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Field Measurement, Model Development, and Building Component Library Population of Retail Plug Loads

Emily Rose Rader
University of Colorado at Boulder, emilyraderneely@gmail.com

FIELD MEASUREMENT, MODEL DEVELOPMENT, AND BUILDING COMPONENT LIBRARY POPULATION OF RETAIL PLUG LOADS

by

Emily R. Rader

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____
Prof. Gregor Henze, PhD, P.E.

____
Larry Brackney, PhD

____
Prof. Michael Brandemuehl, PhD, P.E.

Date____________

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Rader, Emily R. (M.S., Civil, Environmental and Architectural Engineering)

Field measurement, model development, and Building Component Library population of retail plug loads

Thesis directed by Prof. Gregor Henze, PhD, P.E.

Miscellaneous electric loads (MELs) comprise a growing percentage of commercial building energy use, expected to increase from 31% to 43% of total commercial building primary energy use by 2030. In building energy simulations, these loads are often poorly modeled or are outright neglected. A big box retail building with grocery was found to contain over 700 MELs. Through this study, 256 of those devices were metered, and the measured time-series data informed the creation of 260 EnergyPlus model snippets. Those model snippets were made publicly available through the newly developed Building Component Library (BCL). The use of these BCL components was worked into a modeler workflow, resulting in accuracy equal to the best of the commonly used plug load modeling strategies for an example building. The precision and detail of the BCL components exceeded the other methods.

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Contents

Tables

Figures

CHAPTER I

INTRODUCTION

Buildings are a vital part of society. They are also a large draw on our natural resources. The commercial building sector in the United States is responsible for 18.4% of total national energy use *(Energy Information Administration, 2011).* That energy use is divided between that necessary to maintain building comfort – heating, ventilation, and air-conditioning (HVAC) – and the loads incurred by the activities of the occupants – lighting and equipment. When building energy efficiency became a focus of study in the 1970s, concentration was primarily on the "traditional" end-uses of a building – HVAC, space lighting, and domestic water heating. All other building energy consumption was relegated to "other" or "miscellaneous" because of its relatively lower energy use and lack of relation to the building shell. As the use of consumer electronics has increased and the traditional end-uses have become more efficient, the percentage of energy use consumed by the "miscellaneous" category has significantly increased *(Nordman & Marla, 2006).* This study sought to delve into the energy use of "miscellaneous" loads, focusing on plug loads and how they are represented in building energy simulation.

1.1 Motivation

Miscellaneous electrical loads (MELs) make up 30% of the energy use consumed by the commercial building sector. That percentage varies by building type from 10% in non-food retail to 60% in the area of food sales *(McKenney, Guernsey, Ponoum, & Rosenfeld, 2010).* With efficiency improvements in building envelopes and HVAC equipment and a marked increase in the number and types of miscellaneous loads, MELs account for a larger percentage of both commercial and residential energy use. In fact, MELs are the fastest growing building end-use and the Energy Information Agency's 2011 Annual Energy Outlook predicts that their energy use will grow by 1.4% per year. *(2011).*

For such a large building end-use, surprisingly little is known about what composes this important category. In a survey of experts in commercial building energy analysis, end-use data about plug loads was considered to be one of the most useful pieces of building data *(Lehrer & Vasudev, 2010).* This shows a lack of knowledge about miscellaneous loads, even in buildings that are intended to be operated for peak performance. Roberson et al. have observed that building energy managers usually fail to account for this significant and growing load *(Roberson, Webber, McWhinney, Brown, Pinckard, & Busch, 2004).* Awareness of what plug loads will be included in a designed building or are present in an existing building allows for energy efficiency strategies to include those devices.

In a report to the Department of Energy (DOE) concerning the energy consumption and characterization of MELs, TIAX LLC recommended that DOE conduct power measurements for a sample of MELs in key building types and additional surveys and measurements to further understand the energy usage of this building end-use *(McKenney, Guernsey, Ponoum, & Rosenfeld, 2010).* This recommendation was based on a lack of available data about the power and usage schedules for a number of prevalent devices. While developing the Commercial Reference Building Models, researchers at a number of DOE National Laboratories also lamented the lack of measured data regarding plug and process load intensity. They were therefore obliged to use engineering judgment as their data source for these values in six of the fourteen building types *(Deru, et al., 2011).* While some studies have addressed data collection of plug loads, few sources of plug load data are available *(Frank, Gentile Polese, Rader, Sheppy, & Smith, 2011).*

In the fifty years since their development, building energy simulation programs have steadily grown in use. More recently, the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) program has rapidly increased the number of building simulations through their minimum energy performance requirement. The most straightforward way to demonstrate this compliance (as well as gain additional energy optimization credits) is to compare an energy simulation of the proposed building to a baseline building. Due to the popularity of LEED, more and more buildings are being modeled – both for projecting actual energy use and for comparison amongst design alternatives *(Turner & Frankel, 2008).*

While a number of well-known building energy simulation specialists caution against using models to predict actual future energy use, building simulation's entry into the vernacular has led to this becoming a widely practiced function of building simulation tools. But energy modeling is limited, especially with regard to operational factors such as plug loads. Unknowns and assumptions in model inputs lead to discrepancies between predicted and actual energy consumption.

The work presented in this thesis intends to demonstrate that plug loads in commercial buildings could be metered to provide standardized energy models. These models will be available to the building simulation community in the hopes of improving the quality of energy models with respect to how plug loads are modeled.

1.2 Questions to be Answered

(1) Can metering of plug loads in a commercial retail setting lead to representative models for those devices?

(2) Can those representative component models be incorporated into a whole building simulation workflow?

(3) If those representative component models are used, is the quality of the simulation improved?

1.3 Thesis Organization

The following thesis presents a process for metering individual plug loads in a retail environment and using the collected data to inform standardized building energy simulation components through a publicly available component library.

First, a review of relevant literature pertaining to building energy modeling and plug load modeling is presented. Literature concerning building energy modeling includes common procedures for building simulations and how well such models compare to actual building energy use. The section specific to plug loads describes what references and sources are used to establish an input value for miscellaneous electric use.

Next, the methodology of this research project is presented. This includes the steps taken to select an appropriate location for the study, requirements for the instrumentation, and the proposed metering plan. The chosen format for the building energy model components, the procedure for populating the building component library, and the method for confirming the veracity of a component library approach to building energy modeling are also discussed.

Chapter 4 discusses in detail the metering effort that took place. It describes the building selected for the study and the inventory that transpired there. It also discusses the process of meter selection, the metering process, and resulting difficulties. The postprocessing of the data includes temperature and occupancy correlations.

The steps necessary to convert collected data into standardized building energy model components are presented in Chapter 5. These discussions provide insight into working with the new modeling platform OpenStudio and the general characteristics of plug loads found in a commercial retail environment.

Chapter 6 provides details about the building simulation component library where the model components are available. Each component has associated metadata and the relevant taxonomy is described in this chapter.

Chapter 7 presents the results of incorporating the component models into a reference building. Comparisons against the reference miscellaneous loads and five years of submetered data are included in this discussion.

Finally, conclusions and recommendations about the metering and component model creation process, and their applicability to whole building energy modeling are presented. Opportunities for future work in the field of modeling miscellaneous loads are also introduced.

CHAPTER II

LITERATURE REVIEW

The following literature review was conducted to support the efforts of this Masters thesis research. The review was primarily concentrated on two topics: (1) how simulated building energy consumption compares to actual energy use in the modeled building and the leading causes of discrepancies, and (2) throughout the industry, what methodologies are used to simulate the plug load portion of building energy use.

2.1 Modeled vs. Actual Building Energy Consumption

ASHRAE Standard 90.1-2004 Appendix G has become the benchmark for simulating building energy consumption. Building modeling is a field with few regulatory standards. The adoption of Appendix G by LEED as a procedure for quantifying energy savings has made it a key reference for building energy simulation.

Appendix G clearly states that its purpose is in rating the efficiency of building designs, not to estimate actual building energy use. “Neither the *proposed building performance* nor the *baseline building performance* are predictions of actual energy consumption.” *(ASHRAE, 2010)*

However, despite this explicit warning and caveats by many professionals in the energy modeling industry, modeling is widely used to predict actual energy performance *(Turner and Frankel 2008; Hong, Chou and Bong 2000)*. These predictions lead to decisions by utilities about electricity demand and building owners about the life-cycle cost of alternate design measures. Additionally, the public often takes these estimates at face value and develops expectations toward a stated energy use for a building.

This common practice of requiring energy models for building certification while there is no expectation of absolute energy performance predictions is a mixed message. The general consensus is that on a project-specific basis, the discrepancy between anticipated and measured energy consumption may be quite high *(Demanuele, Tweddell and Davies 2010; Turner and Frankel 2008; Westphal and Lamberts 2005; Macdonald 2002; Norford, et al. 1994)*. The accuracy of these energy predictions on an individual project level is very inconsistent, as shown in a study of LEED certified buildings by *(Turner and Frankel 2008)*. One exception to this general finding is the Research Support Facility (RSF) on NREL's main campus. A key distinction of this project is the priority placed on accurately accounting for plug loads during the modeling and design stage *(Pless, Torcellini, & Shelton, 2011)*.

While the Turner and Frankel study was an analysis of 121 buildings, the remainder of the papers tend to be case studies of one (or a few) building(s) which document discrepancies between simulated and actual performance *(Demanuele, Tweddell and Davies 2010; Torcellini, et al. 2006; Norford, et al. 1994)*. They show that in addition to uncertainty in the designed building, there are also uncertainties in the baseline energy models. While project-specific energy predictions are often unreliable, the Turner and Frankel study showed that program-wide predictions faired much better. Averaged across all the building models, simulation accuracy is quite high. Although there is a large amount of spread in the energy use intensity (EUI) of the simulations analyzed, the ratio of measured to predicted EUI for the entire sample is 92%. This indicates that building energy simulations may be more appropriate for community-scale analysis.

How far off are energy simulations from actual building energy use? In the Turner and Frankel study, the measured EUIs for more than half of the projects differ by at least 25% from their predicted values. Other studies have suggested that errors could be as high as 61% or deviate by 25% on average *(Macdonald, 2002)*.

The following is a list of the most commonly cited variables found to be mishandled in the energy modeling process:

- Infiltration rate
- Plug load values
- Plug load schedules
- Wall constructions built to design specifications (e.g., U-values)
- HVAC set points/schedules

Both erroneous assumptions and differences in the actual versus modeled operation of the building can lead to these errors.

One of the above listed most commonly mishandled variables is plug and process loads *(Demanuele, Tweddell and Davies 2010; Turner and Frankel 2008; Macdonald 2002; Norford, et al. 1994)*. In their investigation of six high-performance buildings, Torcellini et al. found that all six buildings used more energy than predicted in their design simulations. One of the top documented reasons was that the energy used by plug loads was often greater than predicted for those models *(2006)*. Observations by Norford et al. *(1994)* showed that unanticipated occupant energy use (lighting and plug loads), resulting from differences in both the magnitude and schedule of those loads, was responsible for 64% of the doubling in energy usage between the simulated and actual building.

In cases of retrofit analysis, the energy modeler is attempting to accurately calibrate the model to utility data documenting the building's performance. Discrepancies in inputs such as plug loads can lead to a model, which is closely calibrated by month but shows a completely distorted end-use breakdown *(Westphal & Lamberts, 2005)*. An analysis based on such a model could lead to inadequate recommendations on retrofit designs.

Inconsistency amongst building simulation professionals regarding how to model plug loads can result in erroneous energy use predictions. A review of 270 projects showed not only a wide range of identified plug loads (as a percentage of total energy use), but also that more than half of those simulations did not include any plug or miscellaneous loads at all *(Turner & Frankel, 2008)*.

2.2 How Miscellaneous Loads are Modeled

Due to the substantial growth of the LEED certification program since its inception in 1998, the community of modelers referencing ASHRAE Standard 90.1 Appendix G has grown larger than ever before. The standard states:

> Receptacle and process loads, such as those of office and other equipment, shall be estimated based on the building type or space type category and shall be assumed to be identical in the *proposed* and *baseline building designs*, except as specifically authorized by the *rating authority*. These loads shall be included in simulations of the building and shall be included when calculating the *baseline building performance* and *proposed building performance (ASHRAE, 2010).*

This procedure makes it difficult to demonstrate how energy might be saved through careful selection of miscellaneous equipment and modifications in occupant behavior. If they do not believe their planned energy reduction strategies can be well demonstrated, that ambiguity may deter building energy professionals from including stringent plug load goals in their designs.

The procedure also requires that the user include plug and process loads, but makes no stipulations about what they should be. Such a guideline leaves room for a large amount of variability in the percentage of overall building energy consumption that this load could represent. One could manipulate the percentage of total building energy comprised by plug loads to artificially inflate the percentage of energy saved by a design case. Perhaps with this reasoning in mind, the 2009 version of LEED stipulates that plug and process loads should be included at a default value of 25% of total baseline energy use *(USGBC 2011).* While this load is now eligible to be included in proposed energy savings for LEED, little guidance exists for how to document such savings for LEED credit. The community could benefit from explicit representation of the devices selected for a building. Such modeling of each plug load would allow for easy documentation of energy savings resulting from careful equipment selection.

In 2008, researchers at the National Renewable Energy Laboratory (NREL) published a methodology for building energy modeling. In that methodology, they distilled a table of plug and process energy intensities by building type from the *California Commercial End-Use Survey (Griffith, Long, Torcellini, Judkoff, Crawley, & Ryan, 2008).*

Multiple DOE laboratories collaborated on a project to develop standard reference buildings for sixteen major commercial building types. These reference building energy models represent two-thirds of the commercial building stock and serve as prototypical buildings for energy efficiency research *(Deru, et al., 2011).*

Data from several sources was combined in order to represent typical building performance in each of the building types. Work from Huang et al. and the Advanced Energy Design Guides was leveraged to present characteristic plug load intensities for various zones based on activity type *(Huang, et al. 1991; ASHRAE 2009).* The internal loads shown in Appendix A of that document can then be thought of as representative energy intensities for hundreds of unique building zone types.

An increasingly popular area of study is how occupancy affects plug load energy consumption. Researchers have built models that couple simulated occupant behavior to variations in equipment load – amongst other variables *(Parys, Saelens and Hens 2011; Clevenger and Haymaker 2006).*

Many other researchers have created statistical occupancy models that could be applied to simulate more realistic miscellaneous energy use. Wang et al. investigated occupant behavior in single person offices, resulting in a probabilistic model *(Wang, Federspiel, & Rubinstein, 2005).* In his dissertation, Jessen Page developed an algorithm that can predict variations in occupancy on both a diurnal and annual basis using a Markov chain approach *(2007).* Page expanded on his algorithm in a 2008 paper, which ultimately applied the model to occupant-dependent inputs, demonstrating an impact on building energy consumption *(2008).* Hoes et al. combined previous research in user presence and user interactions to create a dynamic simulation of building energy *(2009).* Experimental data and statistical methods were used in a Tabak and de Vries study to create a model for predicting the intermediate activities, which interrupt typical behavior in an office *(2010).* Any of these occupancy models could be coupled to miscellaneous energy use scheduling for an occupancy-driven method of modeling plug load energy consumption.

2.3 Conclusions

A wide range of literature exists regarding building energy simulation and the assumed plug loads values used in such simulations. Literature pertaining to energy predictions for actual building energy use generally indicated that there was room for improvement. Poor assumptions regarding miscellaneous electric use was one of the most commonly cited sources of error. The LEED certification process has avoided this question by prescribing a default value of 25% of total building energy use to the miscellaneous equipment model input value. Two DOE reports provide tables of plug and process load energy intensities by zone activity type. Other researchers are presenting statistical occupancy models that have applications in miscellaneous loads.

This thesis will expand on the topic of plug load energy intensities in building energy simulation. This research will take a metering approach to quantifying energy use for individual plug loads and presenting the collected data as model components. The focus will be on retail environments, a building type that is lacking in suitable miscellaneous load research. Model component standardization and citability through a model component library will be introduced in this thesis.

Two commercial reference buildings have been adopted for use in this Masters thesis research. In particular, the stand-alone retail and supermarket buildings were combined by floor area to represent a big box retail with grocery. This will act as the building model for a trial application of building component models. This thesis will lay the groundwork for applying metered plug load data to statistical occupancy models for an occupancy-dependent representation of miscellaneous energy use.

CHAPTER III

METHODOLOGY

The goals of this study were to collect typical plug load data under real use conditions and improve the realism and accuracy of building energy simulations through the inclusion of standardized plug loads in a library of building modeling components. To that end, the following methodology has been adopted.

(1) Characterization of MELs

(1a) Selection of Representative Building

This research focuses on the miscellaneous loads in a building. Therefore, the building shell and HVAC equipment are not of concern when choosing a representative building. The main concern is that the chosen building has a sufficiently wide distribution of space types and therefore a statistically sound representation of plug loads.

A 2008 report indicated that 75% of all miscellaneous loads are consumed in buildings larger than 50,000 ft^2, so a large building was preferred for this study *(McKenney, Guernsey, Ponoum, & Rosenfeld,* *2010).* Plug loads in retail environments are among the least studied miscellaneous loads and thus the chosen setting for this project.

(1b) Measurement Plan

As many types of plug loads as possible needed to be metered under actual operating conditions. Priority was given to the most prevalent devices since they compose the largest percentage of miscellaneous electric use and are likely to appear in most other big box retail environments. When multiple devices of the same model existed in the store, a "more frequently used", "average use", and "less frequently used" case were metered to record dependence on user habits. It was assumed that some miscellaneous loads would be immeasurable due to meter capabilities, store regulations, or inaccessibility.

(1c) Instrumentation

In order to properly characterize the behavior of plug loads, multiple variables must be metered. Five variables were deemed essential to a proper metering effort: power, voltage, current, energy consumption, and power factor. The meter must therefore have either 1) sufficient internal memory to store data for an extended period of time, or 2) incorporate Ethernet, wireless Ethernet, Zigbee, or another method for transmitting data to a local or remote repository. An automatic time stamp and an internal clock were desired features, because of the importance of time series information in this study.

This project could not interfere with the business of the study location. Therefore, the meters needed to be small and minimally invasive. They had to be listed by Underwriters Laboratories (UL) to reduce potential safety risks associated with monitoring electrical loads. Also, they had to be tested to ensure they would not trip ground fault circuit interrupters or switch off circuit power via internal relays, resulting in lost power to refrigerators or data losses from computers improperly shut down.

(1d) Data Acquisition Period

The ideal metering period for a plug load study is a year, so that annual as well as diurnal and day-of-week dependencies may be recorded. Four weeks is a sufficient metering period to elucidate any day-of-week dependencies and establish the time-of-day patterns. The time period also allows the researcher to see any propensity for annual trends; plug loads that show such potential can then be monitored for an extended period of time. Four-week samples also allow for a moderate number of meters to be rotated amongst the hundreds of plug loads in a commercial retail building.

(1e) Data Postprocessing and Analysis

A number of data processing techniques were used to refine the collected data for use in characterizing and modeling the plug load behavior. Missing and corrupt data had to be identified and flagged.

Operating states had to be identified as well as transitions between operating states.

Plug loads with refrigeration elements are thought to have a dependence on zone temperatures. Equipment that is user-operated (as opposed to displays that are tied to store operating hours) is thought to have a dependence on zone occupancy. Correlations to zone temperature and occupancy were calculated for these devices.

(2) Building Energy Model Component Creation

A repository of power use data for plug loads provides a good opportunity to inform other areas of research such as building energy simulation. The data collected in the metering portion of this research was processed for the creation of standardized component models.

Ultimately, the goal of this project is to share these model snippets with the building simulation community. NREL's Building Component Library (BCL) provides an ideal environment for this pursuit *(Long, Fleming, & Brackney, 2011)*. An OpenStudio model (.osm format) is one of the available formats for model input in this publicly available library. Additionally, OpenStudio's ability to store metadata with a component makes it the ideal system for the energy modeling of specific products.

In OpenStudio (as well as most other building simulation programs), a complete record of the energy use profile of a plug load is composed of both information about the equipment itself (name, design power level, etc.) and the corresponding use schedule. A component model is comprised of both these objects. Different components were created for different use cases of the same device when applicable (e.g. a television on display vs. a television used in a nail salon).

(3) Building Component Library Population

Each of the component models had to be loaded into the BCL. An appropriate tag from the selected taxonomy was assigned to the component. Additionally, attributes pertaining to all aspects of the plug load were assigned to the component so that the it would be easily searchable. Manufacturer, model, and type of use are examples of important attributes. Complete component models and all corresponding metadata could be uploaded to the BCL via a web interface.

(4) Sample Application of Models to Reference Building

In order to show that the library of plug load components could be incorporated into the workflow of an energy modeler and that the resulting model would have improved accuracy as well as detail, the components were applied to a DOE Commercial Reference Building.

A Ruby script was used to create a mock user interface to insert user-selected components into a building zone. The entire inventory of plug loads was added to the supermarket reference building. The resulting miscellaneous electric use was then compared to the sample W/ft^2

assumptions applied to each of the zones in the original model. These two methods were compared to five years worth of submetering data for the store.

CHAPTER IV

METERING AND CHARACTERIZATION OF PLUG LOADS

A multi-laboratory effort to meter commercial miscellaneous loads began in February of 2010. Four DOE laboratories – National Renewable Energy Laboratory (NREL), Lawrence Berkeley National Laboratory (LBNL), Pacific Northwest National Laboratory (PNNL), and Oak Ridge National Laboratory (ORNL) – collaborated on a proof-of-concept demonstration of the methodology and technology necessary to measure the power and energy use characteristics of a large sample of plug loads in a variety of commercial building types. This process involved distributing nine space types – office, non-food retail, food sales, food service, education, warehouse, health care, public assembly, and lodging – amongst the four laboratories. Each laboratory was then responsible for selecting a representative building or buildings, inventorying all of the miscellaneous loads in the space, selecting an appropriate meter, and monitoring the energy characteristics of plug loads according to the devised methodology *(Frank, et al., 2011).* The energy consumption information from the NREL portion of this project was ultimately able to inform a report and pamphlet for retail owners and operators on reducing plug loads *(National Renewable Energy Laboratory, 2011).*

4.1 Representative Building and Plug Load Inventory

NREL opted to focus on miscellaneous loads in five building types – office, non-food retail, food sales, food service, and health care. All the selected space types are available in a single big box retail and grocery store. Such a store contains a full grocery – including a bakery, deli, and produce section – as well as a pharmacy, vision center, bank, hair salon, photo center, and fast food restaurant.

NREL had a relationship with a few commercial partners and chose to continue working with a store they had been submetering for five years. That store is located in the Denver, Colorado area and was built in 2004. It has a total floor area of 218,400ft^2, 171,400ft^2 of which is sales floor.

This store met all of the criteria for a representative building established in the methodology in this report. It is a large retail building with a wide variety of space types, and thus a large distribution of plug loads. It includes both food and non-food retail – the two building types with the highest and lowest energy use intensity due to loads in the commercial stock *(McKenney, Guernsey, Ponoum, & Rosenfeld, 2010)* – so it should enable a study of plug loads in both typical retail environments.

Before beginning the inventory, an LBNL taxonomy *(Nordman & Marla, 2006)* was adapted to the specific needs of a big box retail outlet. The inventory included an initial effort to record the bulk of miscellaneous devices in the store as well as a follow-up effort to revise that inventory because of new or previously unrecorded devices. Due to security or privacy concerns, no inventorying or metering could be conducted in the bank, the pharmacy, or the security monitoring room. The following information was recorded (when available) for each device: manufacturer, model, production year, serial number, nominal voltage, rated current, rated power, electrical plug type, load type, external power supply specifications (if available), and ENERGY STAR rating (if applicable). Additionally, the location and quantity of a given device in a particular space type were recorded.

A retail-specific obstacle was encountered in this inventory effort. Consumer electronics – televisions, radios, and laptop computers – have a very high turnover rate. Therefore, it was prudent to catalog the number of such devices present at any given time and concern oneself with the specific models only when metering.

The completed inventory revealed that only one device of a particular model was present in the store for 80% of the inventoried models. These unique devices made up 44% of the total quantity of devices in the store. This statistic confirms the miscellaneous nature of the non-traditional end-use load, verifying why this load can be so difficult for building owners and modelers to estimate.

4.2 Meter Selection

An exhaustive search of commercially available electric load meters was performed in order to identify the best meter for the needs of the project. A plug-through meter was chosen because it is the simplest to use. The selected meter is designed to work with 120-Volt, 60-Hz, and 15-amp circuits. It is capable of recording any of the following variables: instantaneous power, minimum power, maximum power, power factor, volt amp (apparent power), cumulative energy, average monthly energy, elapsed time, duty cycle, frequency, cumulative energy cost, average monthly energy cost, instantaneous line voltage, minimum voltage, maximum voltage, instantaneous current, minimum current, and maximum current.

It met the requirement of being UL listed, with listings to both standard UL 610010-1 and CAN CAS/C22.2 61010-1. The meter had a typical NEMA 5-15P female outlet.

While remote data storage would have been ideal – alleviating the need for physical trips to the location to manually retrieve data – the store Wi-Fi network was restricted to corporate use and remote storage was not an option. The selected meter is one of the few commercially available meters that offers data storage. Most others either provide only instantaneous display or require real-time data collection via a computer. In a commercial retail environment, a computer acting as a local repository would have been at risk of theft or accidental damage, so on-board data storage became a requirement. The selected meter has internal data storage of up to 120,000 records. The sample rate can be set at intervals of one second to 24 hours.

Unfortunately, the selected meter did not have an internal clock. This caused problems both for accurately time stamping the data and with plug loads that are frequently unplugged during their normal course of daily use. More information about these difficulties is provided in section 4.3.

Accuracy is of course vital to a metering project such as this. The meters have an accuracy of ± 1.5% of the displayed value. According to the user's manual: For loads of less than 60 W, the current and power factor measurements decrease in accuracy. Wattage and other variables will still be within 1.5%. This is a known problem of plug load meters. The final NREL report can be read for more information on the accuracy of the selected meter *(Frank, et al., 2011).*

Data could be retrieved from the meter via a USB cable. The USB interface allows for tabular and graphical viewing of recorded data as well as the ability to set the time stamp for the first record. The data could then be stored as a CSV text file.

4.3 Metering Process and Difficulties

More than 700 individual devices were catalogued in this one store. Those devices represent 308 different models of plug loads. An effort was made to meter as many of these devices as possible within the time and budget constraints of the project.

Fifty meters were deployed throughout the store. Each meter was configured to record power, voltage, current, energy consumption, and power factor at a 30-second sample rate. Thirty seconds was considered to be a good balance between fine enough granularity to elucidate rapid transient load behaviors in devices such as microwaves and conveyor belts and a large enough sample size to allow the meter to run for at least a week before reaching its data storage capacity. The meters were configured to stop recording when the internal memory was full, rather than write over earlier data.

Due to the active retail environment in which this study was conducted, all of the meters had to be out of sight and off the floor to prevent tripping hazards.

During meter installation, each device had to be unplugged, then plugged back in through the meter. A basic diagram of this setup can be seen in Figure **1**. The complete process for metering a plug load for one week is as follows:

(1) If damage could occur to the device from being unplugged in an active state (e.g. cash registers, computers), have an employee properly turn off the device.

(2) Unplug the device. Plug the meter into the wall socket. Plug the device into the meter. (If the device has a twist lock or other non NEMA 15-5P male plug, it must be plugged into an adapter before being plugged into the meter).

(3) Clear the memory on the meter.

(4) Manually record the start time.

(5) Leave the meter to log data for one week.

(6) Retrieve the data with a laptop via a USB cable, using the "USB program" to complete this transfer.

(7) Input the start time into the program to update all of the time stamps associated with the data.

(8) Save a text file of the data.

(9) Clear the memory to begin logging again.

Each device was metered for a total of four weeks, then the meter was rotated to another plug load in the store that had yet to be metered.

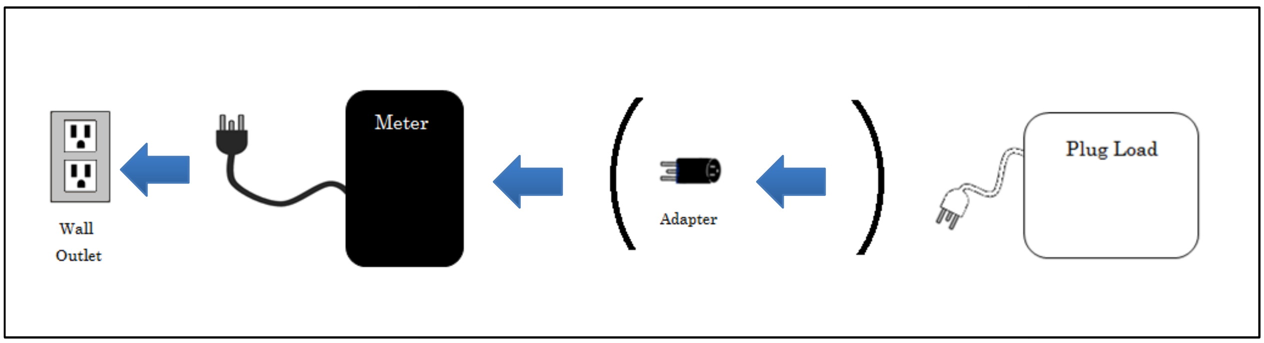


Figure 1: Setup of a plug-through meter with possible plug adapter.

The first look at the data for plug loads with refrigeration elements seemed to indicate that the energy use profile might be dependent on the zone temperature. Five temperature sensors were acquired and beverage refrigerators and refrigerated vending machines were remetered with simultaneous temperature measurements. The temperature sensors were discrete USB stick sensors that could be taped to a fixed object near the plug load. The sensors had automatic time stamping. The data was collected from these sensors once a week during the data collection from the electric meters.

A number of obstacles were present during the metering phase of this project. The first such problem was the inability to meter certain devices. Some plugs were physically inaccessible – behind immovable objects, inside locked cabinets, or at great heights. The bank branch prohibited metering of any of their equipment (including the ATM) because of privacy concerns. The Health Insurance Portability and Accountability Act Privacy Rule prevented the metering of any plug loads within the pharmacy. Some plugs that were accessible did not conform to the typical 120-V standard NEMA 5-15P plug. Devices such as cash registers use twist locks and required a NEMA L5-15R adapter. Those devices which operated at 240 V or 480 V could not be metered because of the limitations of the meters.

The wire management policy in the hair salon prevented the metering of any station tools. A meter could not stay with each tool and the employees could not be expected to always plug the same tool into the same outlet for the duration of the study. Therefore, only the fixed devices (e.g. hooded hair dryers) were metered. Devices such as electric wheelchairs and floor cleaners are mobile devices. For perspective, a full 10% of the devices inventoried are regularly moved and unplugged. An additional two dozen plug loads may be moved occasionally during daily business (e.g., fans in the bakery, blow dryer in the paint center). The regular unplugging of these items posed two problems: 1) how to meter devices that do not remain plugged in for the duration of the study, and 2) how to meter devices that may be moved and plugged in to multiple outlets. To meter these mobile devices, the meter had to stay with the device with its cord acting as the plug for the device.

Once data was collected from the plug loads, additional quality issues were discovered with the metered data. The meters showed a number of failure modes – applying incorrect calibration constants, recording constant power when power was not constant, and recording very noisy time series. Some meters demonstrated inconsistent internal timing, so that the reported total collection period did not match the actual time period. In some cases, a seven-day period of data yielded as many as nine days worth of time stamps or as few as four. Twenty-one meters (41% of those used) were responsible for these errors, suggesting a problem with the meter model rather than with individual meters. In addition to hardware deficiencies, the data collection process – particularly the manual assignment of time stamps – allowed the opportunity for human error. Incorrect assignment of initial time stamps resulted in shifted or overlapping data series.

The combination of hardware error and human error resulted in 20% of the data series having questionable time series. Ultimately, 31% of the plug loads metered had some portion of their data that was considered inaccurate during the four-week metering period. An attempt was made to remeter each of these plug loads until four complete weeks worth of data existed for each device. Unfortunately, the nature of some devices (e.g. paper shredders) consistently thwarted the meter calibration, causing them to be unmeterable with the given metering equipment.

The deficiencies with the meters are detailed in Frank, et al. *(2011).* The necessity for a UL listed meter in a functioning retail environment limited the meter options to commercially available choices. Those options were searched exhaustively for the most appropriate meter for the project. Each device was metered until four weeks of quality data existed for that device. Data from the few devices that resisted quality metering was removed from the remainder of the study.

Two hundred and fifty-six plug loads were successfully metered in part or in total during the metering phase of this project. That number represents 165 unique device models, nearly half of all unique plug loads inventoried. Most have four consecutive weeks of associated data, although complications during metering caused some to have discontinuous data. Twenty devices were metered for an extended period of time – five to nine months – in order to deduce any annual trends that may exist. Those 20 devices included duplicates of the same device with different use patterns (e.g., cash registers) and other plug loads that were predicted to have increased use (and thus energy use) due to increased store occupancy during the holidays.

As indicated in section 4.2, the accuracy of the current and power factor measurements was known to degrade below 60 W. Meter testing verified these inaccuracies at low power levels *(Frank, et al., 2011).* This unreliability posed a significant problem because 61% of the plug loads studied have at least one operating mode below 60 W and 40% operate entirely below 60 W. The power, voltage, and energy consumption maintained their stated accuracy at these low levels, so all analysis revolved around these variables. No techniques using current or power factor could be used in this study.

4.4 Postprocessing of Data – Temperature Correlations

Localized temperature data was collected concurrently with electrical variables for eleven devices. None of the studied devices was located outdoors, so they were not subjected to extreme weather conditions. The plug loads that experienced the greatest temperature swings were the soda vending machines located in a partially conditioned entrance vestibule. The temperature sensors were attached to the side of each vending machine. The heat produced by the refrigeration cycles caused the air between the devices to reach temperatures as high as 44.2 ℃ (111.6 °F). These devices were also subjected to the lowest temperatures of 7.8 ℃ (46°F) due to their location a few feet from an exterior door. The three devices in the vestibule were subjected to a temperature swing of 36.4 K (65°F) throughout the duration of the study. In comparison, the largest temperature swing experienced by devices within the building was 18.7 K (19.5°F).

The goal of this analysis was to provide a mathematical relationship between the energy consumption of refrigerated plug loads and the zone temperature in which they operate. To this end, the timestamps of the collected temperature and power data were aligned. Power vs. zone temperature was plotted in order to establish a relationship. Both instantaneous (30-second) data and the variables averaged over an hour were considered. The curve-fitting tool within MATLAB was used. All curves were considered until the highest R^2 (coefficient of determination) was achieved, denoting the best possible fit.

Contrary to expectations, the collected data did not follow any curve closely. Figure **2** shows a typical example of this comparison. The linear fit does show an upward trend with increased zone temperature, but the R^2 is only 0.0995, which implies that about 90% of data variance in electrical consumption is unaccounted for by using temperature alone. The large amount of variance among the data indicates that a statistical model involving temperature only would be a poor predictor of future outcomes. In the case of an energy model, it would be a poor representation of actual device behavior. None of the refrigerated devices studied had a correlation stronger than $R^2=0.4$. Given the large temperature range over which these plug loads were studied, and how small a temperature swing building zones typically encounter, there is no statistical evidence to support a relationship between temperature and power consumption of these devices within the temperature range found in typical building spaces.

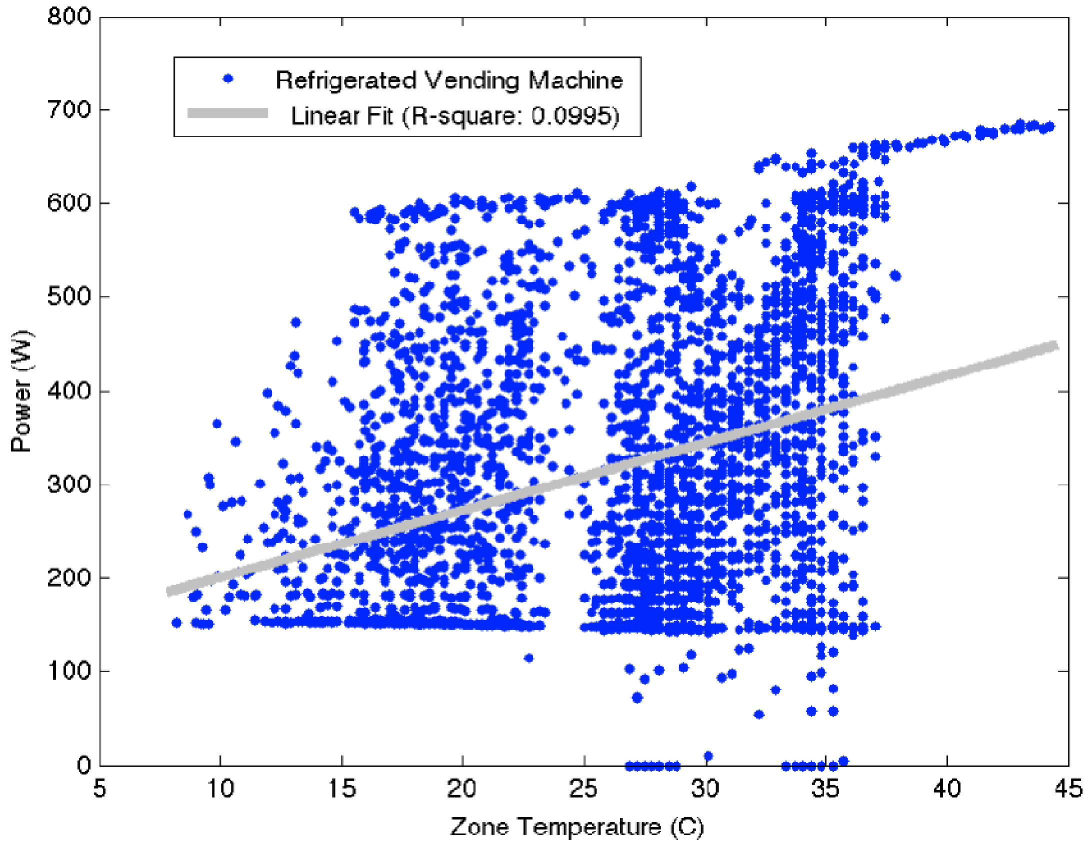


Figure 2: Relationship between hourly average power level and hourly average zone temperature for a refrigerated vending machine. A visual inspection confirms the low R-square value. The data is not described by any curve within the MATLAB curve fitting suite for the available input data.

CHAPTER V

BUILDING ENERGY MODEL

COMPONENT CREATION

The large amount of plug load data that was collected provided an opportunity to inform the building simulation field. The recorded data was leveraged to create representative energy model components. The following sections detail the modeling format used and the creation of 260 plug load model components.

5.1 Overview of OpenStudio

A long list of building energy software tools are available for both whole building and specialized analyses, many of them as freeware *(Department of Energy, 2011)*. EnergyPlus is one of the most powerful and feature-rich energy modeling programs. However, one of the main complaints about EnergyPlus amongst the modeling community was that there was very little user interface.

Input and output files are in text format, which can be hard to manage without a graphical user interface (GUI). With that need in mind, developers at NREL created OpenStudio *(2011)*.

OpenStudio is an open source collection of software tools for EnergyPlus to support both whole building energy modeling and daylighting analysis. The original application was a plug-in for Google Sketchup that allowed EnergyPlus geometry to be created and viewed in a 3D environment. The package now also includes ModelEditor, SystemOutliner, RunManager, and ResultsViewer. ModelEditor is a GUI that allows the modeler to browse objects within the model, SystemOutliner enables modelers to graphically create and edit mechanical system loops, RunManager helps the user manage multiple simulations, and ResultsViewer allows modelers to browse and plot time series output data.

The extension for EnergyPlus input files is .idf – Input Data File (IDF). OpenStudio files contain all of the information of an IDF with additional information for the OpenStudio environment. The extension used for OpenStudio files is .osm. All of the applications in the package currently allow IDFs to be converted to OSMs. Additionally, OpenStudio allows files generated using one of its applications to be saved as IDFs, although information is likely to be lost in this process.

The long-term vision for the model components created through this research is for them to be downloaded into local user libraries in the OpenStudio environment. They would then be available to drag and drop into a whole building model in either the SketchUp Plug-In or some other OpenStudio application. With that reasoning in mind, all of the models were designed to be compatible with the OpenStudio environment.

5.2 EnergyPlus Plug Load Modeling Format

In EnergyPlus, an IDF is the input file that contains all of the information describing the building and HVAC system to be simulated. Unlike many other building energy simulation programs, EnergyPlus does not come with default values – the IDF must be built from the ground up. In order to be executable, the IDF must include building and zone geometry, material and construction information, and basic HVAC sizing criteria. Furthermore, it must include a simulation control object, a run period, and a location with a related weather file. Additional details can be added to the IDF following the syntax of the Input Output Reference available through the EnergyPlus download *(EnergyPlus Development Team, 2009).*

One of the key outcomes of this project was to provide standardized models of plug loads for other modelers to include in their whole building energy simulations. Therefore, only the information pertinent to the behavior of plug load devices was included in these model snippets. While the snippet is saved as an IDF, it is an incomplete model that is not executable. Each component consists of a piece of equipment and its corresponding schedule.

The possible input objects for an IDF are grouped by type in the reference manual. One of these groups is Internal Gains. The manual explains that not all energy consumption in a building is the result of envelope and external conditions, and that this group of objects deals with the internal loads that may influence building energy consumption – People, Lights, and Other Internal Zone Equipment.

The EnergyPlus object of interest in this research is the ElectricEquipment object. The following fields comprise a complete ElectricEquipment object: Name, Zone or ZoneList, Schedule Name, Design Level Calculation Method, Design Level, Watts per Zone Floor Area, Watts per Person, Fraction Latent, Fraction Radiant, Fraction Lost, and End-Use Subcategory.

The Zone or ZoneList refers to the zone(s) in which the equipment appears. The schedule refers to a schedule object, which dictates the operational schedule of the equipment. The Design Level Calculation Method is a choice field that indicates which of the next three fields is filled. The method for calculating the electric equipment level in the zone may be expressed in terms of total electrical power of equipment (Design Level), a function of the floor area (Watts per Zone Floor Area), or a factor based on the number of people in the zone (Watts per Person). The next three fields describe the heat gain to the zone from the electric equipment, characterizing it as Fraction Latent, Fraction Radiant, Fraction Lost, and the remainder is assigned to fraction convected. The End-Use Subcategory is a user-defined field used to group electric equipment objects as the user sees fit.

5.3 Population of Equipment and Schedule Fields

In order to avoid fatal run errors, each ElectricEquipment object in an IDF must have a unique name. To ensure that no two objects have the same name, a specific naming convention was created. Each ElectricEquipment name consisted of a brief description, followed by an underscore, followed by the manufacturer, another underscore, and the model name. If the equipment schedule differed based on the operating hours of the building, two copies of the model component were created – a 24-hour store model and a 10am-9pm store version. [A more flexible version of this dependency could be created to function with any store hours. More information on this type of model can be found in section 5.4]. These similar object names are suffixed with _24 and _109, respectively, to distinguish between the two possibilities. For consistency, the ElectricEquipment name also served as the name of the model component. An example of this naming convention is TV_Emerson_LC220EM1_24.

The Zone field must be filled in with the correct zone name from an already modeled building. Therefore "ENTER ZONE NAME" was inserted into this field to act as a placeholder. When adding a component to a whole building model, this field could manually be replaced, or an interface could be created to automatically replace this field with the user's intended zone destination.

The Schedule Name refers to the schedule that describes the behavior of the ElectricEuipment throughout the day, week, and year. The schedule is the other of the two objects that are necessary to completely describe a plug load. Thus, a component is comprised of both an ElectricEquipment object and a Schedule:Compact. Just as an ElectricEquipment object has to have a unique name, a schedule must have a unique name. For simplicity, the corresponding schedule for each plug load was created as the ElectricEquipment name followed by _Schedule (e.g. TV_Emerson_LC220EM1_24_Schedule). More detail on the schedule fields and the manner in which representative schedules were created can be found in subsequent sections of this chapter.

A Watts per unit floor area is perhaps the most frequently used method for calculating the miscellaneous equipment load in a zone. The commercial reference buildings as well as other available references list assumed equipment energy intensities by the activity type of a zone. This is a key distinction of this work: each piece of equipment is accounted for individually rather than making an estimation based on the floor area. Therefore, the most appropriate of the three Design Level Calculation Methods was EquipmentLevel.

The Design Level is used to represent the maximum expected electrical load from the specified piece of equipment that is then multiplied by a fractional schedule. Accordingly, the largest measured power was recorded in this field for each plug load. The next two fields were left blank due to the Design Level Calculation Method selected.

Insufficient data was collected about the studied devices to accurately inform the Fraction Latent, Fraction Radiant, and Fraction Lost fields. According to Hosni, Jones, and Xu the radiant fraction for plug load devices varies between 20 to 80% (1999). An analysis was done to determine the impact of that parameter of a plug load component. Figure **3** shows the results of varying the radiant fraction of all of the plug load components in a model from 0 to 1. The energy use of the whole building model varies linearly with the radiant fraction of the components in the model. There is less than 3% difference between components that are 100% radiant vs. 100% convective. Since the radiant fraction has such a limited impact on the overall result of the energy model, a default value of 0 was used for the radiant fraction of each model component until that value is one day physically measured for each component.

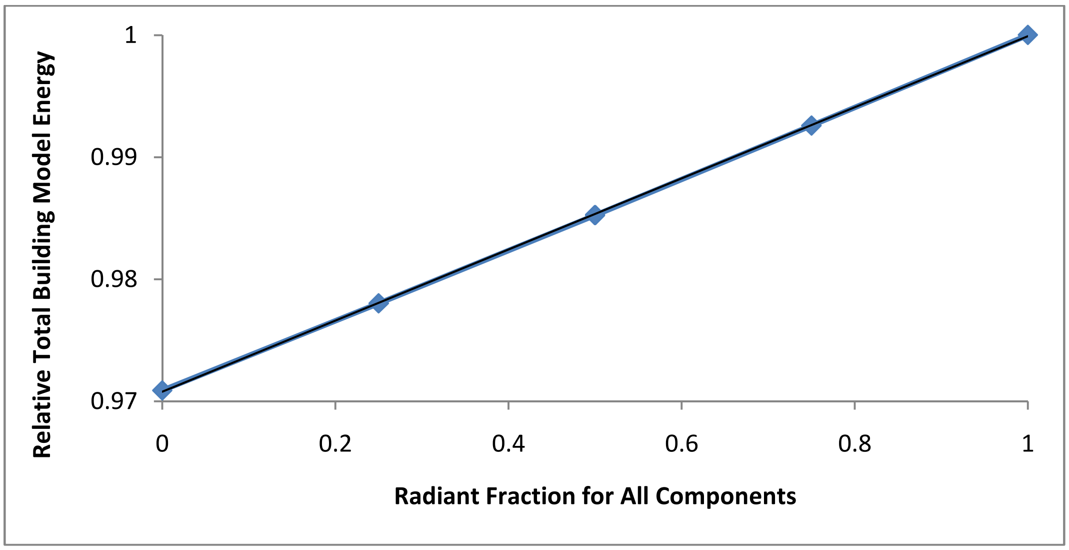


Figure 3: Whole building energy use as a function of the radiant fraction of all plug load components.

The amount of granularity required in the End-Use Subcategory field is a user-specific decision. In whole building simulations, "miscellaneous load" is typically all the detail a modeler needs from the output. Consequently, the End-Use Subcategory field was completed with "MiscPlug" for all components. Should a modeler performing a miscellaneous energy study need more detail, this field could be modified to match the device description (e.g., TV).

The second object in a plug load component is the schedule that dictates the behavior of the ElectricEquipment. EnergyPlus has both a compact and linked day/week/year schedule options. However, at this time OpenStudio is only capable of handling a compact schedule object, so all schedules were formatted as compact.

A Schedule:Compact is different from other EnergyPlus objects in that the number of fields and their position are not set. The field-set includes the following elements: Through (date), For (days), Interpolate (optional), Until (time of day), followed by a value. Most of these "titled" fields must include the title in the object description. All the features of the schedule components are accessed in a single command.

Each Schedule:Compact must cover all the days of a year. This includes day typing by day of the week as well as holidays. Seasonal changes can be expressed through the annual schedule. Also, each hour of the day must be accounted for. Sub-hourly timesteps are an option for the daily portion of the schedule, but hourly profiles are the most common for schedules. Smaller timesteps cause longer simulations with little benefit.

One optional field is a Schedule Type Limits Name. A fractional schedule type varies from 0.0 to 1.0 continuously. Since the Design Level for the ElectricEquipment was set as the maximum recorded power, a fractional schedule was chosen to express the energy use as a fraction of that maximum power.

As part of the postprocessing of the metered data, the operating modes were extracted via a clustering technique described in the 2011 conference paper "Extracting Operating Modes from Building Electrical Load Data" *(Frank, Gentile Polese, Rader, Sheppy, & Smith, 2011).* The metered plug loads behaved in a variety of ways. Some devices exhibited constant power usage. Plug loads that were regularly switched off either went to zero power or a standby value. Other devices had multiple distinct modes or simply varied continuously from a maximum to minimum power throughout the course of the day (no distinguishable modes).

Some devices had multiple instances in the store. For plug loads where multiple instances were metered, each step of the analysis was conducted separately for every dataset. Once multiple instances were found to be consistent, the datasets were averaged together so a single model component could be created. Multiple instances of the same device were metered when they were subjected to different use patterns. For example, all the components of a cash register (i.e. the register, barcode scanner, demagnetizer, conveyor belt) were used with varying frequency depending on whether an aisle was a high, medium, or low use aisle. These devices were intended to be modeled as different use cases – high, medium, low – but the analysis ultimately revealed that the spike in energy caused by use was not of a long enough duration to increase the hourly average. Therefore, the energy use profile of each of these devices was found to be the same and only one component was created for each device.

Since an hourly timestep was chosen for the plug load schedules, the first step in converting the metered data into a standardized schedule was averaging the 30-second data into hourly pieces. These hourly values were plotted across the four-week time period for an initial visual inspection of the data. This inspection allowed the type of device behavior to be initially qualified – constant, multimode, etc. – as well as an impression about the consistency of the data to be made. If the visual inspection and the mode extraction signaled a constant device, no further analysis was needed.

Each of the four weeks was then considered separately. The four one-week datasets were compared to each other to identify any possible day-type behavior. In a typical office building, day-typing is common for plug loads. With the office closed on the weekend, devices are often shut down. The results of metering plug loads in a retail environment did not show this trend. For devices that exhibited time-of-day dependency, each day of the week showed similar behavior. This is likely due to the fact that big box retail stores are operated seven days a week. Fifty-five percent of the devices measured were time-of-day dependent. Those that were not fell into either the category of devices with refrigeration elements or constant loads left on all the time (e.g. modem, safe, etc.).

Refrigerators, freezers and soda vending machines have a compression cycle that is independent of time-of-day. Figure **4** and Figure **5** show time series data collected for two of these devices. The length of the compression cycle varies per device from eight minutes to six hours. For the sub-hourly cycles, the detail gets lost in the hourly model schedule (Figure **4**). For refrigerated plug loads with longer cycles, like Figure **5**, the cycle was represented with the hourly schedule.

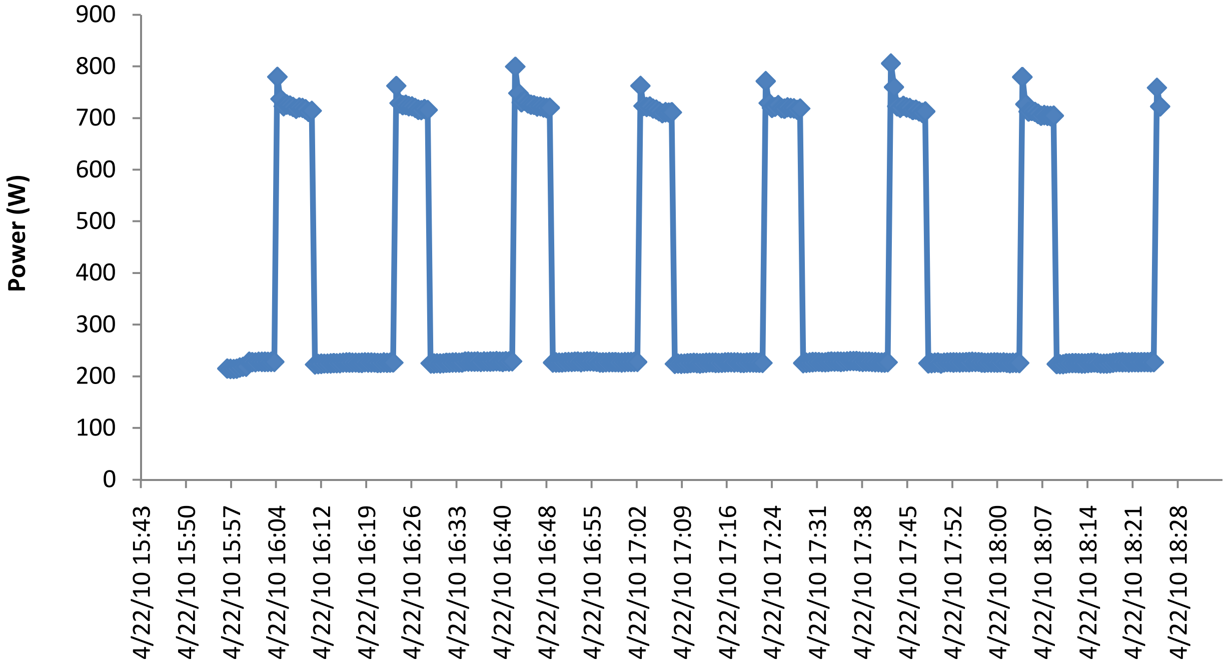


Figure 4: Measured power profile from a soda vending machine with a cycle shorter than one hour.

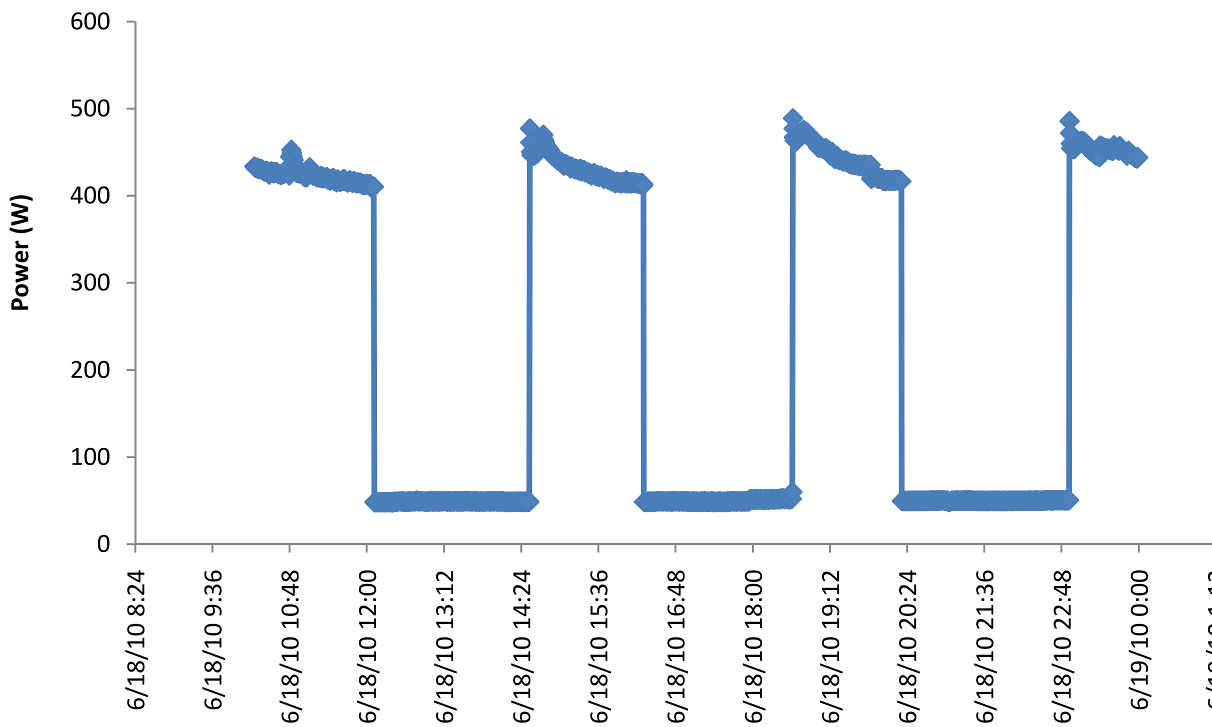


Figure 5: Measured power profile from a beverage refrigerator with a cycle longer than one hour.

As previously mentioned, three time scales must be considered when making an annual schedule: day, week, and year. All model schedules have to have a day schedule. No plug load devices in this study required a distinct week-level schedule. Most of the devices in the study showed no potential for any seasonal changes in pattern. The few devices whose energy profiles were seen to be based largely on occupant interaction were monitored over five to nine months rather than the standard four weeks. Just as the influence of occupant behavior did not cause a difference between high- and low-use cases, the seasonal (even the Christmas shopping season) fluctuations in store occupancy did not have a significant impact on the hourly energy use of any of the devices studied. Since occupancy was not measured, the occupancy level of the store throughout the year was inferred from anecdotal data for this analysis.

By far the majority of the plug loads metered exhibited constant load behavior. Display devices in the electronics section of the store are a good example of constant loads. It was found that in a 24-hour store, the consumer electronics are left on all day, every day. A day's worth of recorded data for one of these display televisions can be seen in Figure **6**. If there was less than five percent difference between the maximum and minimum recorded power levels, the device was considered to be constant.

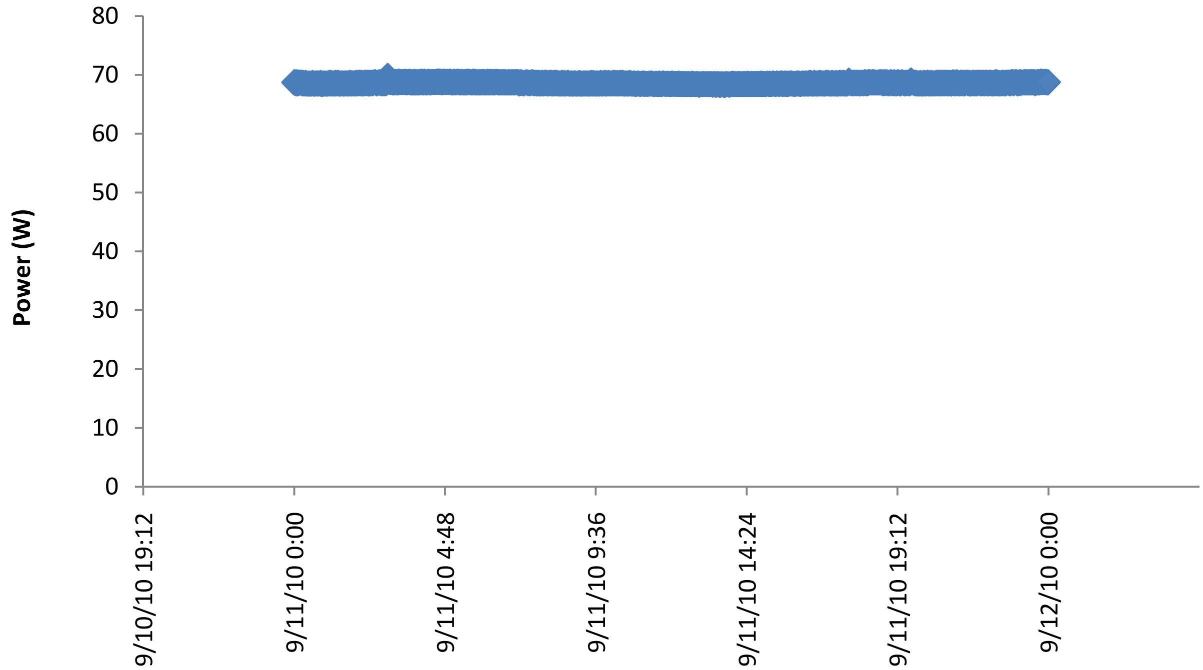


Figure 6: Measured power profile from a television operated in a 24-hour store.

Assuming the store operators are responsible about energy, the display devices in the electronics section of a non 24 hour store are examples of on/off devices. In the building used in this study, the vision center, fast food restaurant, nail and hair salons, bakery, and deli did not remain open 24 hours a day. Many of these devices were found to exhibit on/off behavior. Figure **7** shows four days worth of recorded data for such a device in the vision center. Other devices were powered down into a distinct standby mode during unoccupied hours. The energy profile is quite similar to an on/off device, the only difference being a low-power value instead of zero.

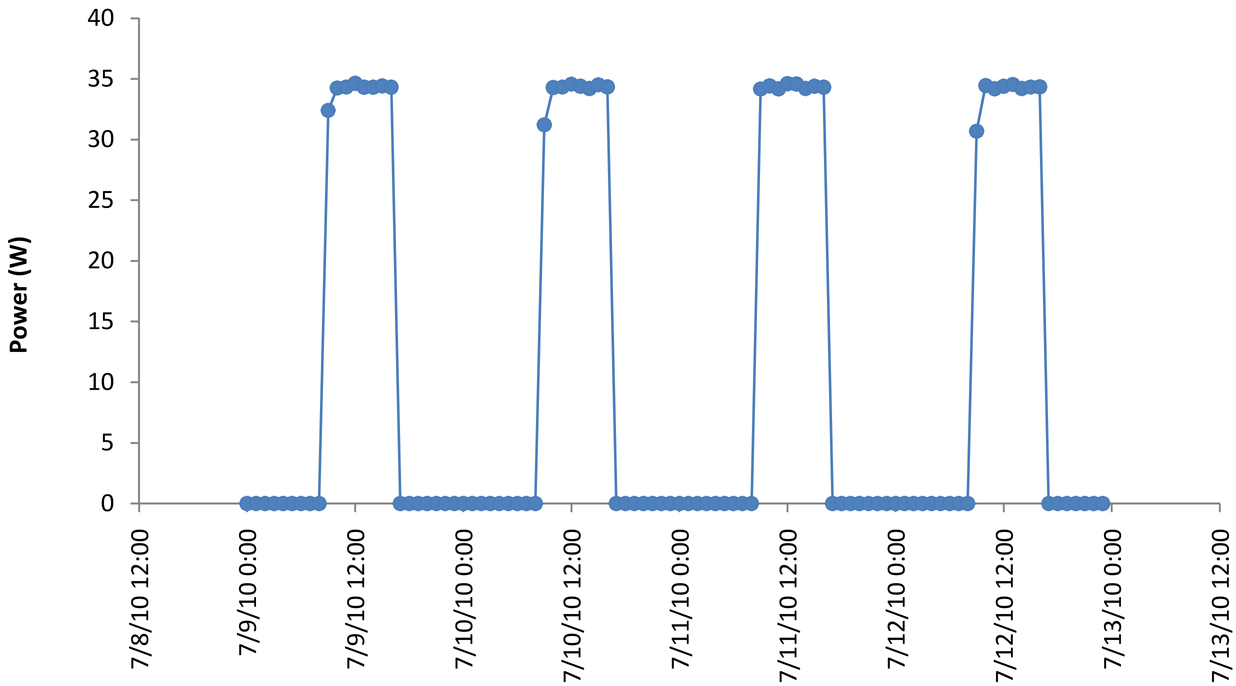


Figure 7: Measured power profile from a refractor – an eye exam device.

Some of the refrigerated plug loads had three distinct modes. The few of these devices that had multiple modes also had sub-hourly compression cycles, so this detail is not represented in any of the components. The most complicated plug loads to model are those that vary throughout the day. This was found to be the result of increased usage of these devices at certain times during the day. The hourly energy use was only increased due to occupant behavior for devices with a large jump in power when the device was operated. Figure 8 shows the profile for a frame tracer in the vision center. Its increased use toward the middle of the day, as well as the operating hours of the vision center can clearly be seen in the figure. Not all of the continuously varying devices have a single smooth curve, some have morning and evening maxima.

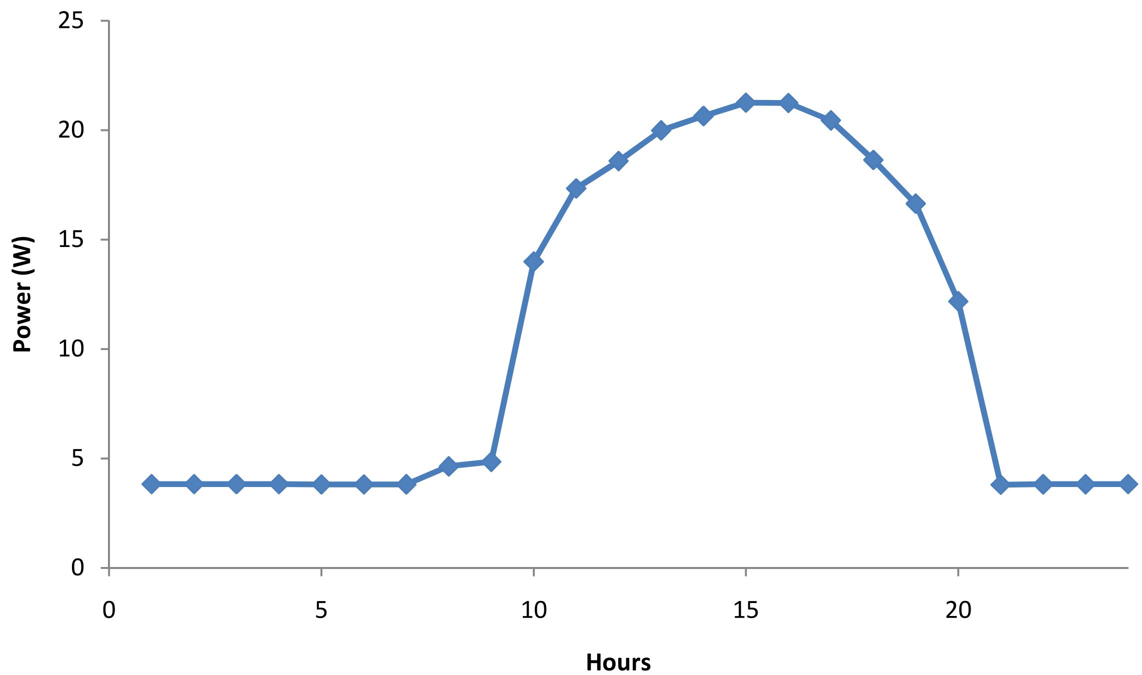


Figure 8: Hourly profile of averaged metered data for a frame tracer for making eye glasses.

Once all of the analyses were complete for a plug load device, a schedule with concrete values was created. Then the schedule was formatted in Schedule:Compact language and all of the fields for the ElectricEquipment object were completed. Example components of a television in each a 24-hour and 10am-9pm store can be seen in Figure **9**. The following section will provide more detail on how the schedule for an object can be tied to hours of occupancy, condensing all “hours of operation” dependent devices to one component per device, and eliminating the need for a _24 and _109 copy of the model.

TV_Emerson_LC220EM1_109.idf

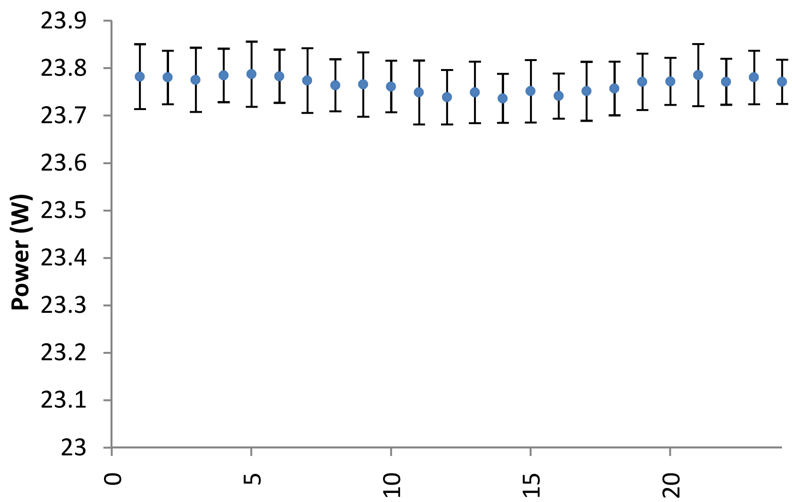
```
ElectricEquipment,
   TV_Emerson_LC220EM1_109,              !- Name
    ENTER ZONE NAME,                     !- Zone or ZoneList Name
    TV_Emerson_LC220EM1_109_Schedule,    !- Schedule Name
    EquipmentLevel,                      !- Design Level Calculation Method
    46,                                  !- Design Level {W}
    ,                                    !- Watts per Zone Floor Area {W/m2}
    ,                                    !- Watts per Person {W/person}
    0,                                   !- Fraction Latent
    0,                                   !- Fraction Radiant
    0,                                   !- Fraction Lost
    MiscPlug;                            !- End-Use Subcategory

Schedule:Compact,
    TV_Emerson_LC220EM1_109_Schedule,    !- Name
    Fraction,                            !- Schedule Type Limits Name
    Through: 12/31,
    For: AllDays,
    Until: 10:00,     0,
    Until: 21:00,   1.0,
    Until: 24:00,     0;
```

TV_Emerson_LC220EM1_24.idf

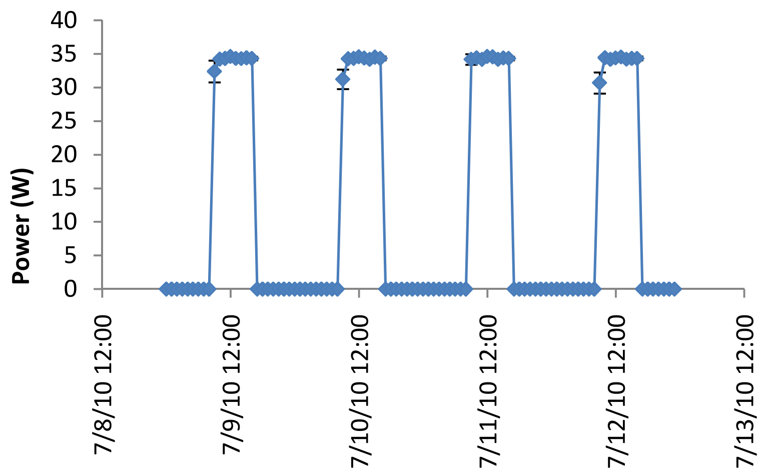
```
ElectricEquipment,
    TV_Emerson_LC220EM1_24,              !- Name
    ENTER ZONE NAME,                     !- Zone or ZoneList Name
    TV_Emerson_LC220EM1_24_Schedule,     !- Schedule Name
    EquipmentLevel,                      !- Design Level Calculation Method
    46,                                  !- Design Level {W}
    ,                                    !- Watts per Zone Floor Area {W/m2}
    ,                                    !- Watts per Person {W/person}
    0,                                   !- Fraction Latent
    0,                                   !- Fraction Radiant
    0,                                   !- Fraction Lost
    MiscPlug;                            !- End-Use Subcategory

Schedule:Compact,
TV_Emerson_LC220EM1_24_Schedule,         !- Name
Fraction,                                !- Schedule Type Limits Name
Through: 12/31,
For: AllDays,
Until: 24:00, 1.0;
```

Figure 9: Files for the same TV in a store operated from a) 10am-9pm, and b) 24 hours a day.

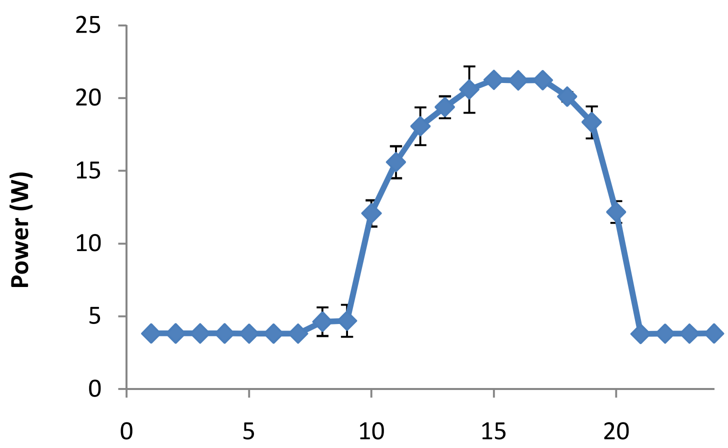
Figure **10** shows error bars with the standard deviation of each hourly value for the three devices shown above. The figure supports the premise that the component models resulting from this closely resemble the behavior observed by each device. It can also be seen that the first “on” point in Figure **10** b) has the greatest standard deviation, indicating that the time that device is turned on each day is somewhat variable. Similarly, the most deviation in Figure **10** c) is during the device’s daily use. The nighttime standby value shows relatively little deviation.



a)



b)



c)

Figure 10: An average profile with error bars indicating the standard deviation of the hourly values for a) an average daily profile of a constant device, b) four days of an on/off device, and c) an average daily profile for a continuously variable device.

5.4 Temperature and Occupancy Dependent Plug Loads

As shown in the previous section, not all plug load energy use profiles follow a simple "always on" schedule. In this study, two main external variables were thought to have an impact on plug load energy use: 1) zone temperature, and 2) zone occupancy. As described in Chapter 4, devices with refrigeration elements were metered concurrently with localized temperature sensing. While no correlation was found for the devices metered in this store, a procedure was developed for modeling any future temperature-dependent device.

Occupancy dependence is a more complicated issue. There are two types of occupancy dependence: binary and continuous. A binary occupancy dependence is based on whether or not there are occupants in a space. Specific to a retail environment, this is more likely to coincide with whether or not the store or tenant space is open rather than if there is an actual customer in the space at any point in time. There are many examples of this kind of dependency in a retail building. A pie warmer in the fast food restaurant is only on during business hours. In a non-24-hour operated store, the display electronics would likely only be turned on when the store was open.

Continuous occupancy dependence implies that the energy usage of a device is contingent on the number of people in the zone at any given time. Plug loads with this dependence follow a probability distribution with regard to the likelihood that so many occupants will lead to use of the device. An example of this type of dependency is a DVD rental machine – it gets used more often (and consequently the average energy usage increases) when there are more people in the store. Based on knowledge of the functioning of each device roughly 28% of the devices studied showed a continuous occupancy dependence, as opposed to 45% with a binary occupancy dependence.

Unfortunately, occupancy sensing is far more difficult and expensive than basic temperature sensing. Occupancy dependence was not a key outcome of this research. Therefore, the time and financial investments necessary for a thorough study of occupancy dependence were not made. A further discussion of this issue as a topic for future work can be found in Chapter 8. Without this detailed data, only a cursory correlation could be found between device behavior and a typical retail occupancy schedule.

EnergyPlus allows for variable interdependence to be coded in through the EnergyPlus Runtime Language (Erl). According to its user manual *(EnergyPlus Development Team, 2010)*, Erl is a simplified programming language typically used to define Energy Management System (EMS) control programs. This application also works well for defining a correlation between an ElectricEquipment object and any other variable.

For this utilization of Erl, three items are necessary: a sensor, an actuator, and a program. A sensor can be mapped to any variable that is available as an output variable in EnergyPlus. The .rdd file resulting from an EnergyPlus run lists all available output variables for a given model. For temperature dependency, the sensor is mapped to Zone Mean Air Temperature; for occupancy dependency – Zone People Number of Occupants. The actuator dictates which EnergyPlus object will be controlled by the EMS program. In this case, that would be the plug load device schedule. Then, a brief program can be written using the Erl statements – RUN, RETURN, SET, IF, ELSEIF, ELSE, and ENDIF – to describe the correlation between the two objects. An example script can be seen in Figure 11.

TV_Emerson_LC220EM1_Erl Code.txt

```
ElectricEquipment,
   TV_Emerson_LC220EM1_109,                 !- Name
    ENTER ZONE NAME,                        !- Zone or ZoneList Name
    TV_Emerson_LC220EM1_109_Schedule,       !- Schedule Name
    EquipmentLevel,                         !- Design Level Calculation Method
    46,                                     !- Design Level {W}
    ,                                       !- Watts per Zone Floor Area {W/m2}
    ,                                       !- Watts per Person {W/person}
    0,                                      !- Fraction Latent
    0,                                      !- Fraction Radiant
    0,                                      !- Fraction Lost
    MiscPlug;                               !- End-Use Subcategory

  Schedule:Constant,TV_Emerson_LC220EM1_109_Schedule,Fraction,1.0;

  EnergyManagementSystem:Actuator,
    TV_Emerson_LC220EM1_Schedule_actuator, !- Name
    TV_Emerson_LC220EM1_Schedule,           !- Actuated Component Unique Name
    Schedule:Constant,                      !- Actuated Component Type
    Schedule Value;                         !- Actuated Component Control Type

  EnergyManagementSystem:Sensor,
    ENTER ZONE NAME_Occupancy,              !- Name
    ENTER ZONE NAME,                        !- Output:Variable or Output:Meter Index Key Name
    Zone People Number of Occupants;        !- Output:Variable or Output:Meter Name

  EnergyManagementSystem:ProgramCallingManager,
    ProgramCallingManager,   !- Name
    EndOfZoneTimestepBeforeZoneReporting,  !- EnergyPlus Model Calling Point
    TV_Emerson_LC220EM1_Schedule_Program;  !- Program Name 1

  EnergyManagementSystem:Program,
    TV_Emerson_LC220EM1_Schedule_Program,  !- Name
    IF (ENTER ZONE NAME_Occupancy > 1.0),
      TV Emerson LC220EM1 Schedule Actuator = 1.0,
    ELSE,
      TV_Emerson_LC220EM1_Schedule_Actuator = 0.0,
    ENDIF;
```

Figure 11: Model snippet for a display TV with Erl program for binary occupancy dependence.

The component shown in Figure 11 was included in a basic whole building model to verify that the Erl code performs as described. Figure 12 shows the zone occupancy and TV power over the first week of the model output. The occupancy schedule for this model is 9am-7pm on weekdays. The TV can be seen to reach its full power (46 W) any time the zone occupancy is greater than 1.0.

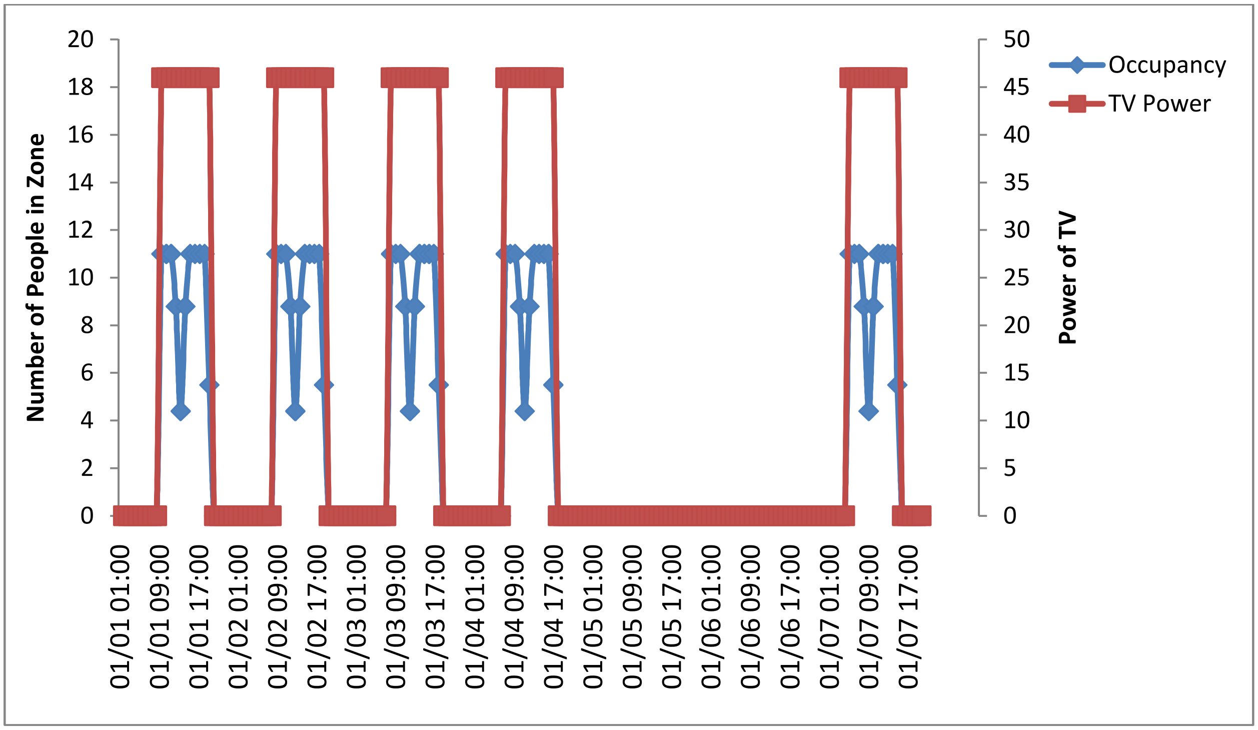


Figure 12: First week of output for the code shown in Figure 11. The TV power is seen to correspond to the zone occupancy.

At the time of the writing of this thesis, none of the objects necessary to execute an Erl script had been incorporated into the OpenStudio platform. Therefore, the model components created for incorporation into the Building Component Library do not contain EMS code. Rather, binary occupancy-dependent devices are modeled in two ways – a 24-hour store and a 10am-9pm operated store.

Plug loads with a continuous occupancy dependence were modeled as static schedules based on typical operation.

CHAPTER VI

BUILDING COMPONENT LIBRARY

One key outcome of this project was to share the plug load component models with the building simulation community. This was achieved through inclusion of the snippets in NREL's Building Component Library (BCL). The following sections include a background of the BCL and the process of including this research in that library.

6.1 Overview of Building Component Library

The BCL is a new web-based database for building energy simulation components that was recently released by NREL *(Long, Fleming, & Brackney, 2011)*. It will allow for storage and sharing of the massive amounts of data that comprise building energy models. The database will ultimately include window and wall constructions, components of HVAC systems, weather data, utility rate data, and whole buildings, as well as plug loads. Components can be stored in

OpenStudio, EnergyPlus or DOE-2 formats and weather files can be stored in a variety of weather file formats. Each component is made up of a web page with metadata and a zip file containing relevant model source code as well as images and video when available. Eventually, it is intended that users will not only be able to read content but also upload user-generated content.

The BCL metadata is comprised of a component type taxonomy with an extensive and expandable set of attributes. The tag taxonomy was kept as flat as possible, with the top layer including construction assembly, HVAC system, schedule, location-dependence, and MELs. So that the taxonomy would not become quickly outdated, the decision was made to let it transform based on user comments. The taxonomy describes the component type, but each component also has an unnumbered set of attributes that further define the component. Example attributes include: length, manufacturer, information regarding the source or data provenance, cost information, and supporting images or video.

An important aspect of the BCL is its capacity for citation. As each component is uploaded or changed, it is versioned and assigned a unique identifier. That unique identifier allows the component to be accessed by a corresponding URL. This allows individual model components to be referenced in publications such as this thesis. This ability is novel in the building simulation community.

Component metadata is used as a method of filtering search results as well as defining a component. Apache SOLR is used as the search engine for the BCL. Multi-faceted searching allows users to quickly locate components that meet their needs. An initial search query returns a list of components with a sidebar for further filtering of the results. The results can be filtered by component type, any of the associated attributes, and the file format. The list of available attributes in the sidebar adapts dynamically as the number of remaining components in the search diminishes. User rating and upload data are options for sorting the resulting search list in addition to relevance.

The BCL was designed with the ability for developers to build front-ends for the component data. The OpenStudio suite is an example of an application that is being extended to align closely with the BCL content. Currently, the OpenStudio forward translators can convert information stored in IDF snippets for use in the OpenStudio environment. Eventually, model source code fragments in the BCL may be stored as OpenStudio component models (.osc). OSCs are able to contain both input data necessary for EnergyPlus and additional information for programs such as Radiance. An additional user interface under development for OpenStudio is ProjectManager, which would include the means of managing a local library of components downloaded by the user.

One of the key goals of the BCL is a benefit to the modeling community through social functionality. The BCL currently offers two aspects of socialization: 1) a component rating system, where 0 to 5 stars can be assigned to evaluate both the metadata and data, and 2) an opportunity for user commenting on individual components. The star rating can reflect both the accuracy and usefulness of a particular model component. The results of a search query can then be sorted by this criterion. Information about which components are most frequently used, which file formats are most popular, and which search criteria were used to find them will also be available, adding to the social utility of this library.

In the future, a module is planned for the BCL that would allow for public submission and revision of components. This module would also include RSS newsfeeds about component updates and user comments. There would be a distinction between components submitted by “trusted” sources such as standards organizations and those submitted by the general public. This distinction would serve as an additional search-limiting attribute so that users could determine the level of vetting appropriate to their needs.

6.2 Taxonomy and Attributes

The top layer of the BCL taxonomy was developed by the creators of the BCL. The remainder of the MELs taxonomy was contributed to the BCL through this study. An LBNL MELs taxonomy was adapted for both the metering and BCL portions of this research. The two parts comprising this section describe LBNL’s development of that taxonomy and its adaptation for this work as well as the numerous attributes that describe the plug loads therein.

6.2.1 Taxonomy Creation and Revision

Prior to 2006, no one had set out to define a consistent naming convention for the multitude of product types that make up the miscellaneous electric end-use. Researchers at LBNL found that while a number of previous studies had categorized product types, this naming and grouping was inconsistent across the studies and auxiliary to the key outcomes of each study *(Nordman & Marla, 2006)*. LBNL desired a consistent framework for product-typing so that comparisons could be made amongst studies with uniform product categorization. Unlike traditional end-use categories, which are limited in number and contain a small number of product types each, the miscellaneous category exists as a catch-all with a rapidly expanding and ill-defined repertoire of devices. Due to the category's diversified nature, the number of miscellaneous product types is exceedingly large – particularly when compared to the traditional end-uses.

Despite this complicated nature, LBNL posited that miscellaneous products could be named in a consistent manner and grouped into logical categories. For the purposes of their taxonomy, LBNL explicitly defined a "product type" as a category of equipment with common functionality. The similarity of function is what drove the categorization rather than required voltage, method of circuit connection, or another criterion.

To ensure a consistent taxonomy, a number of conventions were devised for the product type naming process. Brand names were never used. Conciseness was valued, so common acronyms such as "TV" were used with utmost frequency. Similarly, ordinary language was regarded over technical terminology. In regard to punctuation – only one comma was allowed per product type name and it was used to distinguish similar products (e.g. TV, CRT and TV, LCD), while "/" was used to denote a list. Parentheses allowed for disambiguation between products with the same name but different functions (e.g. Amplifier (network) and Amplifier (audio)).

The word “portable” was used to designate a physical mobility, not whether something is battery-powered. The similarity in function, the applied technology, general size and power level, and typical usage drove the disaggregation of similar product types.

From the beginning, LBNL’s taxonomy was intended to evolve with continued product diversification. It is meant to describe the current product stock rather than devices which are for sale but not yet in widespread use. Due to the limited number of commercial taxonomies in the relevant literature, the commercial portion of the taxonomy was more limited in scope than the residential and was seen as an area of expected future development.

The key distinction between the LBNL taxonomy and the one used in the BCL is that the top level of the LBNL taxonomy (Electronics, Miscellaneous, and Traditional) was removed from the BCL version. Primarily, the BCL taxonomy was intended to be as flat as possible and this seemed like an unnecessary layer. While these end-use categories would be important to a modeler considering a whole building simulation, they are not intuitive to users trying to narrow their search – the principle function of the BCL taxonomy.

Some product type names were modified to be more clear or specific. An “other” product type was added to each of the categories and the naming was kept consistent (e.g. Other audio in Audio and Other cash exchange in cash exchange), so that all components would accurately fall into one tag category. Other than these simple adjustments, the overall taxonomy remains true to the one set out by LBNL.

Appendix B details the complete taxonomy of commercial MELs used in this project, including all changes made to the original LBNL version.

6.2.2 Component Attributes

Attributes are meant to describe the specifics of a component within a particular product category. Some components require many attributes to differentiate them from the other components in their category, some require very few. Since this study deals entirely with plug loads, the manufacturer and model of the device studied are the primary attributes. Every plug load that was added to the BCL includes these two attributes and every plug load thereafter should also include them. In some cases, these values were not known and were listed simply as "unknown". In each component, "derived from measured data" was also listed. The number of attributes ranged from just those three required ones to nine total fields.

There are essentially two types of attributes for plug loads: 1) those that describe the physical object, and 2) those that describe the typical user behavior captured by the model component. Attributes that fall into the first type are characteristics such as television screen size or whether the product is ENERGY STAR qualified. User qualities include store hours assumed in the schedule and the actual use of the device that was metered (i.e. a handheld hair dryer in the paint center would have different energy use than the exact same hair dryer in a beauty salon).

Display electronics had the largest number of attributes. Each had a 24-hour and 10am-9pm option. A corresponding attribute indicated whether the device was assumed to be turned off when the store was closed. Each TV listed screen size, screen type, whether it was an HDTV, and ENERGY STAR qualified.

The less specific attributes recorded concepts like “type” and “use”. “Type” could refer to a mounted vs. handheld scanner or the type of item charged by a battery charger. “Use” could indicated anything from the setting in which the device was used in the study to a longer description of what the device did. These fields essentially provided the opportunity to list more information about the device. They informed specifics a user may not know he/she wanted. The web page for an example component, displaying its tag and all attributes can be seen in Figure **13**.

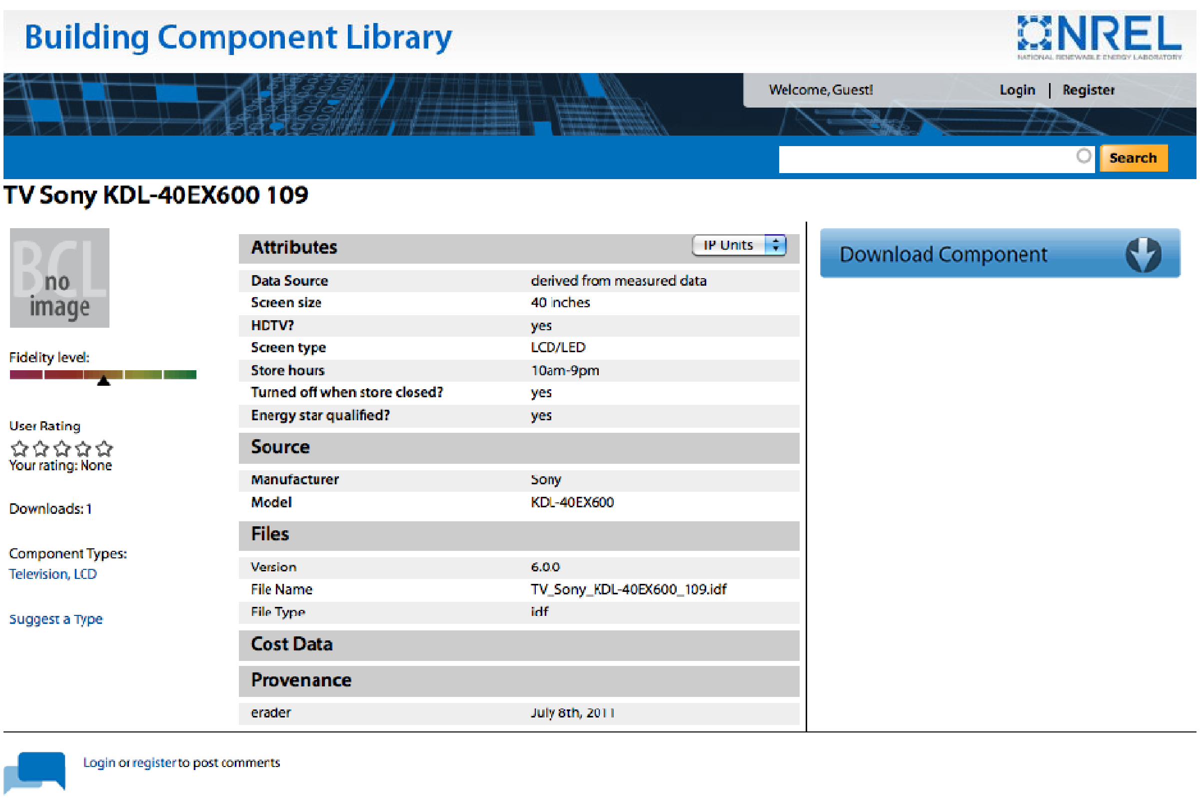


Figure 13: The BCL page for a television, complete with tag and attributes *(National Renewable Energy Laboratory, 2011).*

CHAPTER VII

APPLICATION OF MODEL COMPONENTS TO REFERENCE BUILDING

Component models in the BCL should be easily integrated into a building energy simulation program. The following sections lay out a demonstration of their incorporation into a reference building through the Ruby bindings for OpenStudio. The resultant energy use was then compared to a DOE reference building – containing typical values for plug loads – and five years worth of submetering for the building.

7.1 OpenStudio Ruby Bindings

From the beginning, OpenStudio was intended to be an open source program to foster development and extension by the community and private sector adoption. The software's website contains a "Developers" tab with source code, documentation libraries, and any other information one might need to develop other interfaces with OpenStudio.

To facilitate developer interaction with OpenStudio, there are Ruby bindings that expose the building energy analysis functionality to the Ruby programming language. The Ruby software development kit (SDK) is provided so that documentation regarding the classes, functions, and their appropriate syntax are available. The functionality of the Ruby bindings was used in this work to apply building energy model components to an OpenStudio whole building simulation.

7.2 Reference Buildings

An appropriate whole building model had to be chosen as the test bed for implementation of the component models. The chosen building model needed to be a generalized model that would contain plug loads similar to the studied building. The DOE commercial reference buildings are widely accepted prototypical buildings of sixteen building types. There is not a big box retail store with grocery amongst the reference buildings. Therefore, the stand-alone retail and supermarket buildings were combined into a single representative building.

Every commercial reference building model includes plug loads in each zone. These input values were selected based on space type data. Deru, et al. details the values used for each zone type and the origin of their source data in the report that accompanies the reference buildings *(2011)*. The plug load values for the stand-alone retail and supermarket buildings are enumerated in Table **1**.

Table 1: Energy use intensities assumed for each zone in the stand-alone retail and supermarket commercial reference buildings.

Stand Alone Retail		Supermarket	
Backspace	8.07 W/m^2	Bakery	11244 W
Core Retail	3.23 W/m^2	Deli	12105 W
Front Retail	3.23 W/m^2	Dry Storage	8.07 W/m^2
Point-of-Sale	21.52 W/m^2	Office	8.07 W/m^2
		Produce	5.38 W/m^2
		Sales	5.38 W/m^2

In order to correctly represent a retail store with grocery, the two reference building models had to be combined. The studied building includes a bakery, deli, dry storage, produce, and an office, so the supermarket was deemed the more appropriate layout for the combined model. The energy use intensities (EUIs) of the stand-alone retail building were weighted by floor area and combined into one value. That value was then substituted for the value in the "Sales" zone. That way, an appropriate mix of backspace, core and front retail areas, and point-of-sale spaces could be represented for the non-grocery portion of the store. The other zones were left to represent the grocery portion of the store. The new "Sales" EUI was calculated to be 4.7 W/m^2. Only the plug loads were considered in this study, so the façade and HVAC equipment were irrelevant. Since most of the reference building plug loads are based on zone floor area, the size of the building had to be scaled to meet the size of the studied building. This will act as the building model for a trial application of building component models.

7.3 Applying Model Components to Building

Ideally, a GUI with dropdown menus would provide the connection between the BCL and OpenStudio. This, however, was a simple command line user interface. This portion of the project hoped to establish how a user might interact with the program and what options (s)he might require. The Ruby bindings were the simplest method of interacting with the OpenStudio environment, so a Ruby script was created to act as this interface. The full text of this script can be seen in Appendix C.

The first concern was ascertaining which building the user intended to populate with plug loads. In practice, the user would access this functionality through an OpenStudio application, so the building model would already be open. In the case of this Ruby script, a simple question was written to the command screen, followed by a get statement to retrieve the name of the target file. That file was then turned into an OpenStudio model object so that OpenStudio commands could be used to add objects to the model. A short loop was written to create an array of all of the zone names in the model.

Since different operating schedules were generated for a 24-hour store and a 10am-9pm store, the user was asked which operating hours their building utilized. The array of available plug load components was then limited to those with the correct operating hours and components independent of store hours.

Next, the list of available zones was printed to the screen and the user was asked which zone (s)he wanted to populate first. Once the zone was chosen, all the available components were listed and the user was asked to select which to add to the zone. Then the user was asked to quantify the number of that particular component to add to the zone. A running list of components in the zone was kept. After every component was added to a zone, the list was presented and the user was given the option to add another component to the zone. The program continued to ask the user to add another component to the zone until the user answered “N”. Then, the user was given the ability to add components to another zone in the building until (s)he opted out.

Once the user selected each piece of equipment, the interface had to add the object to the OpenStudio model. The first step was to open the IDF for the component and get the ElectricEquipment and Schedule:Compact objects. The getObjectsByType command allowed for this. Then, the Zone Name field was changed from “ENTER ZONE NAME” to the zone selected by the user.

Different methods were used to add the equipment and schedule objects to the model. Only one copy of the component schedule needed to be added to the model. All copies of the equipment could reference the same schedule name. Therefore, the model.insert command had to be used to incorporate each schedule into the model. This command searches the file for the object name and only includes the object information in the model if it is the first instance of an object by that name. The ElectricEquipment object does not yet have a “quantity” field. Consequently, one ElectricEquipment object must be added for each instance of a component. The model.addObject command renames the model object if an object by that name already exists. The schedule names for these components reflect the original name of the component, so none of the detail is lost as a result of this practice. The script looped until the desired number of components of that type were added to the zone. The model was then saved as an OpenStudio model file (.osm).

The Ruby script described above was used to populate the reference building with plug loads. The reference building was stripped of all ElectricEquipment fields prior to population with the components. The inventory taken during the metering phase of the project was used to inform the number and type of components included in each zone. The ModelEditor application of OpenStudio was used to verify that the components had been added to each zone, as can been seen in Figure 14. Prior to following the procedure just described, this model did not contain any ElectricEquipment objects nor their corresponding schedules.

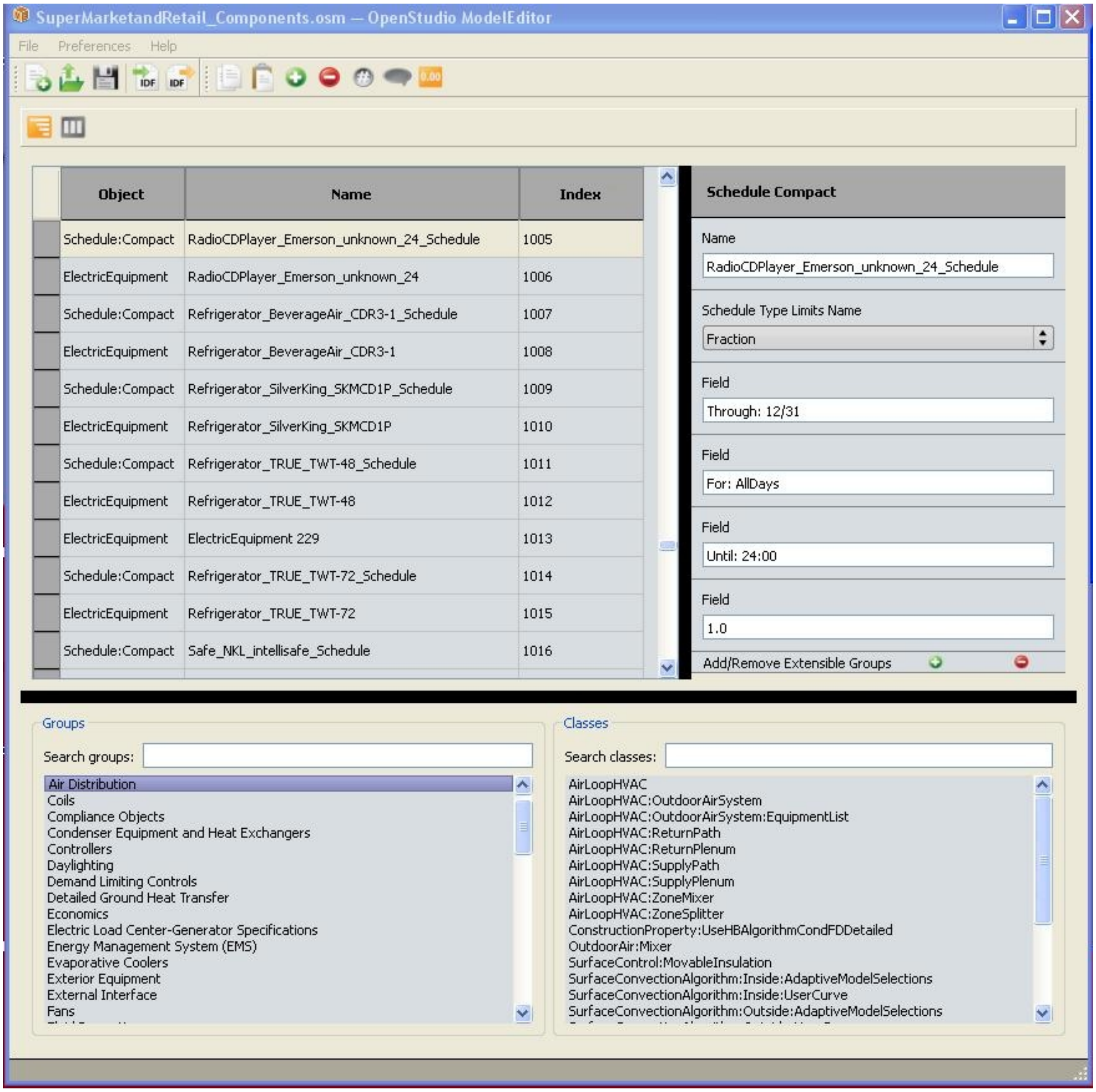


Figure 14: The ModelEditor application tabulates the objects in an OpenStudio model. A few of the plug load components can be seen in this photo.

7.4 Comparing Reference Building, Component Building, and Submetered Data

Researchers at NREL have been submetering the energy use of the building studied in this project for the last five years. The data was recorded in 15-minute increments. No distinct seasonal trends could be seen in the "other electrical loads" end-use over the five-year period, supporting the similar findings in the component-level study. The researchers estimated that on average 276 MWh/year of energy could be attributed to the type of miscellaneous plug loads examined in this research (*personal communication 2011*). The remainder of the "other electrical loads" end-use is likely due to loads such as hard-wired sliding doors and security equipment.

Once all of the devices inventoried in the store were added to the whole building model, an EnergyPlus simulation was run. While a variety of outputs are available from EnergyPlus; the datum of interest was the annual energy use in the interior equipment end-use category. Since none of the components produced had any seasonal variation, a comparison of the results on a sub-annual basis was deemed unnecessary. The building component strategy predicted an annual energy use of 221 MWh/year.

The scaled up version of the combined stand-alone retail/supermarket reference model simulation showed a plug load consumption of 216 MWh/year. Using a W/ft^2 input value puts the burden of accuracy on the sizing of each zone within the building. To reflect this range of possible zone geometries, a maximum and minimum plug load energy use was calculated for the modeling strategies using EUIs. The maximum value assumed the entire building was modeled with the highest of the zone EUIs for that strategy. Similarly, the minimum assumed the lowest zone EUI for the entire building.

As was found in the literature review, there are a number of common approaches to modeling the energy use of plug loads. Consequently, the decision was made to compare the simulated energy use to additional approaches besides the reference buildings. All plug load input values were applied to the same whole building model employed for the component and reference building simulations.

EUIs suggested in the Methodology for Modeling Building Energy Performance *(Griffith, Long, Torcellini, Judkoff, Crawley, & Ryan, 2008)* were applied to the appropriate zones within the model. The maximum and minimum possible values were calculated similarly to the reference building. Finally, national averages from the CBECS database *(Energy Information Administration, 2003)* were applied to each zone as EUIs. The possible range was also found for this approach. All of the plug load simulation strategies and their resultant energy use can be seen in Figure **15**.

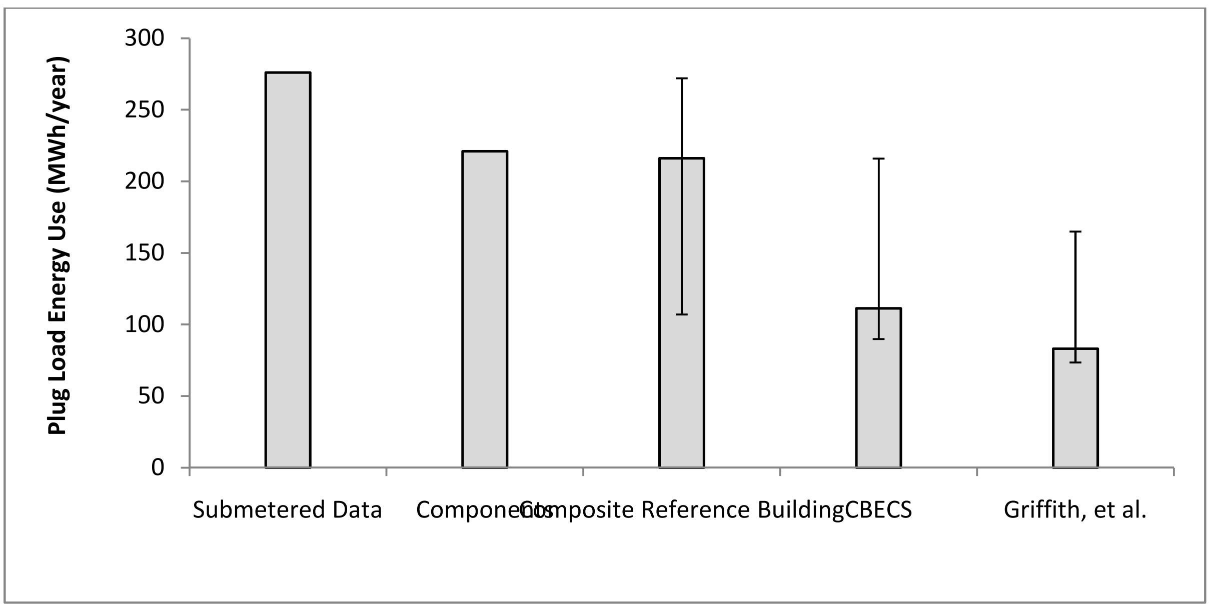


Figure 15: Range of annual plug load energy use estimates for the same building, resulting from the most common plug load simulation strategies.

As can be seen from this figure, the range of possible plug load energy use is quite large. All of these strategies for modeling plug loads are recommended in literature, yet there is a moderate range of resultant energy use. Often, plug and process loads are neglected entirely in whole building simulations. This analysis calls attention to the need for a standardized methodology for modeling plug loads.

Only the upper end of the reference building range accurately predicted the annual energy use of the plug load end-use in the simulated building. The model populated with the BCL components anticipated the energy use slightly better than the composite reference building model. The component method, however, leaves less room for variability amongst modelers. Each piece of electric equipment is accounted for, rather than basing the total plug load energy on the size of a zone. This method is repeatable; if the components used in a model are cited, another modeler can precisely repeat the analysis.

The expected outcomes of this project were that the BCL components would increase both the accuracy and the detail of building energy simulations in the plug load end-use category, as well as improving the repeatability and reducing the level of effort in constructing models. The accuracy of this strategy was shown for one big box retail building with grocery, but the process improvement for consistent and repeatable modeling is really the key contribution to this field.

An EUI input for a zone tells the user nothing about what devices are located in that zone. Beyond recording user notes in the text input file for a program, there is no way for a building modeler to record such details for years to come or to share the detail with collaborators. Components from the BCL clearly state not only the type of device modeled, but its manufacturer and model name too. This aspect is especially important to modelers hoping to demonstrate a reduction in building energy use through wisely selected plug load devices. Replacing a particular TV with a more efficient one can be easily documented through the simulation stage with BCL components.

CHAPTER VIII

CONCLUSIONS AND FUTURE WORK

8.1 Conclusions

In collaboration with researchers at the National Renewable Energy Laboratory (NREL), 256 plug loads were metered in a big box retail and grocery store. The primary work of this thesis revolved around using this time series energy consumption data to inform the creation of EnergyPlus model components. These components encapsulate the behavior of a specific device – maximum power, operating schedule, etc. – in a set of EnergyPlus code that can be added to any whole building model. Devices were found to be constant loads, on/off, on/standby, multimodal, and continuously varying and were modeled with these characteristics. This process was explained in detail in Chapter 5 and provides a procedure for modeling temperature- and occupancy-dependent plug loads. Appendix A offers a list of all the components created in this project.

The components created through this research were then made available to the public through NREL's Building Component Library (BCL). Their inclusion in the BCL gives them each a unique URL, making each component independently citable. That capability allows for a novel approach to modeling plug loads. The library of model components affords both easy access to information about the energy usage of plug loads as well as a clear path to repeatability. The most common method of modeling plug loads is through a W/ft^2 approximation or equipment power density (EPD). Model components allow for a process in which each plug load in the store is accounted for.

The component procedure of representing these loads provides some benefits over the EPD method. First, it accounts for the actual devices using energy in the store rather than assuming a certain floor area will result in a certain amount of plug load energy. Second, the citable nature of the components makes the model more easily repeated. Last, linking the energy performance of a component back to its metadata (manufacturer, model, etc.) enables details about the device to stay with the model. That trail of documentation would allow for modelers to clearly demonstrate the results of substituting one device for another – perhaps encouraging energy analysts to more carefully consider plug loads as a part of building energy use. The components procedure accomplishes all of these things while still achieving energy model outcomes as good as any method in common practice.

In addition to using NREL's Building Component Library, this research helped in the development of the library through the establishment of the tag taxonomy for miscellaneous electric loads (MELs). A suitable taxonomy was located from Lawrence Berkeley National Laboratory (LBNL) and adapted to the primary need of the BCL system – searchability. In addition to contributing the taxonomy for the MELs category of the BCL, this study provided the first 260 MELs components to the library. In doing so, the robustness of the newly implemented tag system was tested and some initial language for MELs attributes was defined.

Through this thesis work, much was learned about the way MELs are classified. There is no definitive standard concerning what exactly constitutes a MEL. The introduction of this thesis called attention to the importance of MELs as 30% of the energy use in the commercial building sector. Included in that 30% figure are non-building MELs such as mobile phone towers and waste water treatment systems. Plug loads (the subset of MELs studied in this paper) represent a smaller fraction of this total. For the building studied in this research, plug loads made up only 5% of the total annual energy use.

Centralized refrigeration is a substantial load in grocery buildings. Depending on convention, this load may be considered a MEL (any building load other than HVAC and lighting) or broken out as its own end use category. This reinforces the need to be considerate about what classifications one uses in one's work. It should be noted how easily a modeler might use an EPD figure that includes centralized refrigeration when that refrigeration had already been accounted for. This is another example of how the component method of modeling can eliminate some of the ambiguity from the process. With each device accounted for, it is much less likely a load would be included twice.

8.2 Future Work

Future work regarding the components developed in this research could focus on the radiant fraction for each device. While it was found that the radiant fraction of plug loads had less than a 3% impact on the overall building model, the value of 0 currently in these components does not accurately represent real-world conditions. A measurement of the radiant/convective split of each device would lead to more correct component models.

In addition to the components produced by this work, this thesis sought to promote the idea of modeling plug loads by components. There is still work to be done to more thoroughly investigate this idea in depth.

While this research endeavored to measure and model all of the miscellaneous electric loads in a retail setting, the limitations of the metering equipment and restricted access did not allow this to be accomplished in its entirety. Only plug loads were measured, and not all of those could be metered. Following the methodology outlined in this thesis, with an expanded scope for non-plug loads, MELs components could be made for a wider range of building types.

The need also exists to test this modeling process in more building types. With a library containing far more components, the component method of MELs modeling could be more thoroughly compared to conventional tactics.

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APPENDIX A – List of Components Added to the BCL

AirCompressor_BakeryCrafts_AB-C4_109
AlarmClock_Durabrand_unknown
AquariumPump_Pan World_NH-200PS_24
AquariumTransformer_MCT_5402.0340.441_24
AutomotiveLift_RotaryLift_FA7196
AutoNonContactTonometer_Reichert_13912_109
BadgeSwiper_unknown
BarcodeScanner_NCR Corporation_7876-8000
BarcodeScanner_NCRCorporation_unknown
BarcodeScanner_Symbol_IPOS SCN
BarcodeScanner_Symbol_MK4900
BarcodeScanner_Symbol_RL475-I152
BarcodeScanningStation_unknown
BatteryCharger_Motorola_CPD-6NNTN4028B
BatteryCharger_Motorola_IU15-4120085-WP
BatteryCharger_Symbol_SYM04-1
BatteryCharger_ZebraTechnologies_UCLI72-4
BeverageFountain_Cornelius_Enduro-150
BeverageRefrigerator_ATCGroup_CTB100
BeverageRefrigerator_TRUE_GDM-26
BevFountainPump_AOSmith_AC Motor
BloodPressureMonitor_LifeClinic_unknown
BluerayDiscPlayer_LG_LHB335
BluerayHomeTheater_Phillips_HTS3051B
BluraySystemSoundbar_Samsung_PS-WWS1
BluraySystemSubwoofer_Samsung_PS-WWS1
BoxFan_Lakewood_101
BugLamp_Gardner_AG-969
BugLamp_Gardner_GT-200-Elite
CameraSecurity_Flexpower_AX900
CarbonatorPump_EmersonMotor_S055NXPDN-7483
CashRegister_IBM_SurePOS700_109
CashRegister_IBM_SurePOS700_24
CashRegister_IBM_unknown
CashRegister_Panasonic_JS-950WS_109
CashRegister_Panasonic_JS-950WS_24
CashRegisterTerminal_multiple_109
CashRegisterTerminal_multiple_24
CDBoombox_RCA_RCD175-B
CDBoombox_Sony_CFD-S01_109
CDBoombox_Sony_CFD-S01_24
CDBurner_Rimage_CDPR21
CDStereo_GPX_HM3817DT
CellPhoneCharger_Blackberry_unknown
CoffeeGrinderStation_Grindmaster_875_109
CoffeeGrinderStation_Grindmaster_875_24
CoffeeMaker_Bunn_VPR_109
CoffeeMaker_Bunn_VPR_24
CoffeeMaker_Bunn_VPR_24avg
CoffeeMaker_GrindmasterCrathcoSystems_AKAP
ComputerMonitor_Acer_P186H_109
ComputerMonitor_Acer_P186H_24
ComputerMonitor_Dell_E773s
ComputerMonitor_unknown_SX-775J_109
ComputerMonitor_unknown_SX-775J_24
ConveyorBelt_Tri-Tronics_CES-1017_109
ConveyorBelt_Tri-Tronics_CES-1017_24
CordlessPhone_Uniden_AMWHP822
CreditCardScanner_Hypercom_T7PLUS
Demagnetizer_Sensormatic_0304-0035-01
Demagnetizer_Sensormatic_0304-0036-01
Densitometer_X-Rite_890U
Desktop_Dell_E178FPC_109
Desktop_Dell_E178FPC_24
Desktop_Dell_Optiplex330-PCNF_109
Desktop_Dell_Optiplex330-PCNF_24
Desktop_Gateway_E-Series_109
Desktop_Gateway_E-Series_24
DigitalPhotoCenter_Fujifilm_Aladdin
DigitalPhotoCenter_HP_IS1700InputStation
DigitalPhotoCenter_HP_SNPRB-0841-01
DisplayLighting_CoffeeGrindingStation_24
DisplayLighting_makeuparea_unknown_24
DVDRental_Redbox_DVD-IN
ElectricWheelchair_MartCart_unknown
ExamChair_Burton_XL3300_109
FingernailGrinder_Urawa_UP201C
FingernailUVLight_IBD_Jet1000
FingernailUVLight_IBD_Jet1000_109
FingernailUVLight_unknown
FingernailUVLight_unknown_109
FloorCleaner_Tomcat_350
FloorWasherCharger_Clarke_40506A
FormPrinterNetwork_Lexmark_2481-100

FrameTracer_Optronics_4T_109
FrameTracer_Optronics_4T_24
FrameWarmer_Hilco_Vava
Freezer_BeverageAir_WTF27A
GamingConsole_Sony_Playstation3_109
GamingConsole_Sony_Playstation3_24
GreetingCardDisplayLighting_109
GreetingCardDisplayLighting_24
HandheldBarcodeScanner_Symbol_LS4071-I112
HomeTheater_Vizio_VSBW201WBS
KeyCutter_Axxess_PC0001
Kiosk_Coinstar_unknown
LabelWriter_DYMO_LabelWriter330-90891
Laptop_Acer_LU.SCL0D.001_109
Laptop_Acer_LU.SCL0D.001_24
Laptop_Acer_LX.PY902.001_109
Laptop_Acer_LX.PY902.001_24
Laptop_Compaq_WQ849UA-ABA_109
Laptop_Compaq_WQ849UA-ABA_24
Laptop_Dell_115R-2217MRB_24
Laptop_Dell_I4020-2903OB_109
Laptop_Dell_I4020-2903OB_24
Laptop_HP_DV6-3019_109
Laptop_HP_DV6-3019_24
Laptop_HP_G62_109
Laptop_HP_G62_24
Laptop_HP_WQ589UA-ABA_109
Laptop_HP_WQ589UA-ABA_24
Laptop_HP_WQ66UA-ABA_109
Laptop_HP_WQ66UA-ABA_24
Laptop_HP_WQ843UA-ABA_109
Laptop_HP_WQ843UA-ABA_24
Laptop_Sony_VPCEE23FX-T_109
Laptop_Sony_VPCEE23FX-T_24
Laptop_Toshiba_PSK0QU-00K00_109
Laptop_Toshiba_PSK0QU-00K00_24
Laptop_Toshiba_PSLY5U-00Q01_109
Laptop_Toshiba_PSLY5U-00Q01_24
LaserPrinter_HP_Deskjet6940
LaserPrinter_HP_Deskjet6940_109
LaserPrinter_HP_Deskjet6940_24
LensAnalyzer_Zeiss_LR96697_109
Lensmeter_Burton_2021_109
MagazineDisplayLighting_109
MagazineDisplayLighting_24
MassageChair_HumanTouch_HT-135-PS
MassageChair_unknown_109
MassageChair_unknown_24
Microwave_Amana_RCS 10MP A
MicrowaveOven_GeneralElectric_JES1039WJ01
MicrowaveOven_Oster_OGF41101
Modem_Netopia_IDSLRouter
Modem_US Robotics_5686
Modem_WYSE_WT3235LE
MoneyGram_MoneyGram_unknown
OpticalScope_Burton_U-566-98_109
OutdoorLighting_Westinghouse_unknown_24
PaintColorScanner_BYK Gardner_auto-matchIII
PaintMixingStation_HERO_2000ColorantDispensers
PaintShaker_RedDevilEquipment_0530000SQ
PaintShaker_RedDevilEquipment_5990AutoPlatformSh
PedicureChair_T4SpaConceptsandDesigns_HT-135-PS
PedicureFootbathDrain_T4SpaConceptsandDesigns_unk
PedicureFootbathPump_T4SpaConceptsandDesigns_463
PictureFrame_Kodak_8932923
PictureFrame_Kodak_unknown1
PictureFrame_Kodak_unknown2
PictureFrame_Phillips_SPF3407-G7
PictureFrame_Phillips_SPF3408-G7
PictureFrame_Phillips_SPF3410-G7
PieWarmer_McDonalds_unknown_109
PieWarmer_McDonalds_unknown_24
Point-of-sale_VeriFone_Omni3300_109
Point-of-sale_VeriFone_Omni3300_24
PortableRadio_Memorex_MP3851BLK B
PretzelWarmer_WISCO_JJ304_109
PretzelWarmer_WISCO_JJ304_24
Printer_MoneyGram_unknown
Printer_VeriFone_DMX-E-4203_109
Printer_VeriFone_DMX-E-4203_24
ProduceSprinklerSolenoid_unknown
PumpandWhirlpool_unknown
RadioCDPlayer_Emerson_unknown_109
RadioCDPlayer_Emerson_unknown_24
Refractor_Zeiss_0297_109
Refrigerator_BeverageAir_CDR3-1
Refrigerator_SilverKing_SKMCD1P
Refrigerator_TRUE_TWT-48
Refrigerator_TRUE_TWT-72
Safe_NKL_intellisafe

Scale_Metteier-Toledo_8461
SecurityMonitor_Synaps_unknown
SecurityMonitor_Ultrax_KM2101CN
SelfCheckoutMonitoringStation_NCRCorporation_1020
SelfCheckoutTerminal_multiple_109
SelfCheckoutTerminal_multiple_24
ShoeInsoleMachine_DrScholls_unknown
SoundBar_Sony_HT-CT100_109
Subwoofer_Vizio_VSBW201WBS
Switch_Belkin_4PortKVMSwitch
Switch_CISCO_SeriesSOHO-A
Switch_Netgear_ProSafe16Port10
TaskLight_unknown_109
TaskLight_unknown_24
TaskLights_unknown_unknown_109
TaskLights_unknown_unknown_24
ToenailUVLight_unknown
ToenailUVLight_unknown_109
TV_Emerson_LC220EM1_109
TV_Emerson_LC220EM1_24
TV_Emerson_LD190EM1_109
TV_Emerson_LD190EM1_24
TV_Emerson_SLC195EM8_109
TV_Emerson_SLC195EM8_24
TV_LG_47LE5400-UC_109
TV_LG_47LE5400-UC_24
TV_LG_55LE5400-UC_109
TV_LG_55LE5400-UC_24
TV_Samsung_LN55C630K1F_109
TV_Samsung_LN55C630K1F_24
TV_Samsung_UN46C5000_109
TV_Samsung_UN46C5000_24
TV_Sanyo_DP19640_109
TV_Sanyo_DP19640_24
TV_Sanyo_DP26640_109
TV_Sanyo_DP26640_24
TV_Sanyo_DP26670_109
TV_Sanyo_DP26670_24
TV_Sanyo_DP50749_109
TV_Sanyo_DP50749_24
TV_Sanyo_DP52449_109
TV_Sanyo_DP52449_24
TV_Sony_KDL-40EX600_109
TV_Sony_KDL-40EX600_24
TV_Sony_KDL-52EX700_109
TV_Sony_KDL-52EX700_24
TV_Toshiba_MD14F51
TV_Vizio_M420NV_109
TV_Vizio_M420NV_24
TV_Vizio_SV472XVT_109
TV_Vizio_SV472XVT_24
TV_Vizio_VFF552XVT_109
TV_Vizio_VFF552XVT_24
TV_Vizio_VO420E_109
TV_Vizio_VO420E_24
TV_Vizio_VX32L-HDTV10A_109
TV_Vizio_VX32L-HDTV10A_24
UVSterilizer_T4SpaConceptsandDesigns_unknown
UVSterilizer_unknown_209
Video-AudioAmplifier_CELabs_AB901HD
VideoGameAisle_several_109
VideoGameAisle_several_24
WasteChemicalFilter_HallmarkRefiningCorp_MK7WX-1
WaterDispenser_Culligan_RW2000E-R_24
WaterPurifier_PureHealthSolutions_PW1R
WaterResistivityMeter_unknown
WaterUseMeter_Culligan_unknown

APPENDIX B – MELs taxonomy included in the BCL (derived and adapted from an LBNL taxonomy) *(Nordman & Marla, 2006)*

Gaming Arcade

- Air hockey table
- Arcade game
- Descending claw machine
- Photo booth
- Pinball
- Slot machine
- Stationary kiddie ride
- Other gaming arcade

Hobby/Leisure

- Aquarium
- Exercise equipment
- Kiln
- Pool
- Pottery wheel
- Ride-on toy car
- Sauna, electric
- Spa/hot tub
- Other hobby/leisure

HVAC

- Air cleaner, mounted
- Air cleaner, portable
- Air conditioning, evaporative cooler
- Ceiling fan
- Controls, HVAC
- Dehumidifier
- Exhaust fan
- Fan, exhaust industrial
- Fan, portable
- Fan, whole house
- Fan, window
- Foot rest
- Furnace fan, other heating
- Heating, fireplace electric
- Heating, fireplace gas
- Heat pump
- Humidifier
- Space heater, portable (electric)
- Space heater, portable (non-electric)
- Other HVAC

Audio

- Amplifier (audio)
- Audio minisystem
- Cassette deck
- CD player
- CD player, portable
- Charger, digital music player
- Drum set
- Equalizer (audio)
- Home theater system
- Jukebox
- Karaoke machine
- Microphone
- Musical keyboard
- Public address system
- Radio, CB
- Radio, table
- Receiver (audio)
- Scanner, radio
- Speakers, powered
- Speakers, wireless (base station)
- Speakers, wireless (speakers)
- Stereo, portable
- Subwoofer
- Tuner
- Turntable (audio)
- Wireless headphones
- Other audio

Cash Exchange

- Automated teller machine
- Bar code scanner
- Bill changer
- Cash register
- Credit card reader
- Point-of-sale terminal
- Other cash exchange

Computer

- Computer, desktop
- Computer, integrated-CRT
- Computer, integrated-LCD
- Computer, notebook
- Computer, server
- Dock, notebook
- Dock, tablet
- Pen tablet
- Other computer

Display

- Computer display, CRT
- Computer display, LCD
- Computer display, plasma screen
- Display, LED
- Game console, portable
- Photo frame
- Projection screen
- Projector, slide
- Projector, video
- Scan converter
- Television, large CRT
- Television, LCD
- Television, plasma
- Television, rear projection
- Television, standard CRT
- Television/VCR
- Other display

Imaging

- Copier
- Fax, inkjet
- Fax, laser
- Fax, thermal
- Multi-function device, inkjet
- Multi-function device, laser
- Print controller (DFE)
- Printer, impact
- Printer, inkjet
- Printer, large format
- Printer, laser
- Printer, photo
- Printer, solid ink
- Printer, thermal
- Scanner, flatbed
- Scanner, multisheet
- Other imaging

Networking

- Amplifier (network)
- Hub, ethernet
- Hub, USB
- Modem, cable
- Modem, DSL
- Modem, POTS
- Monitoring system
- Router, ethernet
- Switch
- Tape drive
- Wireless access point
- Other networking

Peripherals

- CD recorder
- Disk storage
- Dock, PDA
- External drive
- Keyboard/video/mouse switch
- Printer, hand-held wireless
- Speakers, computer
- Tag and price scanner, hand-held wireless
- Whiteboard, digital
- Other peripherals

Security

- Book demagnetizer
- Card reader
- Closed circuit camera
- Infant monitor, receiver
- Infant monitor, transmitter
- Intercom
- Security system
- Surveillance system
- Video surveillance console
- Other security

Set top

- Set-top box, analog
- Set-top box, digital cable
- Set-top box, digital cable with PVR
- Set-top box, game console with internet connectivity
- Set-top box, internet
- Set-top box, satelite
- Set-top box, satelite with PVR
- Other set-top

Telephony

- Answering machine
- Caller ID unit
- Charger, mobile phone
- Dictation equipment
- Integrated voice server
- PBX system
- Phone switchboard
- Phone, conference
- Phone, corded
- Phone, cordless
- Phone, cordless with answering machine
- Transcription system
- Walkie-talkie
- Other telephony

Video

- Charger, still camera
- Charger, video camera
- DVD player
- DVD recorder
- Game console
- VCR
- VCR/DVD
- Video, PVR (no multifunctionality)
- Videocassette rewinder
- Other video

Appliance

- Clothes dryer, electric
- Clothes dryer, gas
- Clothes washer, horizontal axis
- Clothes washer, standard
- Clothes washer and dryer combo
- Cooktop, electric
- Cooktop, gas
- Dishwasher
- Fan, rangehood
- Freezer
- Garbage disposal
- Oven, electric
- Oven, gas
- Refrigerator, general
- Refrigerator, wine cooler
- Trash compactor
- Other appliance

Business Equipment

- Adding machine
- Binding machine
- Hole punch, industrial
- Hole punch, standard
- Laminator
- Mail/shipping equipment
- Microfich reader
- Overhead projector
- Pencil sharpener
- Shredder
- Stapler
- Time stamper
- Typewriter
- Other business equipment

Commercial Kitchen Equipment

- Coffee maker, commercial
- Espresso maker, commercial
- Freezer, reach-down
- Freezer, reach-in
- Fryer, commercial
- Hot food holding cabinet
- Ice maker
- Microwave oven, commercial
- Oven/range/cooktop, commercial
- Refrigerator, reach-in
- Refrigerator, visi-cooler
- Scale, food
- Soft serve machine
- Slush machine
- Steamer, commercial
- Vending machine, freezer
- Vending machine, non-refrigerated
- Vending machine, other
- Vending machine, refrigerated
- Water cooler
- Other commercial kitchen equipment

Electric Housewares

- Automatic griddles
- Blender
- Bread maker
- Bread slicer
- Broiler
- Can opener
- Clock
- Clock, radio
- Coffee grinder
- Coffee maker, residential
- Dish dryer
- Espresso maker, residential
- Fondue maker
- Food processor
- Food sealer, vacuum
- Food slicer
- Frying pan
- Grill
- Hand mixer
- Heating pad
- Hot plate (kitchen)
- Ice cream maker
- Iron
- Juicer
- Kettle
- Knife
- Mug warmer
- Oven, microwave
- Pasta maker
- Rice maker
- Roaster
- Sewing machine
- Slow cooker
- Soda fountain pump
- Stand mixer
- Steamer, clothes
- Toaster
- Toaster oven
- Vacuum, standard
- Waffle iron
- Water dispenser, bottled
- Other electric housewares

Infrastructure

- Breaker, AFI
- Breaker, GFCI
- Detector, carbon monoxide
- Detector, smoke
- Door activator
- Door, revolving
- Door, sliding
- Door, swinging
- Doorbell
- Elevator, freight (electric)
- Elevator, frieght (hydraulic)
- Elevator, other
- Elevator, passenger (electric)
- Elevator, passenger (hydraulic)
- Elevator, platform
- Elevator, stairlift
- Escalator
- Garage door opener
- GFCI outlet
- Lift, automobile
- Moving sidewalk
- Utility meter
- Wire losses
- Other infrastructure

Laboratory

- Autoclave
- Centrifuge
- Hot plate (medical)
- Microscope
- Oven, drying
- pH meter
- Refrigerator/freezer, laboratory
- Scale, lab
- Spectrophotometer
- Stirrer or shaker
- Other laboratory

Lighting

- Dimming switch
- Emergency light, interior
- Grow lamps
- Lamp, decorative
- Lamp, fluorescent
- Lamp, halogen
- Lamp, incandescent
- Lights, holiday
- Low voltage landscape
- Motion sensor, exterior
- Motion sensor, interior
- Night light, interior
- Photosensors, exterior
- Sign, lighted
- Timer, exterior
- Timer, interior
- Track light
- Other lighting

Medical Diagnostic

- Bladder scan
- Blanket warmer, built in
- Blanket warmer, portable
- Blood pressure monitor
- Cart, prescriptions
- Cart, supplies
- Charger, (defibrillator, suction pump, glucometer)
- Charger, oto-opthalmoscope
- Charger, specify
- Chart illuminator
- Defribrillator
- EKG machine
- Endoscope
- Eye exam projector
- Eye exam screen, lighted
- Fundus camera
- Lensmeter
- Lift, patient
- Magnetic resonance imaging (MRI)
- Microwave
- Opthalmoscope
- Optical coherence tomography
- Other
- Oto/opthalmoscope
- Oxygen meter
- Peripheral vision tester
- Phoropter
- Scale, body
- Ultrasound system
- Vital signs monitor
- X-ray light box, fluorescent
- Other medical diagnostic

Medical Treatment

- Gel warmer (EKG)
- Infant warmer
- Instrument cabinet or table
- IV cart
- Patient bed, labor and delivery
- Patient bed, other
- Suction device
- Surgical saw
- Temperature monitor, alarmed
- Ventilator
- Other medical treatment

Other

- Bookshelves, mobile
- Fountain, indoor
- Litterbox, self cleaning
- Waterbed
- Other miscellaneous

Outdoor Appliance

- Charger, hedge trimmer
- Charger, weed trimmer
- Coil, snow melting
- Grill, outdoor
- Heater, gutter
- Lawn mower
- Pump, pond
- Timer, irrigation
- Other outdoor appliance

Personal Care

- Air freshener
- Aromatherapy burner
- Bidet
- Curling iron
- Dental irrigation
- Faucet
- Hair dryer
- Hand dryer
- Heat lamp
- Home medical equipment
- Massage chair
- Massager
- Shaver, men's
- Shaver, women's
- Shower head
- Toilet
- Toothbrush
- Towel warmer
- Urinal
- Water softener
- Other personal care

Power

- External power supply
- Plug-in transformer
- Power line conditioner
- Power strip
- Power supply
- Surge protector
- Timer
- Uninterruptible power supply
- Other power

Transportation

- Auto engine heater
- Bicycle, electric
- Car, wheelchair or golf cart
- Other transportation

Utility

- Bicycle light
- Charger, battery
- Floor polisher
- Heat tape
- Lift/jack
- Pet fence
- Power tool
- Power tool, cordless
- Pump, industrial
- Pump, sump
- Pump, well
- Soldering tool
- Ultrasonic cleaner
- Water purifier
- Welding tool
- Wet/dry vacuum
- Other utility

Water Heating

- Water heating, instantaneous single point of use
- Water heating, point of use tank
- Other water heating

APPENDIX C – Ruby Source Code for Apply Components to Building Model

```
# Defining target file
puts( "Define target file")
target_file = gets().chomp()

# Open target file
## Makes list of zone names
# Makes an array from lines of text file
#idf_array = IO.readlines("Zone names only.txt")
idf_array = IO.readlines(target_file)

# Turns that array into one big string
idf_string = " "
idf_array.each do |line|
  idf_string += " " + line + " "
end

zone_arr = []
# Loops to find all zone names
while /Zone,
/ =~ idf_string

  # Matches first instances of "Zone," and uses everything after
  match_zone = /Zone,
  /
  first_match =match_zone.match( idf_string )
  new_string = first_match.post_match

  # Matches first comma of new string and uses everything before
  comma = /,/
  second_match = comma.match( new_string)
  new_string = second_match.pre_match

  # Strips down to just zone name
  new_string = new_string.strip

  # Adds that zone to an array
  new_string_arr = [new_string]
  zone_arr << new_string_arr

  # Replaces the keyword "Zone," with "VOID" so that it will skip over
  i = /Zone,/ =~ idf_string
  idf_string[i..i+4] = "VOID"
```

```
end

# Defining store hours
puts( "Does this store operate from 10am-9pm or 24 hours?")
puts( "Enter '10-9' or '24'")
  operating_hours = gets().chomp()
while operating_hours != '10-9' and operating_hours != '24'
  puts("Please respond '10-9' or '24'")
  operating_hours = gets().chomp()
end

# Selecting original zone to populate
puts( "Which zone do you want to populate with MELs?")
puts("Please select a zone from list.")
puts (zone_arr)
  ## restrain to zone from list
zone_name = gets().chomp()

# Selecting MEL for original zone
puts( "Which piece of equipment do you want to add to #{zone_name}?")
puts("Please select a MEL from list.")
  ## list all available MELs
  ## restrain to MEL from list
MEL_name = gets().chomp()

# Defining the number of individual MELs in original zone
puts( "How many #{MEL_name}s do you want to add to #{zone_name}?")
quantity = gets().chomp()

#Creating an array of the MELs in a zone
if quantity.to_i <= 1
  MEL_i = quantity << " " << MEL_name
else
  MEL_i = quantity << " " << MEL_name << "s"
end
arr = [MEL_i]

#Loop to ask to add more MELs to zone until answer is no
input_a = ''
while input_a != 'N'
  #Listing MELs in zone
  puts( "The following MELs are in #{zone_name}")
  puts arr
  puts("Do you wish to add more MELs to this zone? 'Y' or 'N'")
```

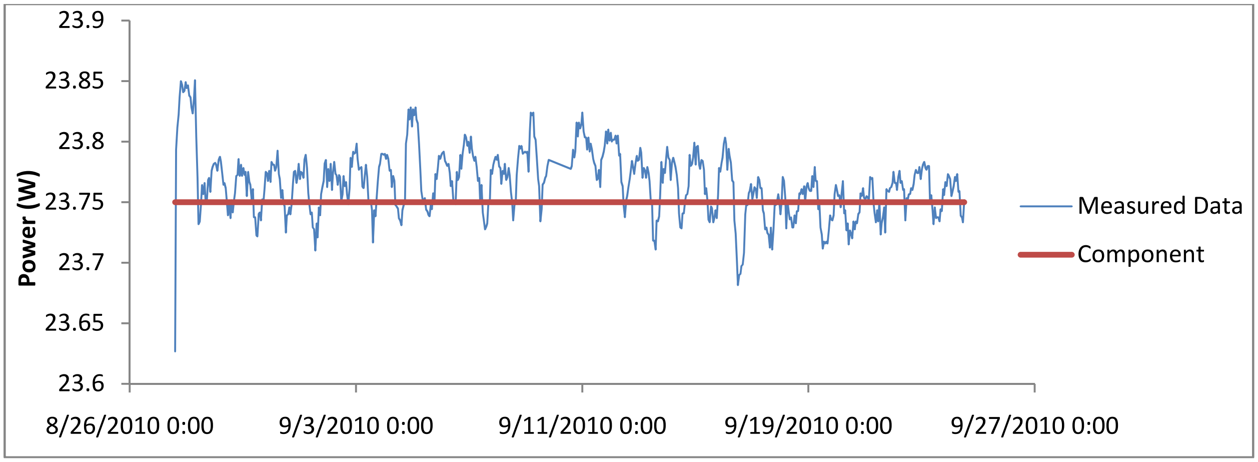
```
  input_a = gets().chomp()
    if input_a == 'N'
      puts(" ")
    elsif input_a == 'Y'
      # Selecting MEL
      puts( "Which piece of equipment do you want to add to #{zone_name}?")
      puts("Please select a MEL from list.")
        ## list all available MELs
        ## restrain to MEL from list
      MEL_name = gets().chomp()

      # Defining the number of individual MELs
      puts( "How many #{MEL_name}s do you want to add to #{zone_name}?")
      quantity = gets().chomp()

      #Adding to array of the MELs in a zone
      if quantity.to_i <= 1
        MEL_i = quantity << " " << MEL_name
      else
        MEL_i = quantity << " " << MEL_name << "s"
      end
      arr_i = [MEL_i]
      arr << arr_i
      arr.flatten

    else
      puts( "Please respond 'Y' or 'N'.")

    end
end



#Loop to ask to add MELs to more zones until answer is no
input_b = ''
while input_b != 'N'
          puts("Do you wish to add MELs to a different zone within this building? 'Y' or
'N'")
          input_b = gets().chomp()
          if input_b == 'N'
            puts( "Bye" )
          elsif input_b == 'Y'
    # Selecting new zone to populate
    puts( "Which zone do you want to populate with MELs?")
```

```
puts("Please select a zone from list.")
puts (zone_arr)
  ## restrain to zone from list
zone_name = gets().chomp()

# Selecting MEL for new zone
puts( "Which piece of equipment do you want to add to #{zone_name}?")
puts("Please select a MEL from list.")
  ## list all available MELs
  ## restrain to MEL from list
MEL_name = gets().chomp()

# Defining the number of individual MELs
puts( "How many #{MEL_name}s do you want to add to #{zone_name}?")
quantity = gets().chomp()

#Creating an array of the MELs in a zone
if quantity.to_i <= 1
  MEL_i = quantity << " " << MEL_name
else
  MEL_i = quantity << " " << MEL_name << "s"
end
arr = [MEL_i]

#Loop to ask to add more MELs to zone until answer is no
input = ''
while input != 'N'
  puts( "The following MELs are in #{zone_name}")
  puts arr
  puts("Do you wish to add more MELs to this zone? 'Y' or 'N'")
  input = gets().chomp()
  if input == 'N'
    puts( "Bye" )
  elsif input == 'Y'
    # Selecting MEL
    puts( "Which piece of equipment do you want to add to #{zone_name}?")
    puts("Please select a MEL from list.")
      ## list all available MELs
      ## restrain to MEL from list
    MEL_name = gets().chomp()

    # Defining the number of individual MELs
    puts( "How many #{MEL_name}s do you want to add to #{zone_name}?")
        quantity = gets().chomp()
```

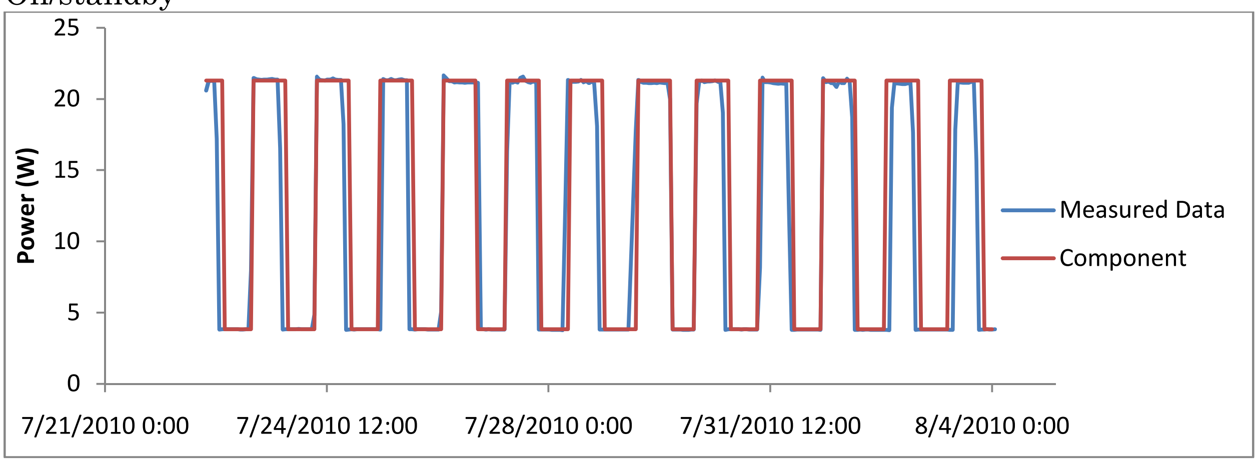
```
        #Adding to array of the MELs in a zone
        if quantity.to_i <= 1
          MEL_i = quantity << " " << MEL_name
        else
          MEL_i = quantity << " " << MEL_name << "s"
        end
        arr_i = [MEL_i]
        arr << arr_i
        arr.flatten

      else
        puts( "Please respond 'Y' or 'N'.")

      end
    end
        else
    puts( "Please respond 'Y' or 'N'.")

        end
end
```

APPENDIX D – Component Model Output Compared to Metered Results

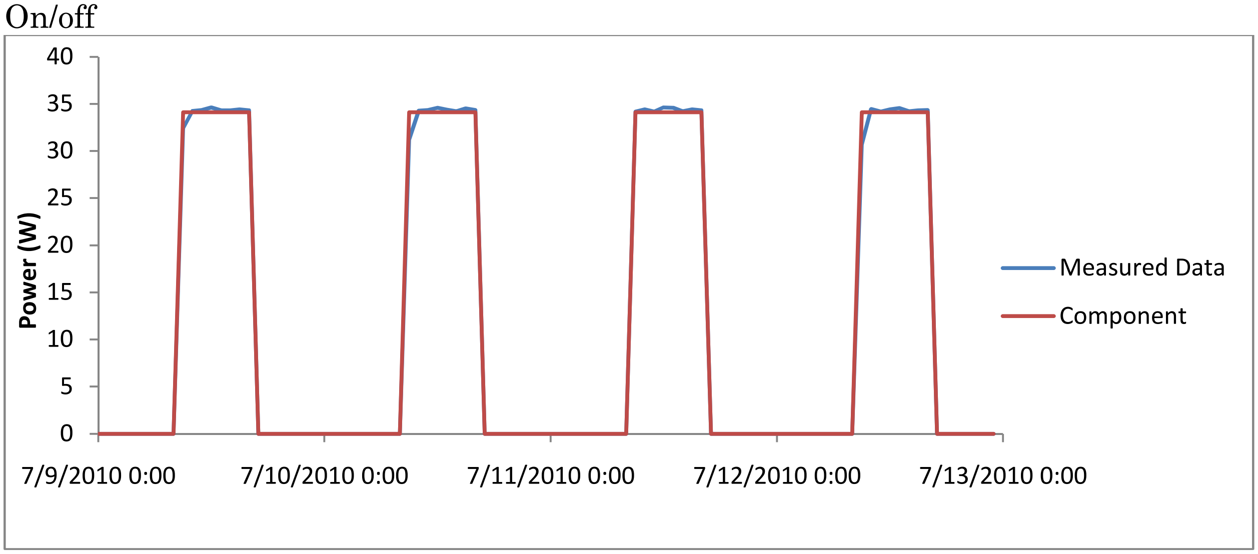
Constant Load



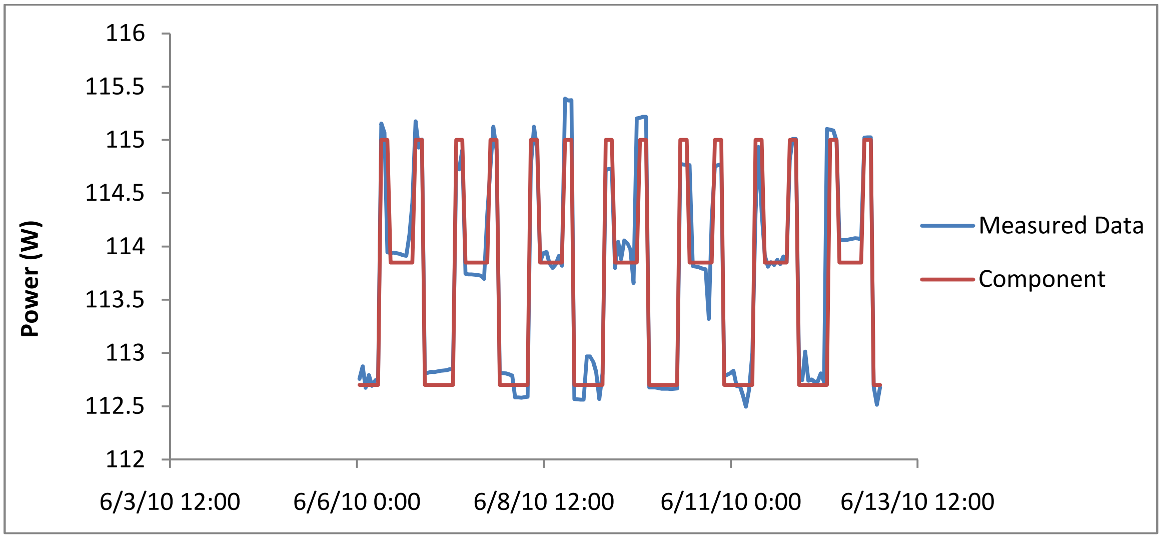
On/standby



On/off



Multimodal



116
115.5
115
114.5
114
113.5
113
112.5
112
Power (W)
6/3/10 12:00
6/6/10 0:00
6/8/10 12:00
6/11/10 0:00
6/13/10 12:00
Measured Data
Component