Measuring and Understanding the Energy Use Signatures of a Bank Building

Yulong Xie, Bing Liu, Rahul Athalye and Michael Baechler,
Pacific Northwest National Laboratory
Greg Sullivan, Efficiency Solutions

ABSTRACT

The Pacific Northwest National Laboratory measured and analyzed energy end-use patterns in a bank building located in Pennsylvania. This work was performed in collaboration with PNC Financial Service Group under the US DOE's Commercial Building Partnerships Program.

This paper presents the metering study and the results of the metered data analysis. It provides a benchmark for the energy use of bank-related equipment. The paper also reveals the importance of metering in understanding building loads. Measurements in this one prototype building helped to identify opportunities for energy efficiency improvements across PNC's portfolio of bank branches. The metering study was crucial to understanding and reducing plug load in the design of a net-zero bank branch. Finally, the study proved the value of calibrating models with measured data.

PNNL worked with PNC to meter a 4,000 ft^2 bank branch. A total of 71 electrical circuits were monitored and 25 stand-alone watt-hour meters were installed. These meters monitored the consumption of most plug loads, all interior and exterior lighting, service water heating, and the HVAC rooftop unit at a 5-minute sampling interval from November 2009 to November 2010. Over 8 million data records were generated, which were then analyzed to produce end-use patterns, daily usage profiles, rooftop unit usage cycles, and inputs for calibrating the energy model of the building.

Introduction

Within the U.S. Department of Energy's (DOE) Commercial Building Partnerships (CBP) Program, building owners (Partners) collaborate with national laboratories and private companies to explore energy-saving strategies for retrofit and new construction projects. The goal with each partner is to build either a new building that consumes at least 50% less energy than ANSI/ASHRAE/IESNA Standard 90.1-2004 (90.1-2004), or to retrofit an existing building to achieve at least 30% energy savings better than existing consumption. PNC Financial Services Group participated in the CBP with an even more ambitious goal to design and construct a net-zero energy bank branch in Florida. This design called for at least 50% better energy performance than 90.1-2004, and using renewable generation to make up the remaining energy loads. Pacific Northwest National Laboratory (PNNL) collaborated with PNC's design team and provided technical assistance with energy analysis, metering, and modeling of a new net-zero building and the renovation of an existing branch. Effects of the study on the net-zero building are the focus of this paper.

PNNL supported the design process for the net-zero building with a whole building energy analysis using DOE's EnergyPlus$^{\text{TM}}$ simulation software (DOE 2011), a powerful and versatile tool that uses data on heating, cooling, ventilation, lighting, and other energy end-uses to predict how energy efficiency measures (EEMs) will perform.

PNC's current prototype design was already more efficient than 90.1-2004. In conceptual design, PNNL developed an energy model of the PNC prototype with the modeling inputs derived from architectural drawings and an inventory of lighting, plug loads and mechanical systems from typical PNC bank branches. To test the viability of further efforts, PNNL applied an optimization algorithm to evaluate many EEMs and created a design package that lead to a 47% energy reduction over the baseline, demonstrating that the project was viable.

As part of the design process, PNNL and PNC launched an extensive metering effort on a single prototype branch. The goals of the monitoring effort were three-fold: (1) to calibrate the prototype model by replacing the generic model inputs (lightings, plug load, operation schedules, etc) used in the conceptual design stage with those derived from the measured data, (2) to understand the breakdown of energy use in an existing bank branch, in particular for plug loads including computers, data servers, ATMs and lighting energy usage, and (3) to evaluate the performance of the EEMs derived from the conceptual modeling stage and revise the EEMs, if necessary, to reach the 50% energy saving goal.

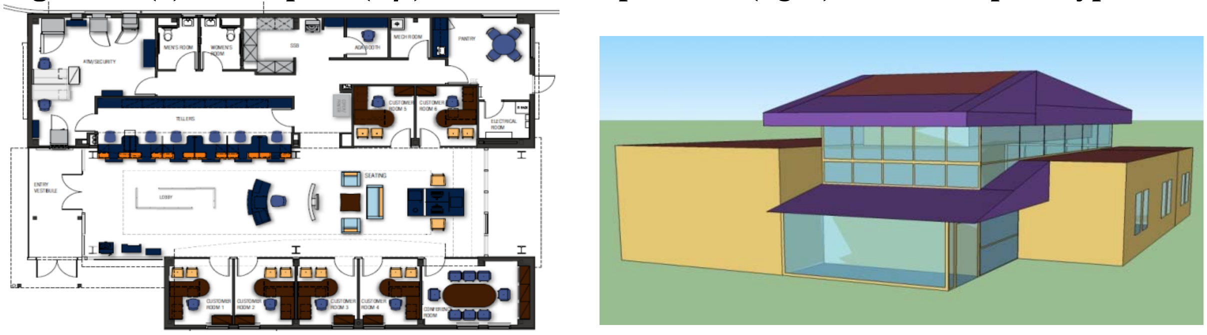
This paper describes the metering efforts, presents the metered data analysis results, and discusses the importance of the metering analysis on guiding the reduction of the plug loads to achieve the 50% energy saving goal.

Metering Plan

Branch Floor Plan and Thermal Zones

Figure 1 shows the floor plan and a corresponding SketchUp model of the PNC prototype building. The building has a total floor area of 4,000 ft^2 and is equipped with a single zone constant volume packaged rooftop unit. Interior lighting is mostly fluorescent, while exterior lighting, including all parking areas, is metal halide. The branch lobby is open Monday to Friday 8 am to 6 pm, and Saturday 8 am to 4 pm and is closed on Sunday. The drive-through opens one hour earlier at 7:00 am.

Figure 1. (a) Floor plan (*left*) and SketchUp model (*right*) of PNC's prototype building



A total of 15 conditioned thermal zones were used in the energy model as well as for guiding the metered data analysis. Identified thermal zones included the Customer Rooms (abbreviated: CstmRm_1, CstmRm_2-4, CstmRm_5-6), Conference Room (ConfRm), Vestibule (Vestibule), Lobby (Lobby), Teller Area (Tellers), Electric Room (ElecRm), ATM Room (ATM), Corridor (Corridor), Rest Rooms (RestRm), Stock Room (StockRm), ADA Booth (ADA Booth), Mechanical Room (MechRm), and Break Room (BreakRm).

Methodology

Usually, commercial buildings are only metered at the utility service entrance providing monthly whole-building energy usage. In order to understand the end-use energy consumption patterns and profiles, metering was designed to perform at multiple levels, including at whole-building level, at electrical panels, circuit breakers, and at the individual receptacles for selected plug loads.

The Onset Energy logger was used for the circuit level metering. The Onset Energy logger is a multi-function, multi-channel data logger. In this implementation, the logger was configured to measure current flowing through the desired circuits. A total of 71 channels were monitored with the focus on two types of loads: lighting and major plug load circuits.

Plug loads, such as computers, monitors, televisions, printers, coffee makers, money counters and other bank devices, were monitored with Watts-up Energy meters. These meters are stand-alone energy loggers that measure power and other energy metrics. A total of 25 Watts-up loggers were installed. Data were collected at 5-minutes intervals from Nov 11, 2009 through November of 2010

Developing Load Profiles

Load profiles are graphic representations of the variation of electrical load (devices, appliance, or equipment) versus time. Buildings and their equipment tend to operate according to schedules and the resulting energy profiles usually show daily, weekly, and/or seasonal cycles. Load profiles can represent these cycles derived through averaging of time-series of data collected from metering devices. Usually 24-hour daily load profiles are generated for different day types (i.e., weekdays, Saturdays, Sundays and holidays) to reveal hour-to-hour variation of energy consumption during a day. Weekly load profiles are also very useful to reveal the patterns between weekdays and weekends within a week.

Generating load profiles is a process of data subsetting and aggregation. To develop a 24-hour daily load profile shown in this paper, high resolution (5-minute) time series data from many days were split into different day types (e.g., weekday and weekend). The data of a given day type were then gathered and a representative value for each hour of the day was calculated by averaging the value at the same hour in the day from all days in the time series. For developing a weekly load profile, the time series data were first divided to individual weeks (use convention starting from Monday and ending on Sunday) and then a representative value for each hour of a week was calculated by averaging the value at the same hour in a week from all weeks in the time series.

The electricity consumption of the whole building and individual end-uses was calculated from the metered data. This was done by converting 5-minute meter interval data into hourly averages for each individual meter. Then, the hourly averages of the individual meters in each end-use group were aggregated together to provide the energy consumption of that end-use group. The whole building electricity consumption was estimated by summing the energy consumption of all end-use groups.

Metering Analysis Results

Interior Lighting

Figure 2 presents three representative types of load profiles of interior lighting, where plot (*a*) is for the Teller Area, plot (*b*) is for Corridor and Rest Room, and plot (*c*) is for the building emergency lighting. The load profile presented is defined by the maximum hourly average load during the day and the fraction of the average load at each hour of the day to the maximum hourly average load. The maximum hourly average loads are listed in Table 1. The emergency lighting is always *on* and is un-affected by bank operating hours. The patterns of other interior lighting meters approximate the bank operation hours. A late evening spike persistently appears in the weekday load profiles and it is coincident with the building cleaning schedule. There is virtually no lighting load at all during Sundays. Plot (*a*) in Figure 2 shows a constant day-to-day pattern with the same maximum energy usage between weekdays and Saturday. Load profiles derived from meters for Tellers, Lobby and Customer Room share this pattern. The pattern indicates that the lights in these zones remain *on* during operating hours and are turned *off* outside operating hours. Plot (*b*) reveals a varying lighting energy usage during the bank operation hours as well as a lower usage on Saturday than normal weekdays. The inspection of the weekly load profiles throughout the metering period reveals that the lights was *on* intermittently within the day, was not always *on* all days of the weeks, and was *off* more often on Saturdays. These features reflect the usage patterns of the restrooms and areas in the branch where lights are not always *on*.

Figure 2. Load profiles of interior lighting

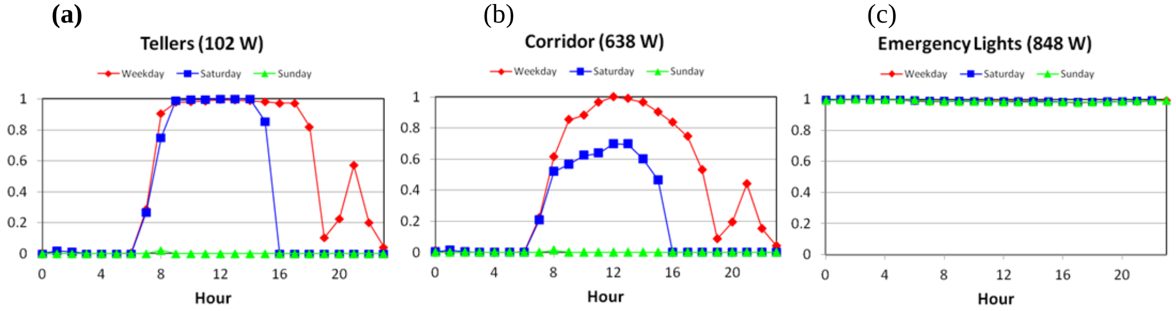


Table 1. Interior Lighting Loads

Plot #	Description	Max Hourly Avg Load (W)
-	CstmRm 1, 2-4, ConfRm	307
-	ATM	301
-	Lobby	1716
a	Tellers	102
-	CstmRm 1, 2-4	30
	CstmRms, ConfRm, ElecRm, RestRm, MechRm, ADABooth,	384
b	Corridor	638
c	Emergency Lights (Lobby)	847

Exterior Lighting

Exterior lighting load profiles can be grouped into 4 different categories as shown in plots (*a*), (*b*), (*c*), and (*d*) of Figure 3. Plot (*a*) represents the load profile of building signage lighting that indicate lights are on from 9 pm to 5 am and lights are off from 8 am to 4 pm. Plot (*b*) represents the lighting patterns of seven lighting channels associated with lights serving the parking lot and decorative lobby night lighting. These lights appear to be controlled by both schedule and daylight sensors. The spike at 6 am is likely the compromise between these two types of control. Plot (*c*) presents the lighting patterns of the logger channels dedicated for drive-through and ATM sign, which appear to be always *on*. Plot (*d*) is the pattern of the bank's canopy lights which cycle with a similar schedule to the parking lot lights. The maximum hourly average exterior lighting loads are listed in Table 2.

Figure 3. Load profiles of exterior lighting

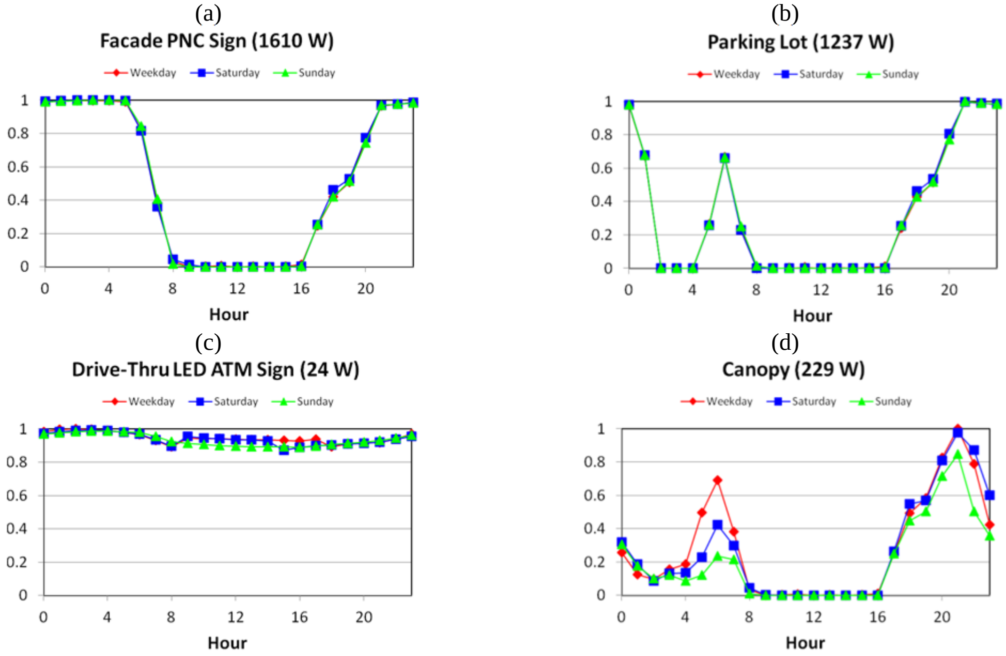

(a) (b) (c) (d)

Table 2. Exterior Lighting Loads

Plot #	Description	Max Hourly Avg Load (W)
a	Façade PNC Sign	1,610
-	Road Monument Sign	197
-	Canopy	324
-	Façade	299
-	Façade PNC Sign	1,705
b	Parking Lot	1,236
-	Parking Lot	1,277
-	Parking Lot	316
-	Parking Lot	966
-	Lobby Decoration	683
-	Lobby Decoration	1,138
c	Drive-Through LED ATM Sign	24
d	Canopy	229

Plug Load

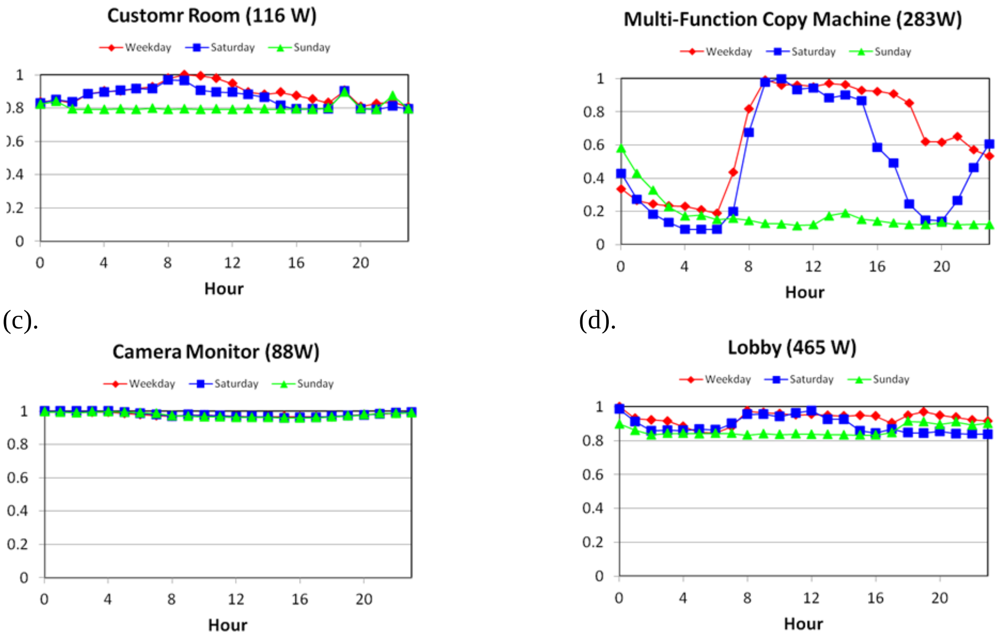
Both the Onset energy loggers and Watts-up meters were used for monitoring the plug loads. The Onset loggers monitored the composite loads of all devices/equipment wired in the circuit breaker. The Watts-up loggers metered individual plug loads of known device types.

Customer room (computer and monitor). Plug loads in Customer Rooms included computers, monitors and, in some cases, a space heater. It was found that the computer/monitor load is around 116 W and a space heater load is around 1,400 W. The load profile of a typical computer/monitor is shown in plot (*a*) of Figure 4, which indicates the existence of a significant base load (about 100W).

Corridor. Two well-established plug loads were metered in Corridor, one is the multifunction copy machine (MFC) metered by a Watts-up meter (as shown in plot (*b*) of Figure 4) and the other is the general plug in Corridor metered by a circuit breaker. There are non-zero loads shown in the Sunday load profiles and one possible explanation is that the device receives software updates just after midnight. Other loads in the Corridor are nearly zero for Saturdays and Sundays. The weekday profile of these loads is dominated by the late evening hours, which corresponds to the building cleaning schedule.

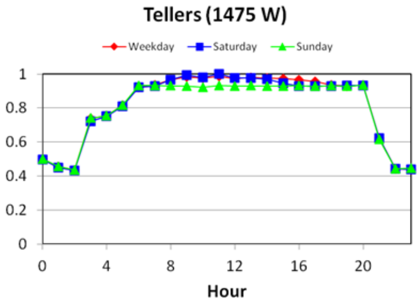
Break room & mechanical room. Plot (*c*) of Figure 4 shows the load profile of a security camera monitor located in the Break Room. As expected, monitoring cameras are always *on*. The electrical water heater located in the Mechanical Room was monitored and the load profile (not shown in Figure 4) indicated that most of the hot water usage occurs in late evening time and can be associated with the building cleaning schedule.

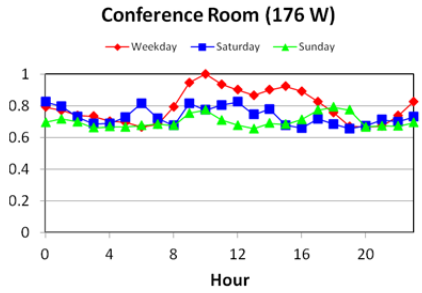
Figure 4. Profiles of plug loads


(a). (b).

(c). (d).

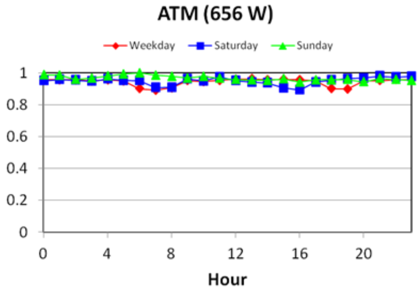
(e). (f).

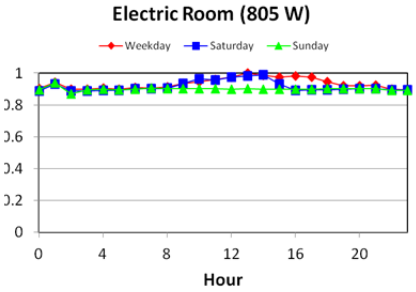




(g).

(h).





Lobby. Plug loads in the Lobby Area include two big screen televisions, an internet station with a computer/ a monitor/a fan, a reception computer monitor, a coffee maker, a coin deposit machine and others miscellaneous equipments. Plot (*d*) of Figure 4 shows the load profiles aggregated from the seven Watts-up meters, which point to a significant non-zero base load.

Tellers. Plug loads monitored in the Teller Area include televisions, printer, copier, money authenticator, money counter, and other miscellaneous teller-related equipment. Plot (*e*) of Figure 4 shows the load profile obtained by aggregating eleven Watts-up meters. The energy usage patterns between weekdays and weekends is quite similar, indicating that the standby loads of these equipment are quite high and the active mode does not add much loads on the standby loads.

Conference room, atm, electrical room. The Conference Room, ATM and Electrical Room load profiles are shown in plots (*f*), (*g*) and (*h*) of Figure 4. Similar to what we see in the Lobby and Teller area, the differences among day types are quite small for these loads. The ATM shows higher usage on Sundays than Weekdays or Saturdays, which appears to indicate more usage of ATM machine when the bank is closed on Sundays.

A common feature in the load profiles of the plugged receptacles is the existence of non-zero base load regardless of operating hours. While it is understandable that some safety and security devices have to be on all the time, turning off non-essential equipment during off hours represent opportunities for energy saving.

Roof Top Units

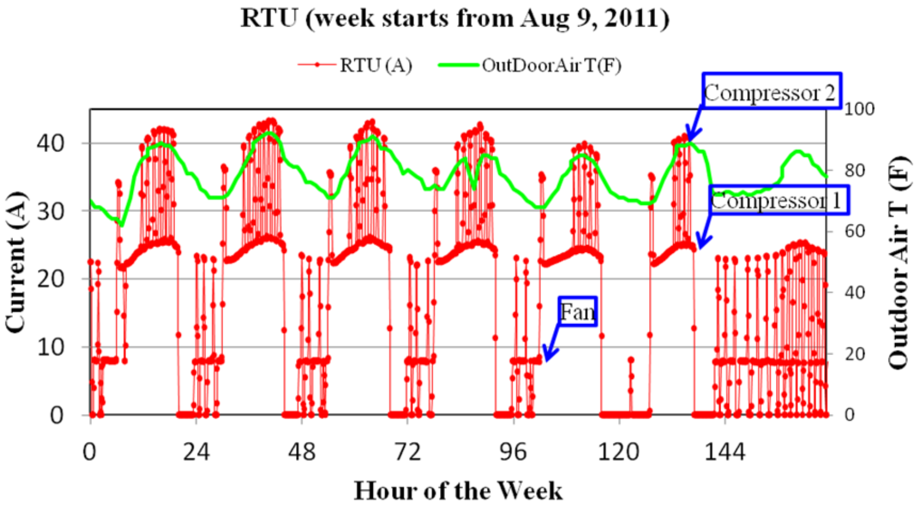
The roof top unit (RTU) serving this bank is a two-stage RTU with compressors rated at 5 tons and 7.5 tons. There are three distinguished stages of the RTU load during the normal operation: fan only, fan with the first compressor, and fan with both compressors. The second compressor only comes on during the hot periods and was found to cycle on periodically between mid-May and the end of September. Figure 5 shows the time series of a typical summer week where three stages of operation can be clearly seen with a clear distinction between the usage on Sundays and the rest of days, as well as narrower operating hours on Saturdays compared to the Weekdays, suggesting the operation of the RTU as being occupancy controlled.

One outcome of the metered data analysis was finding that the RTU was oversized. The time fractions of each of the three RTU operation stages were calculated on a monthly and weekly basis for both all periods and occupied periods only, respectively. Table 3 presents the calculated time fractions of each RTU operation stages on the monthly basis. From the table it can be seen that the second compressor comes on only between the months of May and September. The highest time fraction usage of the second compressor occurs during several weeks of July and August with the time fraction less than 20% (30% on the weekly basis) for the occupied hours, and less than 10% (15% on the weekly basis) overall. Because the runtime fraction of the second compressor is quite small, the RTU can be downsized.

Table 3. The monthly run time percentage (%) of each stage of the roof top unit

		Overall				**Occupied**			
Year	**Month**	**Off**	**Fan**	**1st Compressor**	**2nd Compressor**	**Off**	**Fan**	**1st Compressor**	**2nd Compressor**
2009	November	53	46	1	0	3	94	3	0
2009	December	46	54	0	0	3	97	0	0
2010	January	46	54	0	0	5	96	0	0
2010	February	46	54	0	0	5	95	0	0
2010	March	50	47	3	0	2	90	8	0
2010	April	50	36	14	0	3	65	32	0
2010	May	40	34	25	1	6	42	53	1
2010	June	35	18	43	4	6	9	82	6
2010	July	25	22	43	10	6	2	75	20
2010	August	30	21	42	8	7	4	78	15
2010	September	45	23	31	2	4	26	66	4
2010	October	53	39	9	0	4	75	22	0

Figure 5. A summer week time series of one of the three phase of the RTU feeder



Whole Building Energy Analysis

The breakdown of the energy consumption by end-uses was calculated for each month during the metering period. While the plug load and the interior lighting consumption do not vary much from month to month, the exterior lighting and RTU consumption do vary. For a comparison between winter and summer energy consumption, an average monthly energy usage was calculated for winter based on three months of November, December and January, and for summer based on two months of July and August. The results are presented in Figure 6. It is apparent that plug load and exterior lighting represent the largest end-uses in the building, followed by interior lighting and HVAC. The RTU consumes more electricity in the summer than in winter since the building is heated with gas, whereas exterior lighting uses less energy in the summer than in the winter, due to long daylight hours. Interior and exterior lighting together consume more energy than plug loads.

Figure 6. Average monthly metered electricity consumption

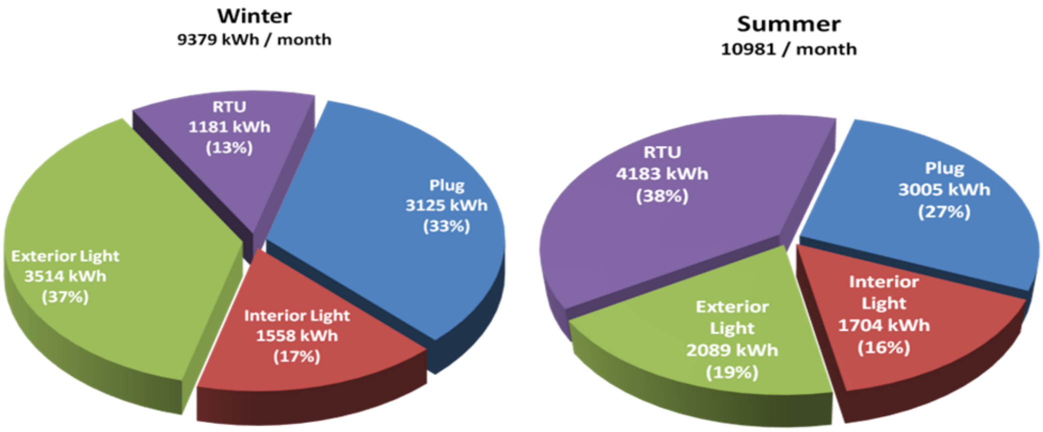


Table 4 shows the annual whole building electricity consumption (Nov ’09 through Oct ’10) broken down by end-use categories. It can be seen that plug loads and interior and exterior lighting consume more than 75% of the total electricity used at the building. This is a very interesting result provided by the metering study. It shows that EEM measures targeted to reduce a typical office building’s HVAC consumption will have only a small impact on the total consumption of this particular building.

Table 4. Annual metered electricity consumption by end-use

Unit	RTU	Interior Lighting[1]	Exterior Lighting[1]	Plug Loads[1]	Total
kWh	25,833	19,405	32,085	36,154	113,478
kWh/ft2	6.5	4.8	8.0	9.0	28.3
% Total	23%	17%	28%	32%	100%

Note 1: Metered data for October 2010 was incomplete and has been estimated based on data from previous months in order to produce the annual consumption

Energy Efficiency Opportunities

After the metering study, generic model inputs used in the conceptual design phase were replaced by the actual measured power and usage schedules derived from the metered data to calibrate the prototype model for the net-zero energy building. After the baseline and the design cases were re-run, energy savings from the conceptual design dropped from 47% to 27% over the calibrated baseline. Therefore, the EEMs needed to be revised or new EEMs needed to be identified to achieve the 50% saving goal. Also, the final design grew in size compared to the metered building, resulting in an absolute increase in consumption, and an increase in the plug load density.

Facing the fact that the majority of energy consumption was due to lighting and plug load, the focus of design was shifted towards reducing plug loads and exterior lighting. The metered data showed that computers and monitors were present in almost every room and were the single largest receptacle load. Other major sources of consumption within plug loads were televisions, the ATM machine, the MFC and Electric Room loads.

To improve plug load efficiency, ENERGY STAR rated equipment was chosen where available. In addition, all non-essential loads were to be plugged into an occupancy-based plug-strip that can be turned off based on an occupancy sensor control. Some of the other loads showing minimum variation between business hours and off hours, such as the television and the MFC were put on separately controlled circuits that could be turned off at night.

Table 5. Energy-saving Measures for Plug Load Equipment and Lighting

Load	Measures	Annual kWh Savings	% Contribution to Whole Building Load Reduction
Computer (CPU) and Monitor	1. Energy Star-rated CPU and Monitor 2. Plug-in strip occupancy sensor to turn off monitor 3. CPU turned off at night (12am-5am)	8,191	15%
Television	1. LED TV with ultra-low consumption 2. Schedule based nighttime turn off	4,104	
MFC	1. Energy Star-rated MFD 2. Schedule based nighttime turn off	319	
Refrigerator	Energy Star-rated Refrigerator	359	
ATM	Fluorescent lamps replaced with LED lamps for the bezel	1,413	
Audio/Video Switcher	Off-hours turn off	1,533	
	Total Plug Load Annual kWh Savings	**15,919**	
Interior Lighting	1. LED dawnlights and recessed 2x2 fixtures 2. Occupancy sensors 3. Daylighting controls in Customer Rooms, Lobby, Tellers	15,242	16%
Exterior Lighting	1. LED fixtures for parking lot 2. LED fixtures for canopy and façade 3. Custom LED fixtures for signage and decorative lighting	27,394	28%
	Total Lighting Annual kWh savings	**42,636**	

To evaluate and implement these energy saving opportunities, the PNC IT department became actively engaged. They designed a software-controlled “turn off” algorithm, where all the CPUs in the branch could be turned off automatically between midnight and 5 am, and then woken up before regular branch operations commence. Table 5 summarizes the electricity savings from efficiency measures for plug loads and lighting. With these measures, the plug load consumption was reduced by approximately 15,919 kWh while the lighting consumption was reduced by 42,636 kWh compared to the calibrated baseline building.

Monitoring showed that 56% of exterior lighting loads came from decorative and monument signage lighting. The design team worked with the signage manufacturer to have LED fixtures designed for monument signage, resulting in a 46% reduction for this load. An LED lamp was used to replace fluorescent lamps in the ATM bezel, which run continuously all year long, resulting in savings of 1,413 kWh.

After correctly characterizing the loads, calibrating the model, and identifying appropriate efficiency measures modeling results showed energy savings jumping from 27% to 57% more efficient than the calibrated 90.1-2004 baseline. Compared to the baseline, the plug load consumption was reduced by 35%, the interior lighting consumption was reduced by 60% and the exterior lighting consumption was reduced by 64%.

Conclusions and Discussion

A metering study of a PNC bank branch under the DOE CBP resulted in a robust data set and provided valuable understanding of end-use energy consumption loads. The energy consumption from lighting, plug load and other non-HVAC loads was much more than that anticipated in the early stages. The monitoring results pointed the way to the most important loads to manage, including plug loads and lighting, to meet the 50% energy saving goal for the new net-zero design. The savings predicted for this new design stand at 57% in comparison to 90.1-2004.

The importance of addressing plug load to achieve energy efficient buildings has been recently recognized (Kaneda et al, 2010). Researchers have been conducted based on building audit or metering (Sanchez et al, 2008, Moorefield et al, 2008) in order to understand the plug load use in offices.

Another significant finding was that the RTU was oversized in monitored bank branch. Recognizing the savings possible from right-sized equipment, PNC will be resizing HVAC equipment in future installations and replacements to reduce both capital costs and energy consumption.

The revised design package focused on reducing the plug load through intelligent controls, increasing the efficiency of decorative lighting and signage, and interior and parking lot lighting, using efficient LED fixtures. PNC worked with their vendors to aggressively attack lighting loads by getting a new specially designed LED monument sign fixture, and to lower the computer base load through software-based turn-off.

This study demonstrates the importance of building metering. In this case, the new design will be replicated throughout the PNC portfolio of buildings, and the lessons learned will help PNC operate their buildings more efficiently. In order to properly model and design energy efficient buildings, a deep understanding of the building energy end-uses and energy consumption patterns is needed. The way to achieve such a deep understanding is through metering and metered data analysis, especially for companies using prototype designs.

Acknowledgements

The authors would like to acknowledge James Kroner and Larry Miltenberger of PNC for their commitment to design and build a new-zero bank branch and for their strong leadership to guide and challenge the design team during the process. Jason Ziolkowski from PNC took ownership of designing the solution to shut-off computers without impacting bank operation. We would also like express our appreciation to the leaders of the design team, including Benjamin Callam from Gensler, Alan Traugott from CJL Engineering, and Naomi Miller from the Pacific Northwest National Laboratory. We also recognize the U.S. DOE for it financial and management support of the Commercial Building Partnerships.

References

ANSI/ASHRAE/IESNA. 2004. *ANSI/ASHRAE/IESNA Standard 90.1-2004, Energy Standard for Buildings Except Low-Rise Residential Buildings.* American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, Georgia.

DOE. 2011. *EnergyPlus Energy Simulation Software.* Retrieved July, 2011, from http://apps1.eere.energy.gov/buildings/energyplus/

David Kaneda, Brad Jacobson and Peter Rumsey, *Plug Load Reduction: The Next Big Hurdle for Net Zero Energy Building Design,* 2010 ACEEE Summer Study on Energy Efficiency in Buildings

Marla Sanchez, Carrie Webber, Richard Brown, John Busch, Margaret Pinchard and Judy Roberson, *Space Heaters, Computers, Cell Phone Chargers: How Plugged In Are Commercial Buildings?* 2006 ACEEE Summer Study on Energy Efficiency in Buildings.

Laura Moorefield, Brooke Frazer and Paul Bendt, *Office Plug Load Monitoring Report*, Ecos Report, December 2008.