Energy End-Use Patterns in Full-Service Hotels: A Case Study

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ABSTRACT

The U.S. Department of Energy (DOE) recently initiated a program – Commercial Building Partnerships (CBP) – to work with private-sector companies in the design of highly-efficient retrofit and new construction projects. Pacific Northwest National Laboratory (PNNL) is conducting a project with a major hotel company to retrofit a full-service, large hotel with the goal of reducing energy consumption by at least 30%. The first step of the project was an intensive metering and monitoring effort aimed at understanding energy end use patterns in the hotel. About 10% of the guest rooms (32), as well as circuits for most of the end uses in public spaces (lighting, elevators, air handlers and other HVAC system components, and various equipment), were equipped with meters. Data are being collected at 1- or 5-minute intervals and downloaded on a monthly basis for analysis.

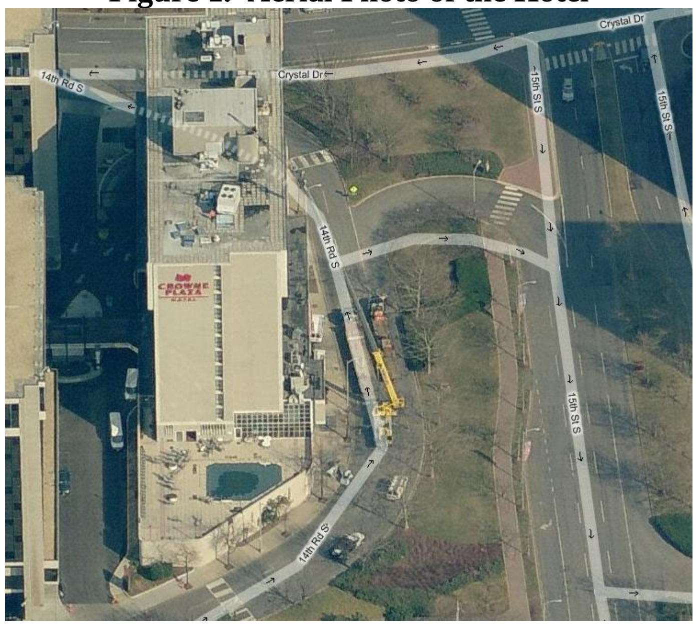
This paper presents results from the first four months of the monitoring effort, which revealed energy end-use consumption patterns, variability of guest room energy use, daily load curves, monthly variations, and other aspects of hotel energy use. Metered end-use data for hotels at this level of detail are not available from any currently-available public sources. This study presents unique information and insight into energy end-use patterns in the lodging sector of commercial buildings and can also serve as a case study of a complex sub-metering project.

Background on the Project

The US DOE's CBP Program is providing technical assistance through several of DOE's National Laboratories to support energy efficient retrofit and new-construction projects being undertaken by about 20 private-sector companies (DOE 2010). The project goals are twofold: 1) to design and build new buildings that are 50% more energy efficient than the ASHRAE Standard 90.1-2004 building code requires, and 2) to retrofit existing buildings in a way that achieves a 30% reduction in energy consumption. Lessons learned from these projects will help the companies alter their design, construction, and building operation practices in the future.

PNNL is working with a major hotel company on both a new construction and retrofit project. The retrofit project, which is the subject of this paper, is a twelve-story, full-service hotel with over 300 guest rooms and gross floor area of 212,000 ft² (see Figure 1). Originally constructed in 1968, the hotel underwent a light renovation nearly 10 years ago. This minor renovation was primarily cosmetic, and there has been very little energy focus at this hotel until this project began. Building energy systems are somewhat outdated. The hotel has an energy management system (EMS) that is not connected to all building energy systems (e.g., the newly-installed chiller, exhaust fans) and is not being used in a fully-functional way. Also, single-pane windows and uninsulated exterior masonry walls result in a thermally-inefficient building envelope, and most of the packaged terminal heat pumps (PTHP) serving the guest rooms are 7-years old or more (though they are gradually being replaced). There was no energy benchmarking or energy audit completed prior to commencement of this project.

Figure 1. Aerial Photo of the Hotel

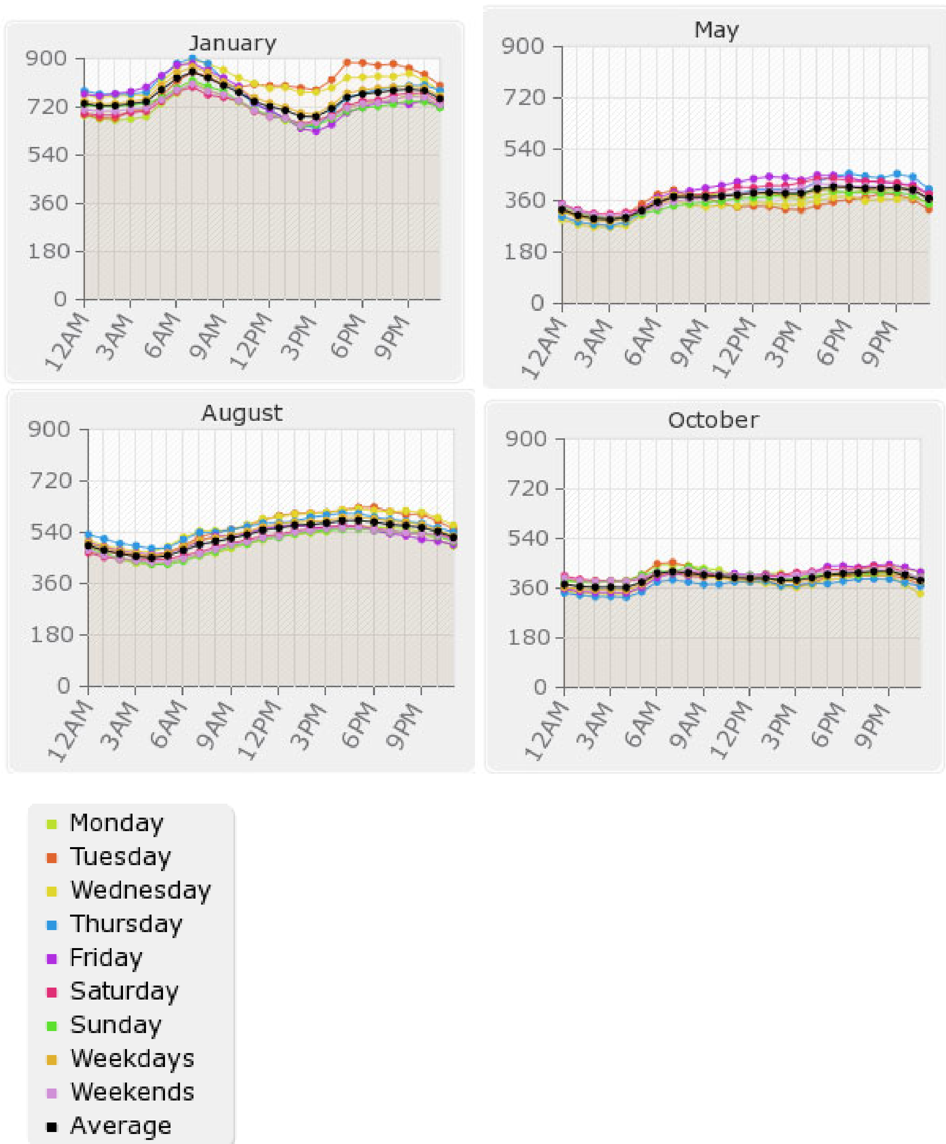


The first step of the project was to measure the baseline energy use and conduct a detailed study of the end-use energy consumption patterns in the hotel. Some information on energy end-use in hotels is available from sources such as the Commercial Building Energy Consumption Survey conducted by the Energy Information Administration (EIA 2005), Energy Star (EPA, 2010) and the California Commercial End-Use Study (CEC 2006). However, these sources are primarily aimed at benchmarking and are typically based on whole-building energy consumption data or modeled/estimated energy loads by end use. One published study monitored lighting in hotel guest rooms (Page and Siminovitch, 1999). The metering effort described here was designed to provide a detailed and accurate picture of energy consumption at this particular property to support building energy simulation modeling and the development and analysis of energy efficiency measures, leading to a 30% or more improvement in energy efficiency. However, the end-use consumption data reported in this paper are also generally useful for describing end-use patterns in the large hotel sector, because the guest room equipment and various other features of the hotel are typical of large hotels in the United States.

The property is a full-service hotel with sit-down restaurant, coffee shop, on-site laundry, offices, and conference/banquet rooms, making it a challenging project. Hotels have a wide diversity of energy uses, with spaces that may or may not be occupied on any given day, and guest rooms that are occupied by different guests with varying habits. As a result, the metering data collection for this project has been considerably more extensive and complicated compared to other projects in the CBP Program.

Initial analysis of the 2009 electricity interval data from the utility (Dominion Power) shows a relatively flat daily load curve in all seasons across all days of the week (Figure 2). The lack of variation between weekdays and weekends is not surprising, given the hotel has a very high occupancy rate and serves both tourists (including weekend stays) and business guests (typically during the week). From these data, it appears that this hotel has almost 400 kW of base load. The peak cooling load is about 200 kW (see Figure 2, August) and the hotel has overall higher electricity use in the winter due to use of electric resistance heat[1] in the packaged terminal heat pumps (PTHPs) serving the guest rooms and the duct heaters serving common spaces.

Figure 2. Daily Electricity Consumption (kW) based on Utility Interval Data in Selected Months



In addition, the hotel uses natural gas for service water heating (a significant hotel load), as well as kitchen appliances and laundry equipment. Table 1 shows the monthly energy consumption for both electricity and natural gas in the year of 2009. At the site, electricity

[1] During the metering period, many of the PTHPs were heating in resistance mode due to a software control issue.

consists of 73% of the total energy consumption. Converting to "source" energy use, electricity consists of 89% of total Btus. The metering and monitoring effort was aimed at breaking down these totals by end use.

The effort to understand the breakdown of energy by end use load involved: (1) extensively metering various circuits and pieces of equipment in the hotel, (2) estimating loads using information about equipment capacity and use, and (3) building energy simulation modeling and calibration using EnergyPlus. This paper will discuss items (1) and (2); the energy simulation modeling is underway and will be described in a future paper.

Table 1. Monthly Energy Consumption, 2009

Month	Site Electricity Consumption		Site Natural Gas Consumption	
	kWh	Billion Btu	Therms	Billion Btu
January	563,995	1.92	4,118	0.41
February	394,642	1.35	4,876	0.49
March	342,010	1.17	6,103	0.61
April	258,781	0.88	5,441	0.54
May	273,499	0.93	5,390	0.54
June	318,592	1.09	4,773	0.48
July	350,831	1.20	4,313	0.43
August	391,549	1.34	3,829	0.38
September	276,165	0.94	3,360	0.34
October	280,615	0.96	4,447	0.44
November	316,914	1.08	3,995	0.40
December	506,513	1.73	4,016	0.40
Total	4,274,106	14.58	54,661	5.46

Electricity Metering Approach and Results

Approach

Since guest room loads were deemed important, approximately 10% of the rooms (32 rooms) were chosen for monitoring and evaluation. PNNL and its subcontractors installed plug-logging electricity meters (Educational Electronic Devices Watts-Up) to measure electricity consumption of plug loads and portable lighting fixtures, including the desk lamp with convenience outlet, floor lamp, two table lamps, the refrigerator, and the TV. In addition, Onset Computer (Hobo) light intensity data loggers were installed at the bathroom lights and wall sconces to determine the on-hours of these hard-wired fixtures. The PTHPs were instrumented with Hobo loggers measuring amperage draw, supply/return air temperatures, and relative humidity. To ensure metering accuracy, a "check-sum" approach was used. For the guest room plug loads the check sum metering was at the electrical panel where the individual breaker serving each room was monitored. For the PTHPs, the check sum was at the sub-panel serving the PTHPs. In both cases the panel-level monitoring was done using a combination of a pulse-output watt transducer (Continental Control Watt-Node) and a pulse collecting data logger (Madgetech Pulse 101). We also installed the same combination of watt transducers and pulse loggers on the two chillers, rooftop exhaust fans, the elevators and elevator HVAC, make-up rooftop unit (to provide outdoor ventilation air to guest floor hallways), the three points (pre-heat, re-heat, and fan motor) for the nine air handing units (AHUs), and various kitchen, laundry, and other equipment circuits. For the lighting, we metered circuits serving various common areas and conference/ballrooms with a combination of Hobo data loggers and current transformers. In total, the metering devices include 96 watthour meters, 158 plug power meters, 91 temperature measurement devices, 32 relative humidity measurements, 109 current measurement devices, and 64 lighting level measurements for a total of 550 measurement devices. The installation was complete and tested on September 25, 2009. Data has been downloaded on a monthly basis.

Metering Results: End Use Loads

Figure 3 shows daily consumption for October 2009 for guest rooms [chart (a)], hotel heating, ventilation, and air conditioning (HVAC) systems [chart (b)], and other loads [chart (c)]. The charts also show average daily outdoor air temperature. Note that, for the purpose of developing an estimate of total load in the hotel, the data for the 32 guest rooms and guest hallway equipment (ice makers and vending machine) were scaled using guest occupancy rates in the 32 rooms versus the hotel as a whole. The PTHP load in Figure 3 (a) is highly correlated with average outside air temperature (R-squared is 92%). As currently configured, the balance point for the guest rooms is approximately 55°F; i.e., at 55°F, the minimum PTHP consumption occurs. Temperatures lower 55° result in significant heating loads, and at temperatures greater than 55°F, PTHP consumption increases due to cooling. The HVAC loads shown in Figure 3 (b) for the common areas in the hotel, including duct heaters, air handling units (AHU), and rooftop units (RTU), also indicate a high correlation between average outside air temperature and heating and cooling consumption. Here the balance temperature appears to be closer to 60°F, as the majority of the HVAC in this portion of the building is running continuously with 100% outside air. The “other loads” shown in Figure 3(c) are not correlated with outdoor temperature. Figure 4 shows monthly energy consumption by end use for the four metered months.

Figure 3. Daily Metered End Use Loads versus Outdoor Temperature (T out) in October (a) Guest Room Loads

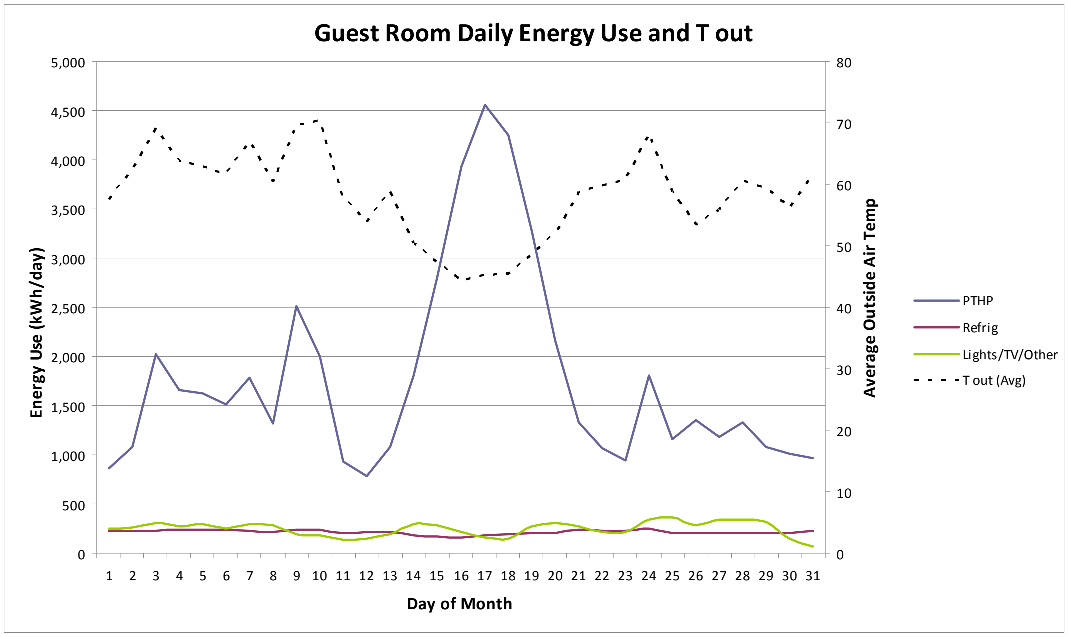
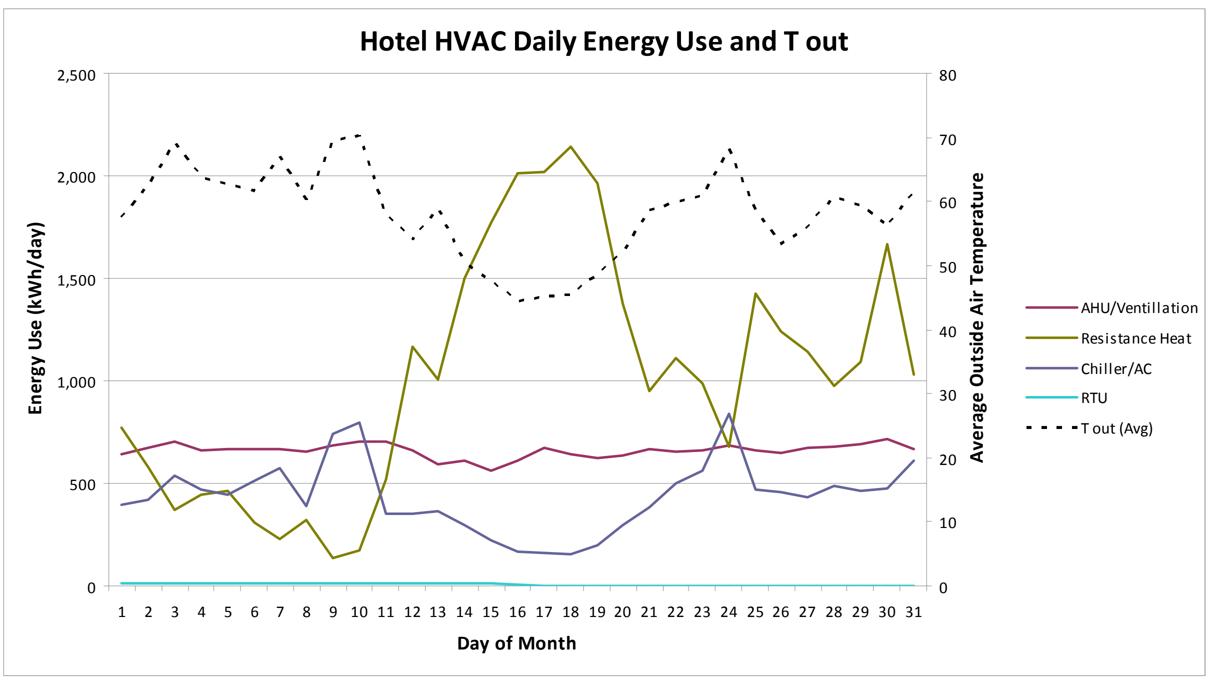


Figure 3 (continued). Daily Metered End Use Loads versus Outdoor Temperature (T out) in October (b) HVAC Loads in Common Spaces



(c) Other Loads

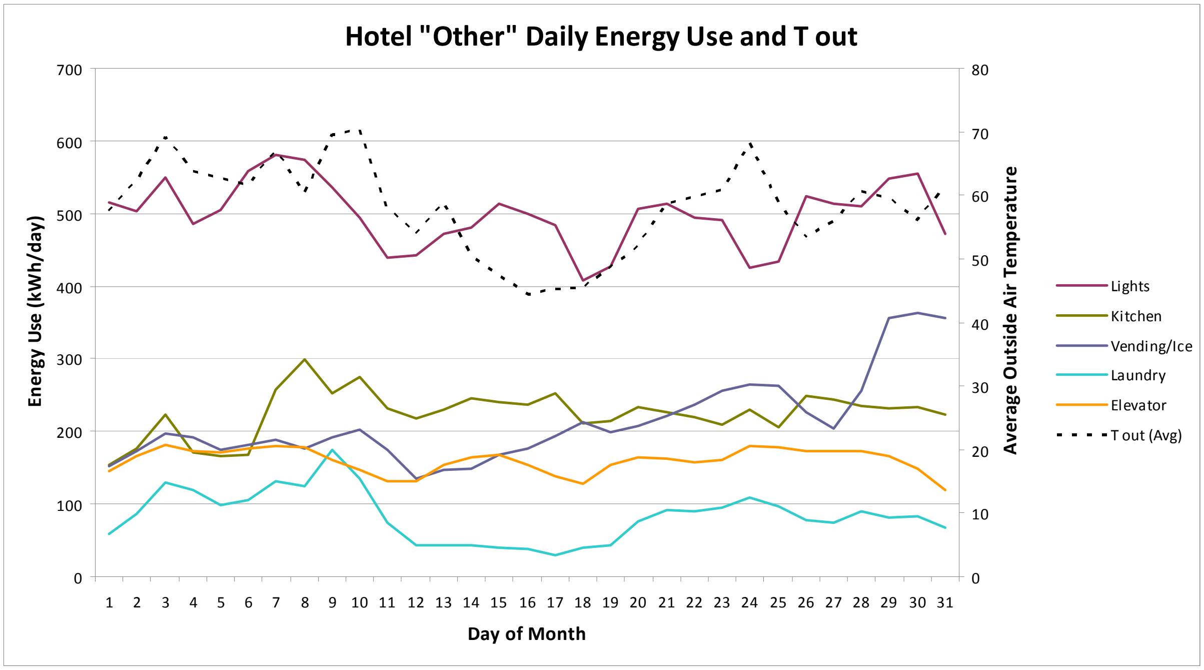
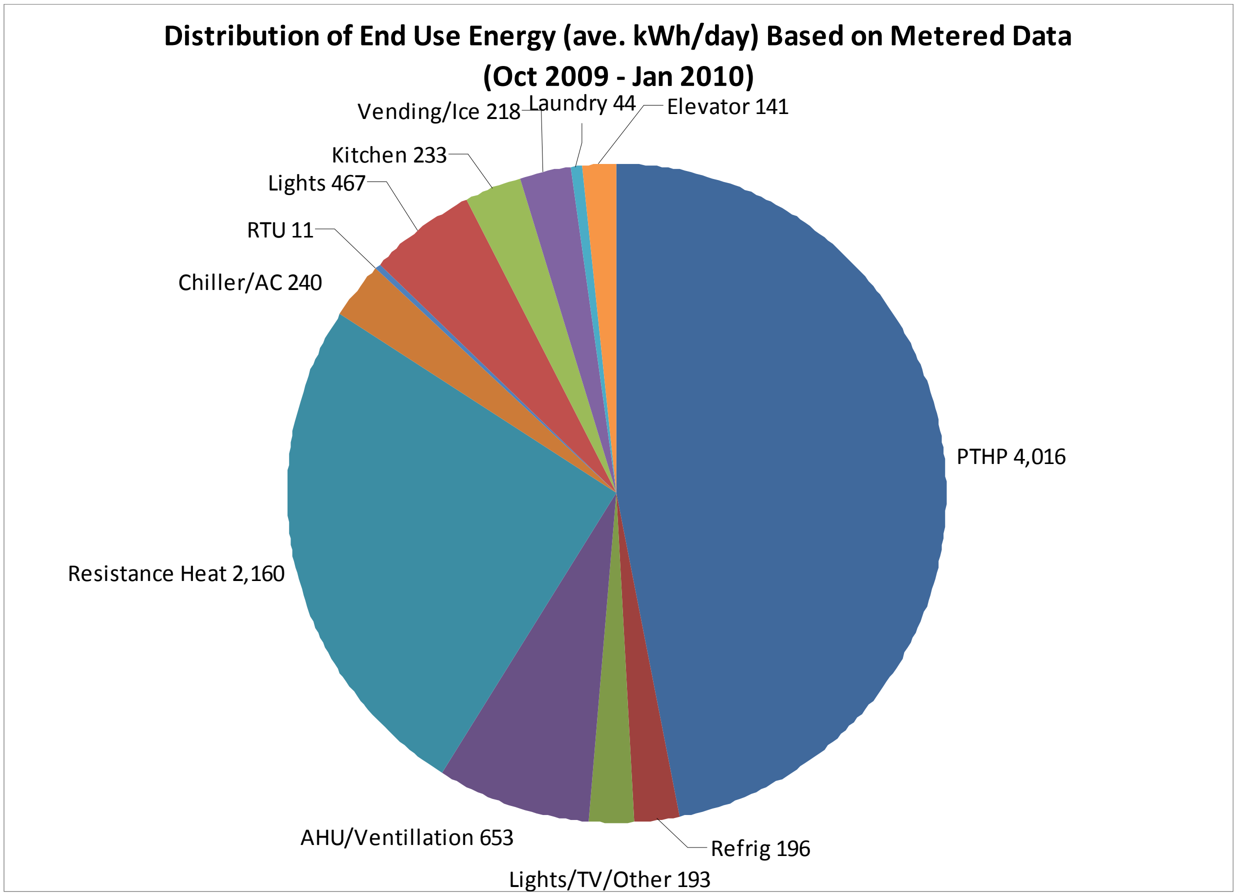


Figure 4. Monthly Electricity End-Use for the Four Metered Months (Combined)



Details on PTHP Energy Use

The PTHP energy consumption in 32 guest rooms was monitored using current measuring devices at 1-minute intervals. The current data was converted to power by multiplying with the one-time voltage measurement (277 volts and an assumed power factor of 0.95). The clouds of dots in Figure 5 shows the average daily power consumption (average Wh/h) as a function of the average daily difference between the outdoor and return air temperatures for selected rooms. The red lines in Figure 5 are the Loess[2] curve fits. Some of the 32 rooms were recently upgraded with new PTHPs, which are slightly more efficient than the older units. Figure 6 shows the comparison of Loess fits for all the 32 metered rooms. Note that the old units (blue lines) generally have higher slope than the new units (red lines), indicting new units are more efficiency than the old units.

[2] Loess in a nonparametric method for estimating local regression surfaces.

Figure 5. PHTP Average Power Consumption as Function of Average Daily Difference in Outdoor and Return Air Temperatures

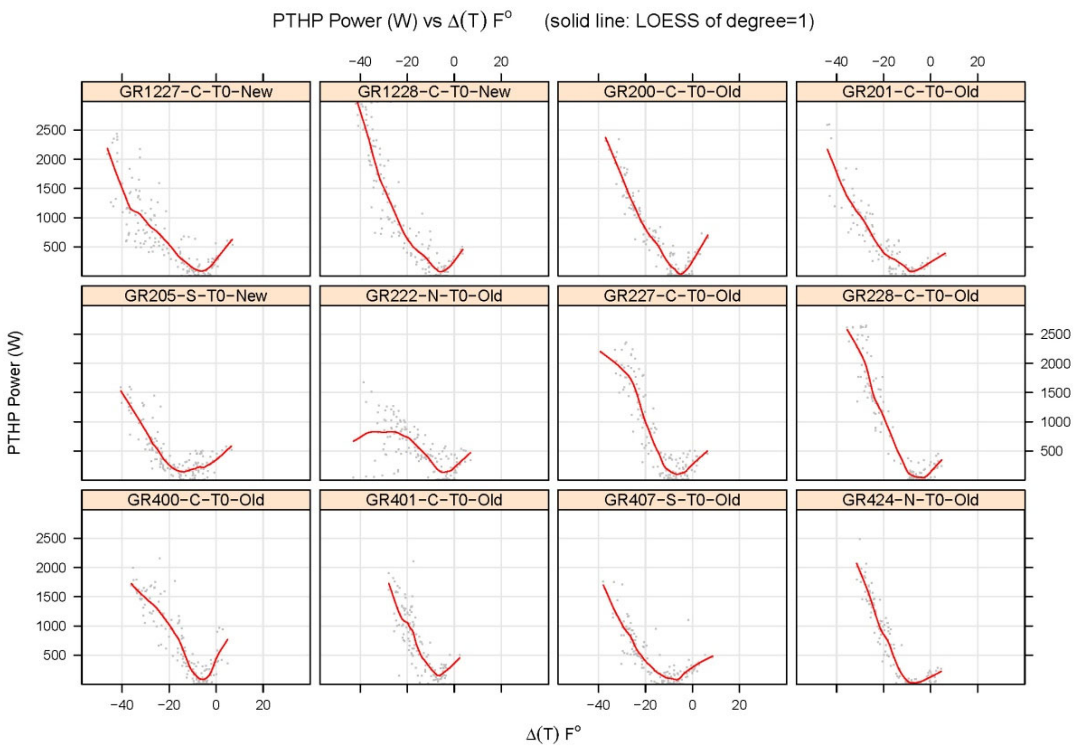
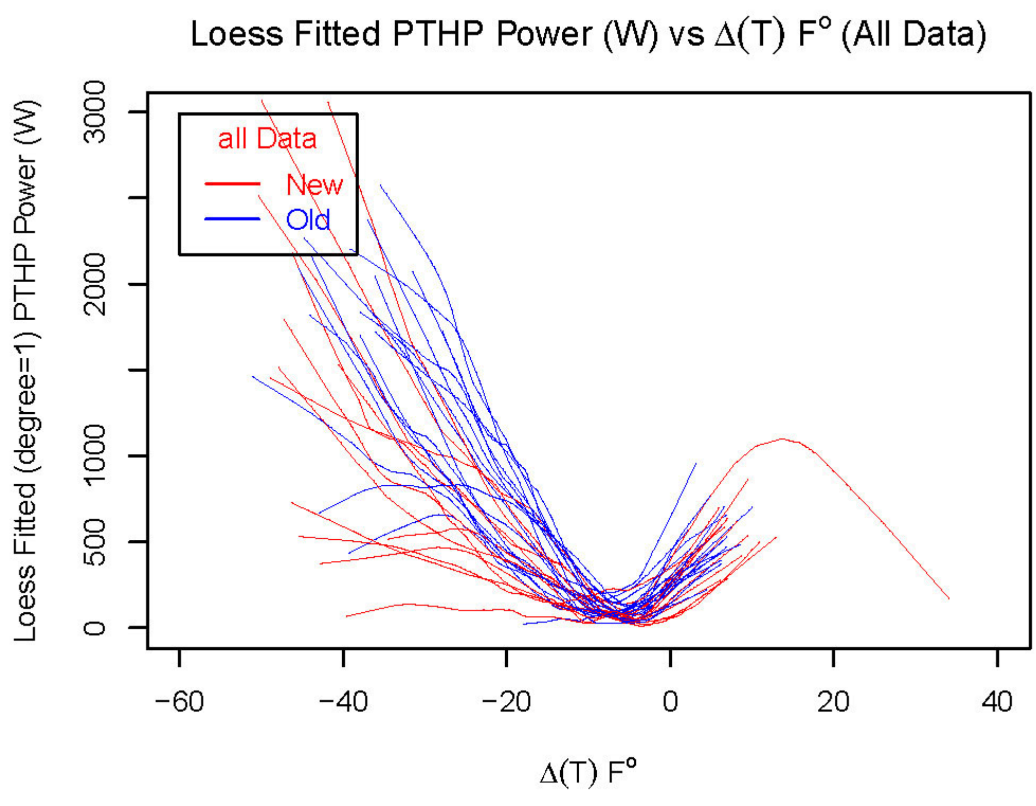


Figure 6. Comparison of Loess Fits for New and Old PTHP Units



Unmetered Load Analysis

Figure 7 shows total daily average electricity consumption at the whole-building meter versus the sum of the metered loads in one month (December 2009). Over the entire period, on average, the individual meters capture about 62% of the total electricity consumption, but the percentage varies from 50% to 83% on any given day.

While the monitored electricity use follows the building level revenue meter very well, the analysis shows a significant unaccounted-for electricity use. To better understand this unmetered use, the following three analyses were conducted:

- Unmetered use as a function of occupancy
- Unmetered use as a function of outdoor air temperature
- Regression of both revenue metered and project monitored usage with outdoor air temperature

Independently, the unmetered loads do not show a strong correlation with either occupancy or outdoor air temperature. Through regression analysis, we correlated both the utility-supplied and project-monitored data with outside air temperature. The premise behind this analysis is that if one data set has an appreciably different relationship to outdoor air temperature, the resulting regression lines will not be parallel. As shown in Figure 8 the lines are, by-and-large, parallel. This consistency highlights the relative constant nature of the difference indicating this difference is not weather variant and is likely driven by miscellaneous base loads.

Figure 7. Whole-Building Utility Data Versus Sum of Metered Data for December

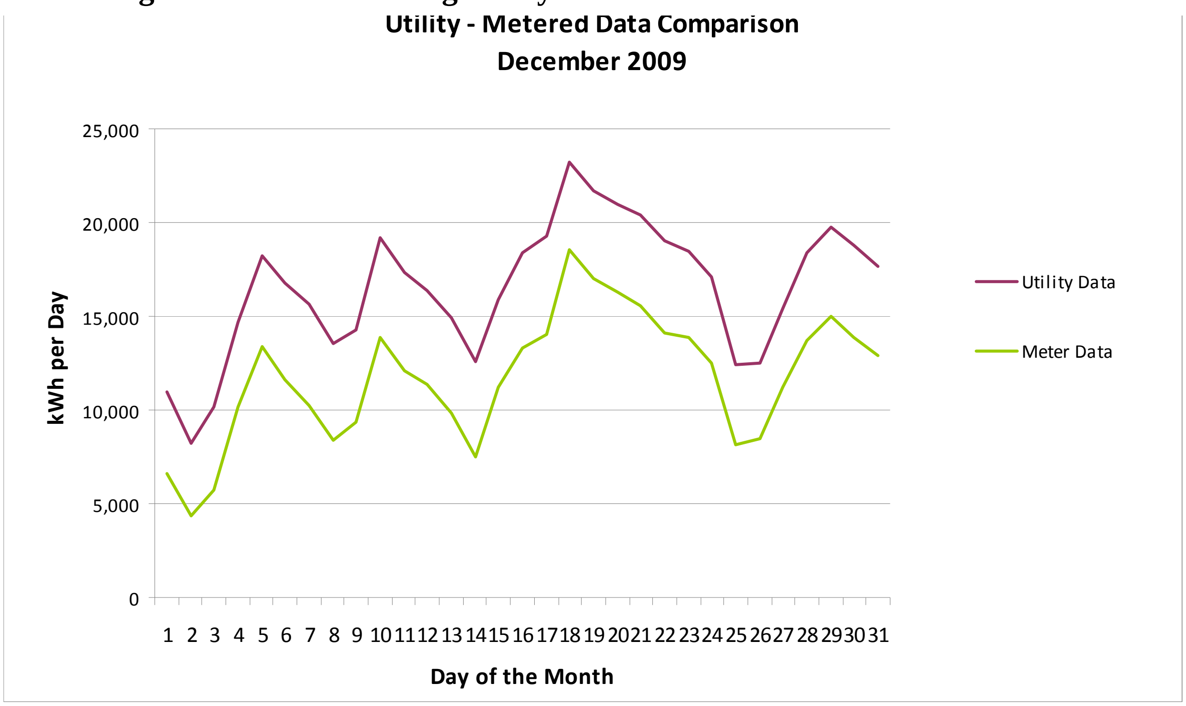
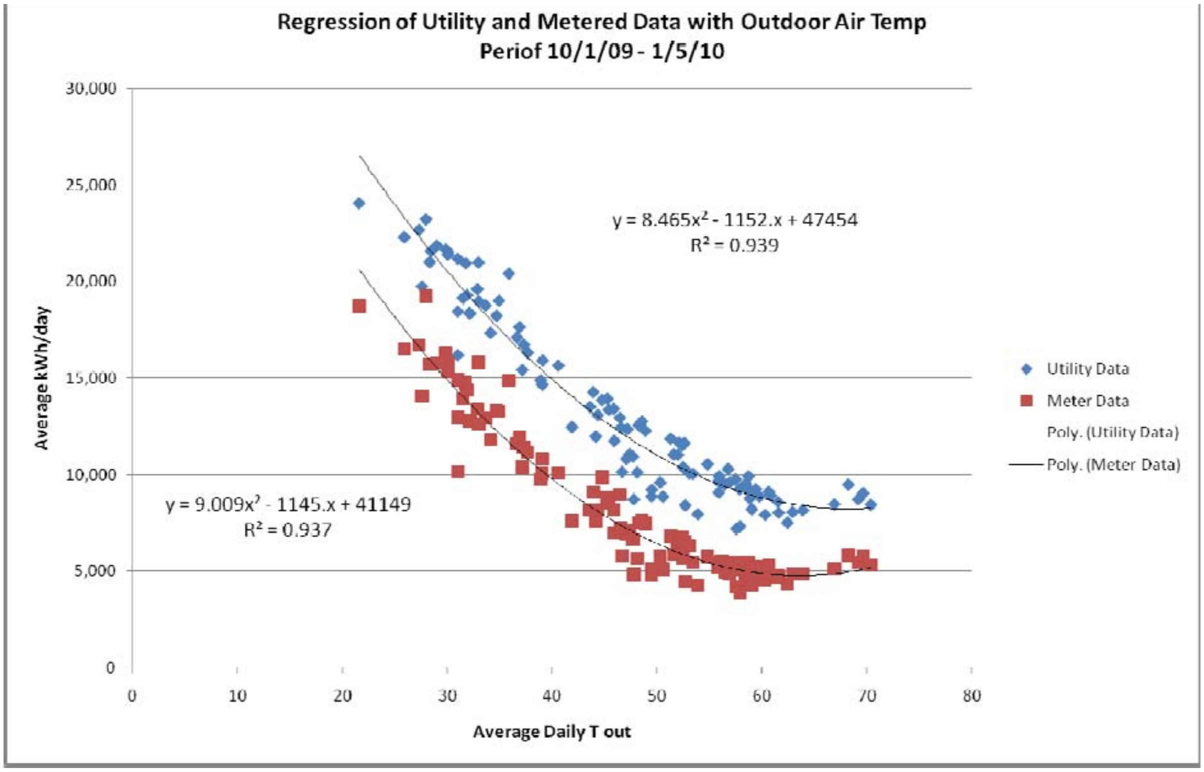


Figure 8. Regression of Utility and Metered Data with Outdoor Air Temperature

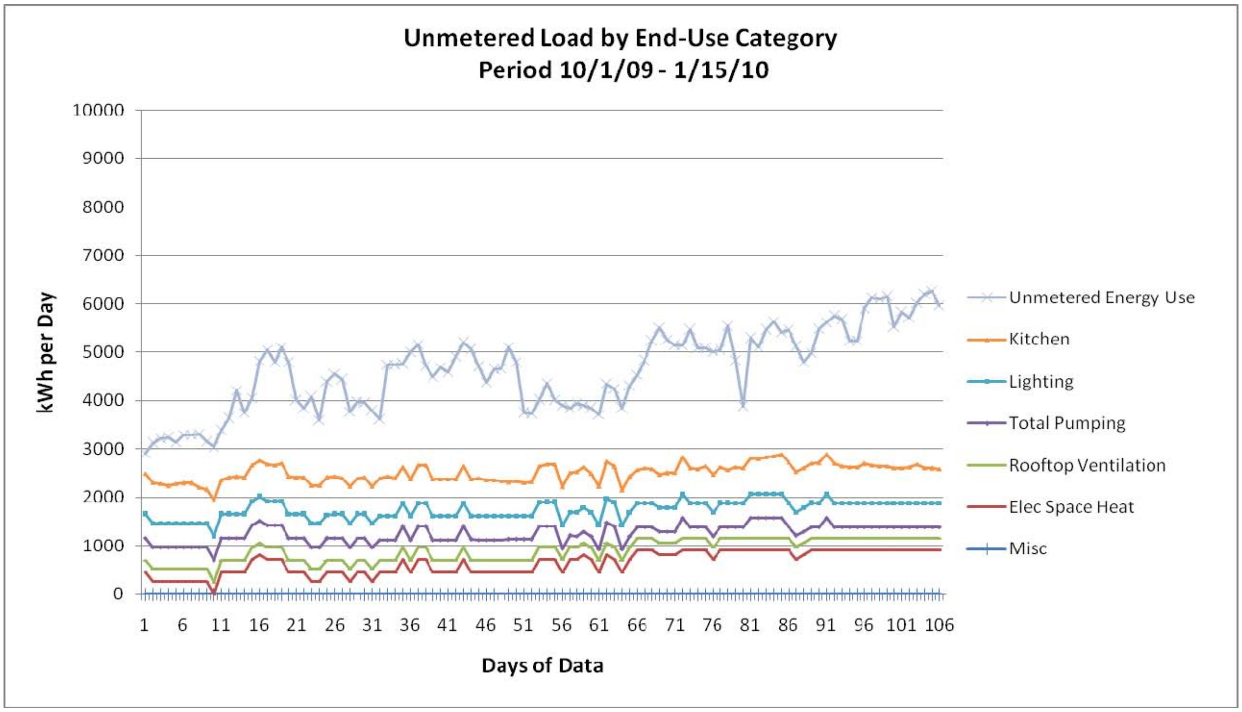


The estimation of unmetered loads began with a thorough review of audit notes, various equipment lists, and installed metering points. Once all major loads were identified, they were reconciled as being metered or not; those not metered were listed for inclusion in the estimation exercise. The five main categories of unmetered loads are as follows:

- ***Pumping.*** Includes all domestic cold water pumps, chilled water and condenser water pumps, domestic hot water recirculation pumps, and the pool pump. Chiller, condenser water, and pool pump energy use were scaled based on metered equipment run times; domestic water pumps were calculated based on schedule.
- ***HVAC.*** Includes unmetered exhaust fans and a variety of electric space heaters. It is likely that this group has additional, yet-to-be discovered, electrical heating loads - possibly including other space heat and pre/reheat coils. (Note: the pool is unheated.)
- ***Lighting.*** Includes all unmetered lighting loads categorized using a detailed lighting audit.
- ***Kitchen.*** Unmetered kitchen energy use was derived based on an audit done by PNNL's kitchen subcontractor. To prevent double counting, these values were input and then reduced by the metered kitchen loads.
- ***Miscellaneous Equipment***. Includes miscellaneous appliance and equipment at the on-site Starbucks, the restaurant bar, the back office, and in the engineering areas.

Once identified, these loads were researched for rated energy use and schedule to estimate whole building impact. The results of this effort are shown in Figure 9.

Figure 9. Unmetered Load by End-Use Category



Note that, in this figure, the top series represents the total unmetered load, and the series below are cumulative, such that they "build up" the estimated unaccounted load. The remaining unaccounted-for load increases with time, indicating a potential for missing heating/ventilation loads, as the outdoor temperature was generally decreasing over the analysis period.

Given the magnitude and complexity of energy use in this hotel, unaccounted-for electric loads are expected. The above analysis reduced the average aggregate unaccounted-for loads from 37.9% to 16.4%. The resulting breakdown of energy use is shown in Figure 10. (Note: average over the four months was 13,285 kWh/day.) Further analysis is being conducted to reduce the percentage of unaccounted-for energy use.

Natural Gas Consumption

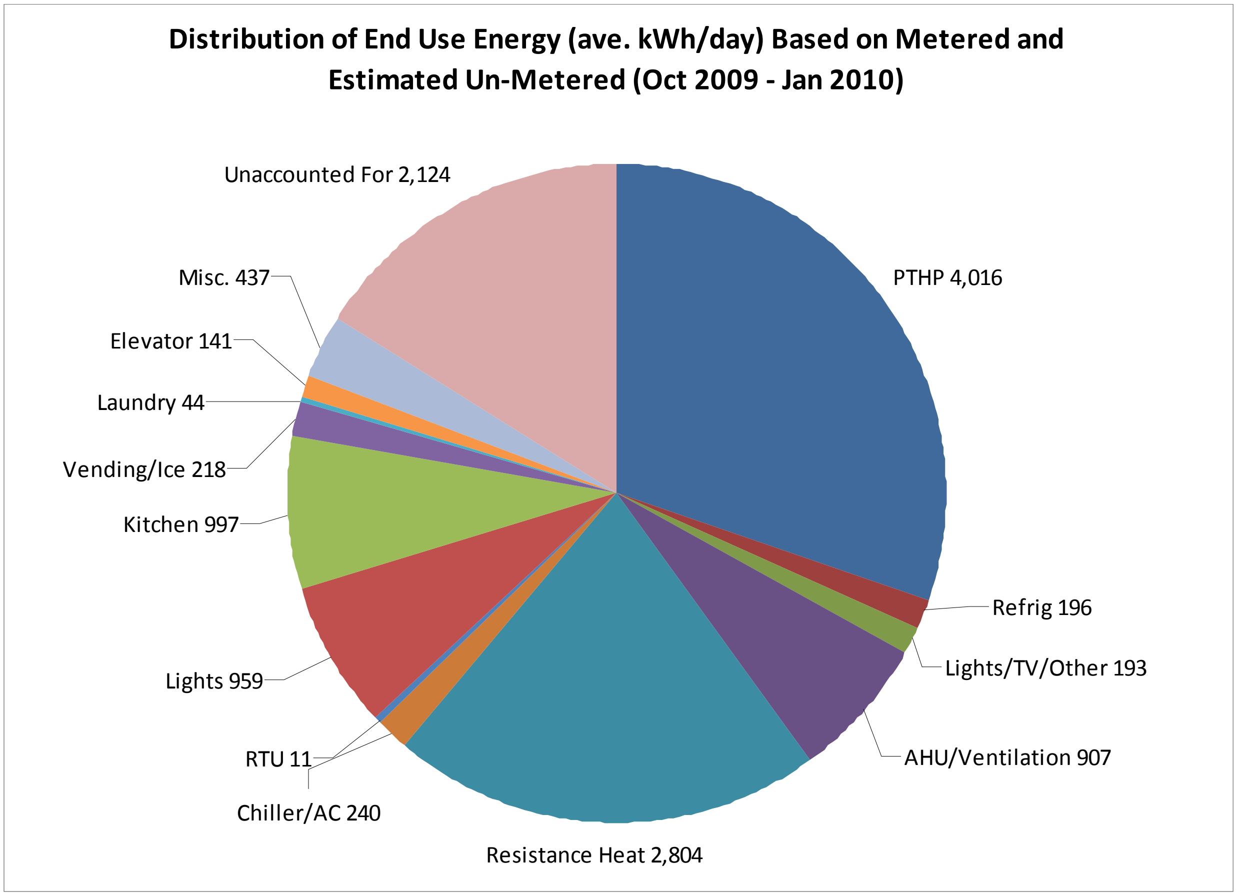
Natural gas use at the hotel is confined to three areas:

- The penthouse where gas is used in three boilers and one water heater to generate domestic hot water.
- The laundry area where gas is used in two water heaters to generate hot water for clothes washers, in three clothes dryers, and in one ironer (known in industry as a "flat iron").
- The kitchen where gas is used in a variety of cooking and warming equipment.

The challenge of this activity was disaggregating the various gas using devices listed above and developing these into relative shares of the whole-building use. While end-use metering of each device was desirable, the cost, complexity, and relative intrusiveness of gas metering made this impractical.

Gas is metered at the building service entrance via a utility-owned rotary style gas meter. Gas bills from this meter were reviewed. In November 2009, the utility meter was retrofit with a pulse output device with full safety isolation. These pulses were now collected by a data logger at 5-minute interval and downloaded on monthly basis.

Figure 10. Metered plus Estimated Electricity End-Use for October through January



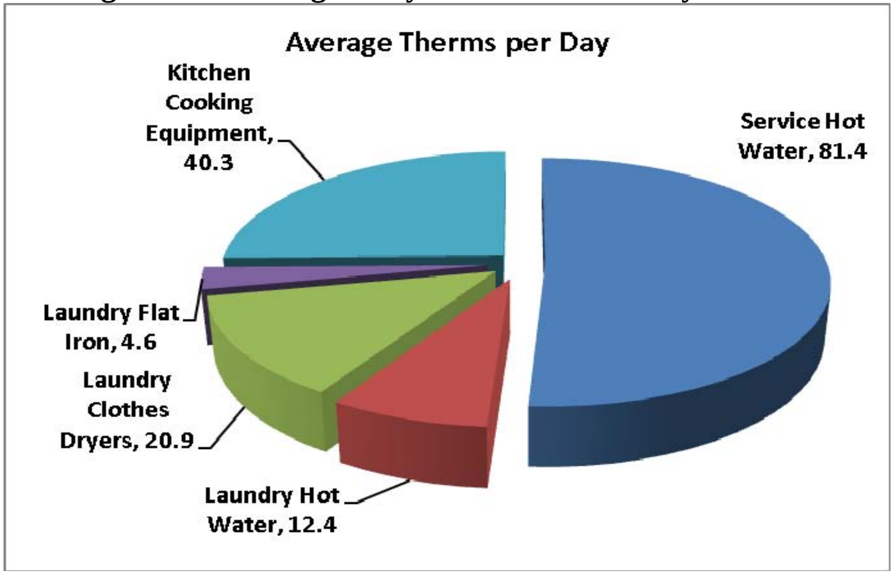
To estimate gas use for the domestic hot water and laundry systems, a number of proxy measurement techniques were employed. Predominantly, these relied on temperature measurements of products-of-combustion either in exhaust stacks (boilers, water heaters, iron) or combustion chambers (clothes dryers). In addition, flow (via a non-intrusive ultrasonic flow meter) and temperature measurements were made in the Penthouse to assess gas used in domestic hot water generation.

By its nature, proxy metering does not measure the variable of interest, rather a surrogate for that variable. As such, the potential for inaccuracy can be significant. To minimize these potential inaccuracies and to improve confidence in the result, secondary measurements or calculations are always recommended. For this activity, all proxy measurements were verified with secondary calculations – typically based on manufacturer-provided energy-use intensities.

Gas use for the kitchen was calculated by a team from the Halton Inc. Figure 11 presents the proxy measurement results by major end-use. Service hot water accounts for 51% of the gas use, with kitchen and laundry accounting for about 25% each.

A comparison was completed whereby the "sum of the parts" gas use (i.e., domestic hot water, laundry, and kitchen) was compared to the "whole" (i.e., the average annual daily gas use). The result was that the former was calculated to be 6.3% greater than the latter. This difference is well within the expected accuracy of a proxy analysis.

Figure 11. Average Daily Natural Gas Use by End Use



Conclusions

The work to date in this project, i.e., to measure, monitor, and estimate end-use energy consumption in a 1970-era full-service hotel in the Middle Atlantic region, was a challenging undertaking and provided a rich source of information about the major energy end uses in hotels. A few major conclusions from the study include:

- Heating of the guest rooms and the public areas is by far the largest consumer of electricity, accounting for almost 60% of total electricity consumption, in the autumn and winter months in this large hotel in the Washington, D.C. area, and would likely the dominant seasonal load in any hotel in a similar climate zone. For new construction projects, more efficient approaches for heating the guest rooms, instead of PTHPs, should be evaluated. In a retrofit situation like the project described here, replacement of PTHPs with the most efficient products available on the market is warranted and is likely to have a significant impact on total energy use. The fact that the PTHPs were not operating properly in this hotel and the energy management system is not fully functional probably resulted in a somewhat higher heating load than would be seen in newer hotels with fully functional energy management systems. For heating of public spaces, alternatives to electric resistance heat and better control systems will be examined in the next phase of this project.

- Not surprisingly, energy consumption in both PTHPs and the other HVAC equipment in the hotel is correlated with outside temperature. This study shows that the correlation is very strong.
- The rest of the loads in this hotel (and most hotels) are diverse, making the development of an energy efficiency improvement strategy complicated. The kitchen consumes about 8% of the electricity and a quarter of the natural gas, hence about 10% of total energy use in the winter (the percentage would be higher in the summer). Unlike office buildings or some other commercial building types, lighting loads in a large hotel account for a fairly modest percentage of electricity consumption (about 7% in the winter and a somewhat higher percentage in the summer). Water heating consumes somewhat less than lighting at about 6%.
- Despite a rigorous metering campaign and subsequent analysis using calculations and proxy measures, we could account for only 84% of the electricity load in this hotel. This underscores the need for better understanding of miscellaneous electricity loads in commercial buildings, including hotels. This issue will be further studied in subsequent work.

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