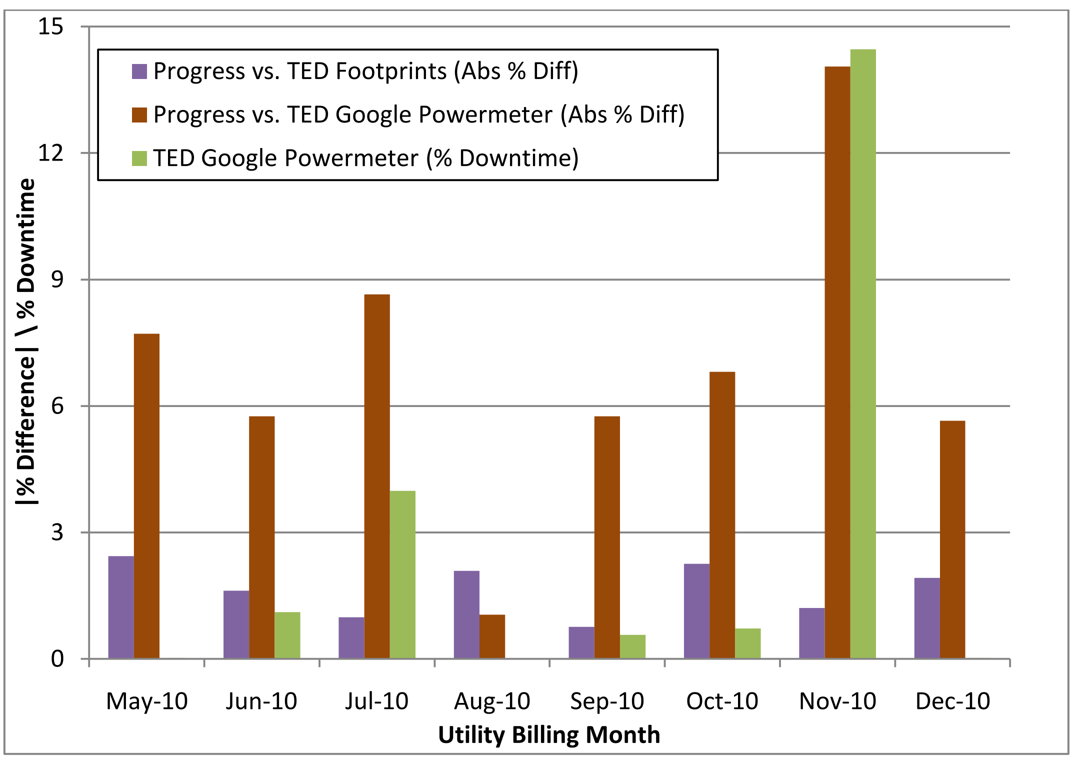


Figure 14 – Comparisons of Metered Energy (TED vs. Utility Meter)



All of the units evaluated in this study were not installed and working together until the last four weeks of 2010. Thus, these four weeks represent the only period of time in which head-to-head comparisons can be made between all of the energy monitors. As utility data is not available for specific days or weeks it cannot be used in a comparison over these shorter time intervals. However, from earlier investigations it is apparent that the TED Footprints data set represents the utility metered data quite well. As such, in the following weekly and daily comparisons the TED Footprints data will be used as the comparative standard.

In Figure 15, the energy use per week for the last four weeks of 2010 can be seen for the following datasets:

- CurrentCost ENVI based Google PowerMeter system
- Blueline PowerCost Monitor based Microsoft Hohm system
- TED 5000-C based Google PowerMeter system
- TED 5000-C PC-based Footprints system

When using the TED Footprints dataset as the reference standard, it can be seen that both the CurrentCost ENVI and the Blueline PowerCost home energy monitoring systems consistently overstate the weekly energy usage of the monitored home. The Blueline PowerCost unit appears to overstate the usage by the largest margin for most of the weeks. Based on the assumptions inherent in the CurrentCost unit's approach, it is understandable that it would over-estimate usage as it assumes nominal line voltage and unity power factor. It is very possible that at times line voltage at the monitored home is slightly less than nominal. Similarly, there may be times when the power factor is substantially less than one. This would lead the CurrentCost unit to consistently overstate usage as seen. In addition, significant amounts of missing data were found with both the PowerCost and Current Cost units. Depending on how the web-based services handle this missing data, significant error in reported usage could occur because of this as well.

The real surprise here is the inaccuracy of the Blueline PowerCost Monitor. As this unit's recorded energy usage is based on readings from the utility meter, it would seem that this unit would be capable of quite high accuracy. This does not, however, appear to be the case. The reasons for its lack of accuracy are not known. It would seem the unit is not recording all of the pulses from the meter, is counting pulses the meter did not generate, or is having trouble encoding the proper energy use attributable to each pulse emitted by the meter. The reasons for the issues seen with the Blueline PowerCost Monitor are not presently understood.

In order to see more specifically what differences exist between the data being recorded by the different systems it was of interest to look at recorded data over shorter time periods. As there was quite a bit of missing data for the Blueline PowerCost monitor during weeks 50, 51, and 52 it was decided to look more closely at week 49. In Figure 16, comparisons of daily energy use for week 49 can be seen for all of the evaluated systems. Again, both the CurrentCost ENVI and the Blueline PowerCost home energy monitoring systems consistently overstate the daily energy usage of the monitored home. The CurrentCost ENVI system appears to be fairly consistent in its overstatement of usage. However, the Blueline PowerCost unit's readings appear less consistent. For example, the unit's overstatement appears lower on Nov 30 and Dec 1 than on the other days of the week.

Figure 15 – Comparisons of Metered Energy for Tested Devices by Week in 2010

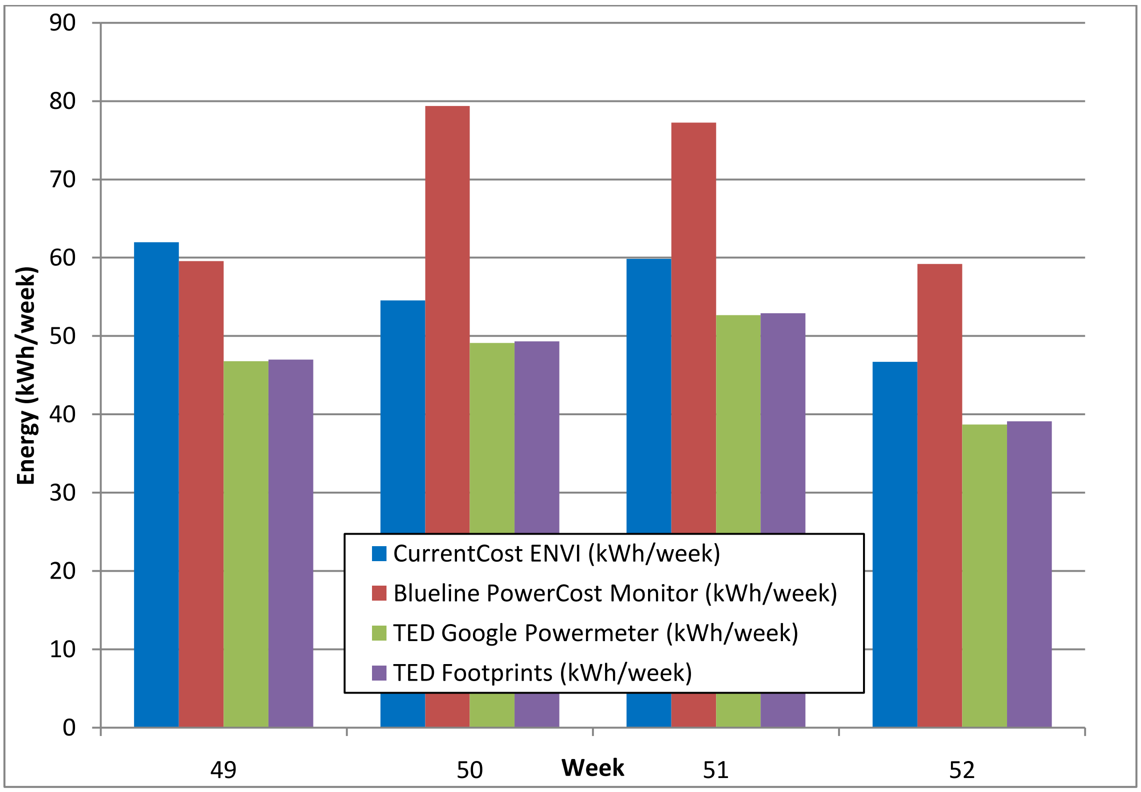
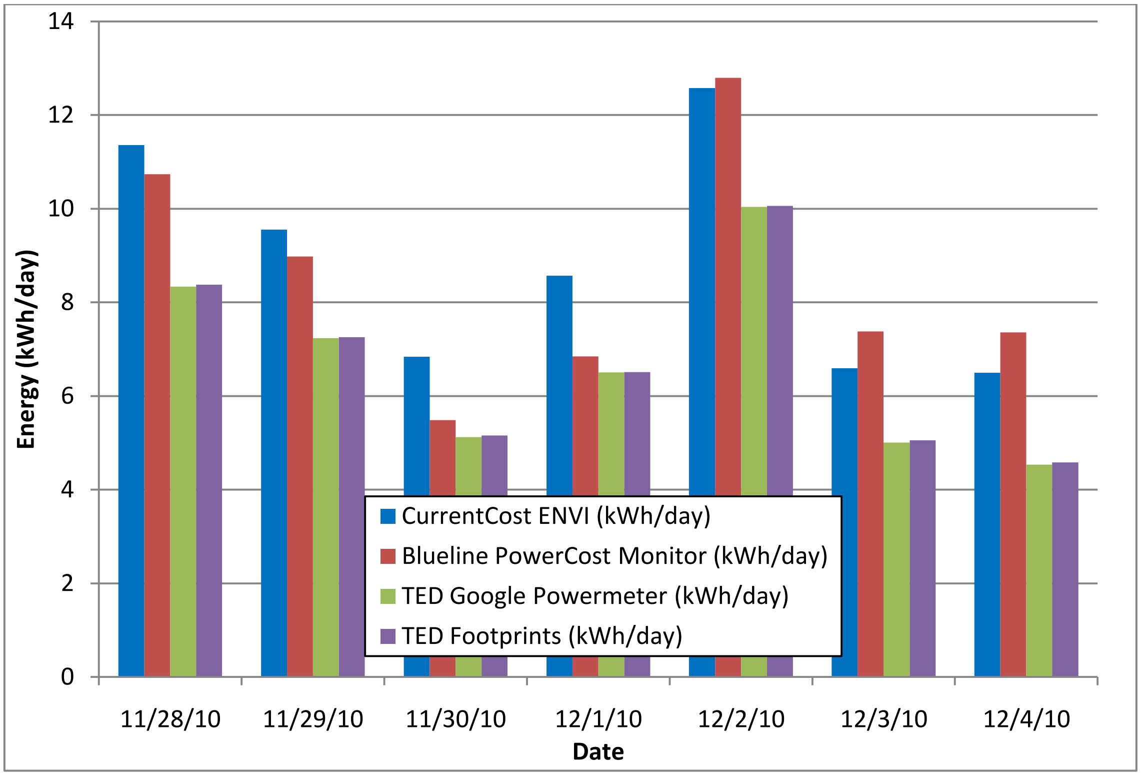


Figure 16 – Comparisons of Metered Energy for Tested Devices by Day for Week 49



In Figure 17, the responses of the three web-based monitor data can be seen plotted as five or 10-minute data sets. Comparing the results from Figure 17 to Figure 16's bar chart shows similar trends. Where the minute data is more consistent (Nov 30 - Dec 1) there is less variation between the units' readings. In addition, from the minute-based data it appears that the Blueline PowerCost monitor data has spikes that do not exist in the other data sets (e.g., Dec 4). In Figure 18, the data from Dec 4 can be seen in greater detail. Here the spurious Blueline PowerCost energy spikes are clearly visible. Again, the reason for this is unknown but this type of false data may be influencing the lower apparent accuracy of the Blueline PowerCost unit.

Figure 17 – Comparisons of Metered Energy for Tested Devices by Day for Week 49 (Nov 28th 2010 – Dec 4th 2010)

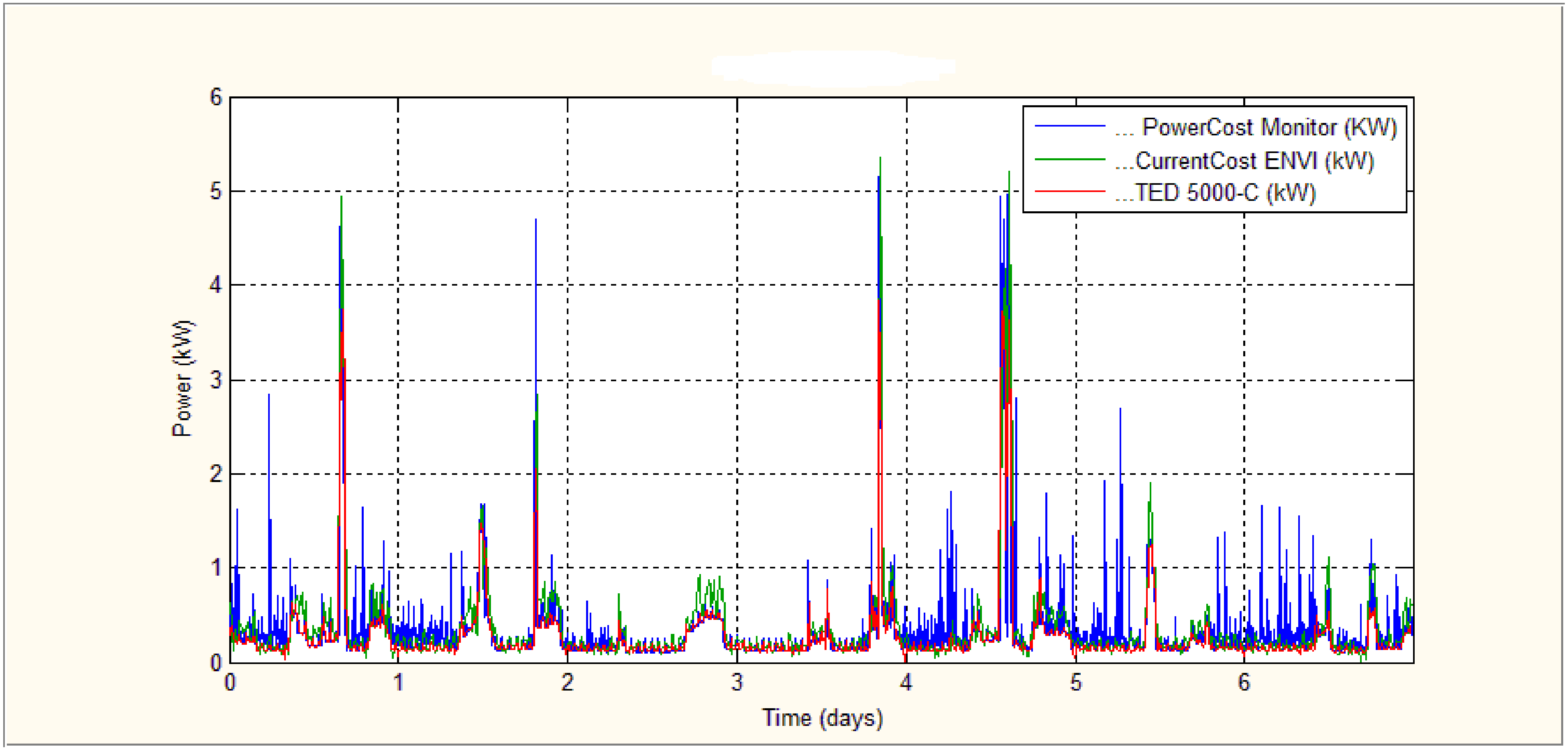


Figure 18 – Comparisons of Metered Energy for Tested Devices on Day 6 of Week 49 (Dec 4th 2010)