

A COMPARATIVE ANALYSIS OF PREDICTING ENERGY SAVINGS FROM
ENERGY SERVICE PROJECTS

A Dissertation

by

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Submitted to the Office of Graduate and Professional Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

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May 2014

Major Subject: Civil Engineering

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ABSTRACT

Implementation of energy service projects continue to increase as building owners are faced with higher utility bills, rigorous environmental regulations, and shrinking capital allocation for such projects. Different techniques and guidelines are available to select and quantify energy service projects. These methods range from various Technical reference manuals (TRMs) developed by state agencies in conjunction with energy consultants to standard protocols developed by energy professional organizations. All of these methods require gathering or estimating representative input variables, with various approaches to data collection that vary from stipulation to measurement-based values. The methods to quantify the savings range widely from engineering algorithms to as-built calibrated whole-building energy simulation models.

In this study, a comparison is made between the engineering algorithms supported by many TRMs and a more accurate as-built calibrated whole-building energy simulation model. The methods to performing the comparison included identifying industry methods through literature reviews, expert interviews, a desk audit of a typical utility assessment report, and constructing an as-built calibrated whole-building energy simulation model of a well-instrumented, large office building near the Texas A&M University campus. Lighting and lighting control energy conservation measures (ECMs) were selected to demonstrate the methodology. As part of the process of constructing the simulation model, a data collection protocol was also created. The data collection

protocol included gathering building and site specific information including sub-hourly measured energy consumption data and measured climatic data for the baseline year.

The study results showed that the industry methods of quantifying the total energy savings for lighting and lighting control ECMs were consistently under-reporting the savings as compared to the calibrated as-built whole-building energy simulation model. In particular, the breakdown of savings was inconsistent between the various industry methods that are currently in use. The differences were perceived to be location specific and weather driven and also included agreements with the local utility companies to quantify the demand savings. Finally, the study results also indicated that the current industry methods could be significantly improved by measuring the occupancy schedule and indoor temperature.

ACKNOWLEDGEMENTS

My deepest gratitude goes to my family for their prayers and support. This journey would not have been possible without your love and trust.

I wish to thank my committee co-chair, Dr. Stuart Anderson, for his encouragement and patience throughout my time at Texas A&M University. I have learned and grown tremendously as a researcher. I am also grateful to Dr. Jeff Haberl, my other committee co-chair, for having faith in me to successfully conduct this study and for the intellectual stimulations you brought to the table throughout this research process.

Thank you Dr. Ivan Damnjanovic, Dr. John Walewski, and Dr. Daren Cline for agreeing to serve on my committee. Your input has made this study more comprehensive.

I would like to thank the senior experts that participated in the interviews. Your input was integral and a key element to the robustness of this research. In addition, special thanks go to the many researchers and staffs at the Energy Systems Lab (ESL), John B. Connally Building (JBC), TAMU's Office of Facilities Planning and Construction (OFPC), TAMU's Utilities and Energy Services (UES) and TAMU's Office of Facilities Coordination (OFC) that assisted with the data collection, site visits, and overall development of this research. Thank you for being so generous with your time and resources.

NOMENCLATURE

| | |
|----------|--|
| AEE | Association of Energy Engineers |
| AHUs | Air Handling Units |
| ASHRAE | American Society of Heating, Refrigeration, and Air-Conditioning Engineers |
| BDL | Building Description Language |
| BLAST | Building Loads Analysis and System Thermodynamics |
| BOMA | Building Owners and Managers Association International |
| CB ECS | Commercial Buildings Energy Consumption Survey |
| CD | Construction Documents |
| CEC | California Energy Commission |
| CEUS | California Commercial End-Use Survey |
| CHW | Chilled Water |
| CPUC | California Public Utilities Commission |
| CV(RMSE) | Coefficient of Variation of the Root Mean Square Error |
| DEER | Database for Energy Efficient Resources |
| DOE | Department of Energy |
| DSLR | Digital Single-lens Reflex |
| EBOM | Existing Building: Operations and Maintenance |
| ECMs | Energy Conservation Measures |
| EEM | Energy Efficiency Measure |
| EERE | Energy Efficiency and Renewable Energy |

| | |
|-------|---|
| EIA | Energy Information Administration |
| EMS | Energy Management System |
| EPA | Environmental Protection Agency |
| EPI | Energy Performance Indicators |
| ESCO | Energy Service Companies |
| ESL | Energy Systems Laboratory |
| ESPCs | Energy Service Performance Contracts |
| EUI | Energy Use Intensity |
| FEDS | Facility Energy Decision System |
| FRESA | Federal Renewable Energy Screening Assistant |
| GPM | Gallons Per Minute |
| GSR | Global Solar Radiation |
| HVAC | Heating Ventilation and Air Conditioning |
| HEED | Home Energy Efficient Design |
| IAQ | Indoor Air Quality |
| IBPSA | International Building Performance Simulation Associations |
| IECC | International Energy Conservation Code |
| IEQ | Indoor Environmental Qualities |
| IPMVP | International Performance Measurement and Verification Protocol |
| IRB | Institutional Review Board |
| JBC | John B. Connally |
| LBNL | Lawrence Berkeley National Laboratory |

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|--------|---|
| LEED | Leadership in Energy and Environmental Design |
| LF | Linear Fluorescent |
| LISA | LCA in Sustainable Architecture |
| M&V | Measurement and Verification |
| MSE | Mean Squared Error |
| NAESCO | National Association of Energy Service Companies |
| NBECS | Nonresidential Building Energy Consumption Survey |
| NCDC | National Climate Data Center |
| NG | Natural Gas End-Use |
| NOAA | National Oceanic and Atmospheric Administration |
| NREL | National Renewable Energy Laboratory |
| O&M | Operation and Maintenance |
| OAHUs | Outside Air Handling Units |
| OBE | Office Building Electricity |
| OFC | Office of Facilities Coordination |
| OFPC | Office of Facilities Planning and Construction |
| OS | Occupancy Sensors |
| PAFs | Power Adjustment Factors |
| PNNL | Pacific Northwest National Laboratory |
| RECS | Residential Building Energy Consumption Survey |
| RESEM | Retrofit Energy Savings Estimation Model |
| RFP | Request For Proposal |

| | |
|-------|---|
| RMSE | Root Mean Square Error |
| SECO | State Energy Conservation Office |
| SMEs | Subject Matter Experts |
| STB | Solar Test Bench |
| T&M | Time and Material |
| TAMUS | Texas A&M University Systems |
| TCEQ | Texas Commission on Environmental Quality |
| Tdb | Dry Bulb Temperature |
| Tdp | Dew Point Temperature |
| TRMs | Technical Reference Manuals |
| Twb | Wet bulb temperature |
| UES | Utilities and Energy Services |
| UMP | Uniform Methods Project |
| USGBC | US Green Building Council |
| VAV | Variable Air Volume |
| VSD | Variable Speed Drive |
| WBE | Whole Building Electricity End-Use |
| WD | Weekday |
| WEH | Weekend and Holiday |

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1. INTRODUCTION

1.1 Background

Reducing energy consumption in buildings is important in meeting both social responsibilities and regulatory requirements. Globally, the International Energy Agency (IEA) estimates that buildings account for 30 to 40 percent of the world's energy consumption and are responsible for 25 to 35 percent of greenhouse gas emissions (Schwarz 2009). In 2010, the building sector (e.g., residential and commercial buildings) was the largest consumer of energy in the U.S. (40 percent), followed by the industrial (32 percent) and transportation sectors (28 percent) (U.S. Department of Energy 2011). The built environment has considerable opportunities for positive contribution to the natural environment through increase efficiency in energy consumption.

Within the building sector, there is a large opportunity to retrofit and implement energy improvements in existing buildings (Waide et al. 2007). In the U.S., roughly 90 percent of existing building stock is over 20 years old and is in need of an upgrade (Diamond 2000). In addition, only about two percent of new floor space is added to the commercial building stock each year (U.S. Energy Information Administration 2010). The vast majority of buildings that will be here in the future already exist. In fact, according to American Society of Heating Refrigeration and Air Conditioning Engineers (ASHRAE), 86 percent of expenditures related to reducing energy are spent on renovating existing buildings (Holness 2008). In addition, considering the entire life

cycle of a building, typically 80 percent of the energy is consumed during the building's occupancy stage (United Nations Environment Programme 2007).

The Energy Information Administration (EIA) conducts the Commercial Buildings Energy Consumption Survey (CBECS) of the existing building stock of U.S. commercial buildings every four years. The survey includes energy-related building characteristics, energy consumption and expenditures. The CBECS is a national-level survey that captures data on buildings greater than 1,000 square feet in size and includes buildings that dedicate at least 50 percent of their floor space to commercial activity. The last CBECS version published was in 2003¹. According to the CBECS 2003, office buildings are the most common type of commercial buildings (17 percent). Considering the distribution and age of U.S. commercial buildings, almost 40 percent of the buildings were built in the southern region of the U.S. and over half (52.3 percent) of the buildings were built from 1970 to 1999. Thus, retrofitting existing commercial buildings to become more energy efficient in southern regions can have a significant impact and makes good economic sense (Energy Information Administration 2008; Haberl 2012). In particular, within the commercial sector, research by McKinsey (Granade et al. 2009) showed that for the commercial sector, retro-commissioning and lighting retrofits represented the largest amount of energy efficiency potential.

¹ The CBECS 2007 did not meet the EIA standards for qualification and was not released for public use. The 2012 CBECS is currently being assembled. The data collection for the 2012 CBECS began in April of 2013 and includes over 12,000 building across the United States that have been identified as potential candidates for interview. U.S. Energy Information Administration (2013). "Commercial buildings energy consumption survey (CBECS) overview." <<http://www.eia.gov/consumption/commercial/index.cfm>>. (July 03, 2013).

1.2 Problem Statement

Despite the well documented opportunities and benefits, there are multiple challenges associated with pursuing energy efficiency project (Granade et al. 2009) (Howard 2010) (Waide et al. 2007). These include: a lack of motivation (incentives), education (knowledge), resources, limited capital, and uncertainty of savings determinations and perception of risk. As a result, without a well-integrated solution to overcome these challenges, the potential to capture and maximize energy savings remain underutilized.

Among the many barriers to increasing energy efficiency in existing buildings, understanding and improving financing is a critical element to promoting dynamic investment in building retrofits. Research by McKinsey (Granade et al. 2009) indicates that by 2020, if the U.S. invests in efficiency measures that are net present value (NPV) positive to reduce annual energy consumption by 23 percent from the EIA's business as usual case, the potential energy savings can be as much as 9.1 quadrillion Btu of end use for industrial, commercial and residential sectors. Net present value positive investments included direct energy cost, maintenance and operation costs, equipment and installation costs with a seven percent discount factor for capital and no carbon pricing. This, however, will require a net present value of \$520 billion of upfront investment (Granade et al. 2009). In another analysis (Kats et al. 2012), the potential for energy efficiency investment was calculated as \$150 billion dollars per year based on energy expenditure by end use sector published by U.S. Energy Information Administration (U.S. Energy Information Administration 2010). The efficiency

measures in this study were assumed to provide 40 percent of average energy savings with an average seven year payback and investment benefits spread across 10 years. However, the current energy efficiency investment is about \$20 billion per year which is only seven and a half percent of the maximum savings potential (Kats et al. 2012).

Subsequently, large financial institutes have recognized the opportunity to develop products to finance energy efficiency projects (Kats et al. 2012) such as Energy Service Performance Contracts (ESPCs) along with the need to increase the use of Energy Service Companies (ESCO). Energy Service Performance Contracts are valued and negotiated based on conditional future savings. Hence, the success of a retrofit project can only be measured in terms of actual energy savings that appear years after the project. As for most cash-strapped owners, the use of stipulated savings approach has become a popular method for calculating savings (ICF International and NAESCO 2007). Stipulated savings are predetermined savings and often expressed as tables and engineering calculations. When used in this form the method to quantifying savings tend to be transparent. Thus, the application of the stipulated savings methodology is well accepted and widespread among the industry for predicting and verifying energy savings from various energy efficiency upgrades. However, the accuracy of the stipulated results is questionable. Studies have shown that occupant behavior, change in operating schedule, weather (Karti 2011) and interactions between multiple energy conservation measures (ECMs) can be too profound to be measured alone with stipulated savings.

1.3 Research Questions

The research problem will be addressed by answering the following questions:

- What is the current state of practice in identifying and selecting retrofit projects and quantifying savings?
- How does this method compare to a more accurate calibrated as-built whole-building energy simulation model?
- What is an effective and measureable retrofit selection process that reduces the error in energy performance of commercial building retrofits?

1.4 Purpose and Tasks

The motivation for this study came from the fact that a number of previous papers showed that stipulated savings, which are based on prototypical buildings, do not necessarily reflect the actual energy savings from energy service projects. Prototypical buildings imply that the models are not calibrated to measured data for a specific building under investigation. Although the stipulated savings may provide a method to gauge a rough estimate of the potential savings, individual building characteristics provide too much variability, which necessitates a follow-up measurement and verification process. In fact, a previous study (Ahmad 2003) found that uncalibrated models do not reflect the real operation of the building that is being simulated. This study showed that a good practice is to define all building envelope details and exact layout of the building to minimize the errors that can occur from default parameters built into the building energy simulation program. Contrary to this, as-built calibrated simulation models have been shown to be superior and more reliable for predicting and verifying savings (Schuldt and Romberger 1998) (Haberl and Bou-Saada 1998).

Based on these previous studies and research questions, this study will perform three major tasks. The first task is to investigate the current industry practice regarding the selection and quantification of energy service projects. This will be performed by conducting an ethnographic study with subject matter experts and by analyzing a typical utility assessment report from a recent energy service performance contract. Previous literature indicates that stipulated savings methods are most commonly adopted by ESCOs. However, no studies to date have confirmed or denied the literature finding regarding this claim. So, the intent of this first task will be to identify any other unique savings calculation practices that the current industry uses to further guide this study.

Secondly, researchers claim that calibrated as-built whole building energy simulation models provide a superior method to identifying and quantifying energy service projects. Therefore, the second task will be to conduct a comparative evaluation of selected retrofits using the current industry methods versus the calibrated as-built whole-building energy simulation method. In this study, lighting and lighting control ECMs were selected to demonstrate the methodology. As for developing the calibrated as-built whole-building energy simulation model, the general perception is that calibrated simulations is labor intensive, requires expert knowledge about the program and building operation, and is highly dependent on expert judgment. Thus, this study will develop a spreadsheet tool that can assist with a comprehensive and systematic process of collecting information to build a calibrated as-built whole-building energy simulation model.

Finally, the third task is to conduct a comparative analysis between the current industry methods of quantifying retrofit savings to the as-built whole-building energy simulation model. The study intends to identify sensitive parameters and practices that will lead to an improved retrofit selection and quantification.

1.5 Organization of the Dissertation

In Chapter I, the introduction sets the motivation and the objectives of this research. Chapter II is a literature review on commercial building energy benchmarks, commercial building energy audits, characteristics of energy conservation measures (ECMs), whole-building energy simulation programs, calibrating building energy simulation models, and measurement and verification (M&V) methods used in the commercial building industry. Chapter III discusses the significance of this study and the scope and limitations of this research. Chapter IV discusses the various research methodologies used to conduct this study. The methodologies for this study include both qualitative and quantitative research techniques. A brief description of both research techniques applied in this study are discussed. The research methods include interview techniques, a process to identify Technical reference manuals (TRMs) and ECMs, and a phased data collection process to build a calibrated as-built whole-building energy simulation model. Chapter V discusses the results of the interviews which include the respondent selection process, the interview instrument, the interview process and the findings. Chapter VI describes the results from reviewing the selected TRMs and a typical utility assessment report. In particular, this study focuses on demonstrating the process by testing ECMs in lighting and lighting control system technical category.

Following that, Chapter VII describes the phased data collection process to develop a calibrated as-built whole-building energy simulation model of the case-study building. Chapter VIII describes the process to calibrate the as-built whole-building energy simulation model. Selected ECMs from lighting and lighting control system retrofits are quantified using the current methodology, and the calibrated as-built whole-building energy simulation. The results are compared and assessed in Chapter IX. Lastly, Chapter X summarizes the findings. Suggested recommendations are proposed for various stakeholders and conclusions about potential future work that is related to this study topic are provided.

2. LITERATURE REVIEW

In order to support this research, the existing literature was reviewed. Literature review topics included: (1) Commercial Building Energy Benchmarks; (2) Commercial Building Energy Audits; (3) Energy Conservation Measures; (4) Whole-Building Energy Simulation Programs, (5) Building Energy Simulation Calibration; and (6) Measurement and Verification (M&V) Methods.

Key sources of relevant publications and proceedings originated from the Department of Energy's (DOE) Energy Efficiency & Renewable Energy (EERE), the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE), the International Building Performance Simulation Associations (IBPSA), the Building Owners and Managers Association International (BOMA), National Association of Energy Service Companies (NAESCO), the International Performance Measurement and Verification Protocol (IPMVP), and the Association of Energy Engineers (AEE). In addition, reports generated by the national laboratories, including Lawrence Berkeley National Laboratory (LBNL), the National Renewable Energy Laboratory (NREL), and the Pacific Northwest National Laboratory (PNNL) were reviewed, as well as reports from the Energy Systems Laboratory (ESL) at Texas A&M University were reviewed.

2.1 Commercial Building Energy Benchmarks

According to the U.S. Department of Energy, benchmarking is a process for comparing the building's current metered energy performance with its baseline, or comparing a metered energy performance with energy performance of similar types of

building (Office of the Federal Register 2007). The baseline is an initial period (typically a 12-month period) of metered energy consumption which is used as a point-of-reference for comparison purposes. In other words, benchmarking allows a reference point for owners and energy auditors. Benchmarks should represent the average or typical energy consumption rate for similar types of buildings in terms of the usage and characteristics that are being investigated (Pérez-Lombard et al. 2009) (Skolnik 2011).

In terms of identifying strategies to improve energy performance, whole-building energy benchmarking permits owners and facility operators to track and set targets by comparing to peers for improvements and allows receiving acknowledgements for superior achievements (Matson and Piette 2005). In the design phase, benchmarking can be used to validate designs. For existing buildings, benchmarking allows for the identification of maintenance and control problems. In doing so, owners can identify savings potential and further prioritize future projects (Mills 2003).

To determine whether an existing building is a good candidate for improvements, a proper benchmarking process should exist and should be carried out prior to any investment audits being conducted. Guidelines from the U.S. ENERGY STAR program discuss the following general steps to benchmarking: 1) identifying issues, 2) establishing goals and project scope, 3) identifying performance metrics, 4) conducting data collection, 5) comparing to similar types of buildings, and 6) developing follow-up recommendation leading to actions. The U.S. Environmental Protection Agency's Energy Star program recommends setting a goal to develop data requirements prior to benchmarking. At a minimum these data should be collected by fuel type at the

individual building or the facility level (i.e., multiple buildings on one meter). The baseline year energy use should be weather-normalized or an average consumption from several historical years. The appropriate metrics should then be identified to effectively, accurately, and consistently express the energy performance of the candidate building. Examples include ENERGY STAR benchmark score, Btu/square foot, Btu/product, total energy cost/square foot (U.S. Environmental Protection Agency 2008). The key decision factors within the benchmarking activity includes: determining the level of benchmarking; selecting a benchmark decision criteria; developing the metrics; and conducting the comparison for further analysis. The extent of the analysis will vary according to the audit requirements but at a minimum should include a comparison of the performance to past years or a comparison to other similar buildings in terms of energy use profile analysis and in areas of any high-cost energy use (U.S. Environmental Protection Agency 2008).

Similar to the U.S. Environmental Protection Agency's Energy Star program, according to Matson and Piette (2005) a typical benchmarking process can be divided into five steps. The *first step* is to make an assessment of the core issues the building is experiencing, followed by collecting data on the subject facility to develop an internal baseline (*second step*). The *third step* is to create a database by collecting energy performance information for other buildings with similar characteristics. The *fourth step* is to analyze and compare the building's baseline data to the external data. The *fifth* and most omitted but significant step is the identification of actions to implement improvements in the building's performance.

The scope of the benchmarking effort is usually defined in terms of scale and time. The scale of the effort may include a part of a facility, the whole building or a portfolio of buildings. Typically the building performance can be measured at three distinctive levels. The broadest and most basic level includes measuring performance at the whole-building level. Energy performance indicators (EPI) or energy use intensity (EUI) is the most common metric for benchmarking at the whole-building level. A frequently used EUI is the annual energy use normalized for the floor area such as kBtu/sqft./yr., kWh/sqft./yr. or \$/sqft./yr. (Nikolaou et al. 2011). The second level of metrics included energy consumption by end use or system. End use energy use included heating, cooling, lighting, ventilation, process loads, plug loads, miscellaneous equipment, vertical transportation and service hot water energy use. The final and most detailed level of performance metrics were at individual component and equipment level. The time frame may be annual, monthly or continuous. Based on the goals and scope, the organization is able to select an appropriate benchmark.

Industry benchmark tools may provide a relatively quick evaluation of the building performance in terms of energy consumption. Commonly used benchmarking tools were investigated as part of the literature review. Table 1 captures summary level information for the individual benchmarking tools. Each tool is further described below.

Table 1. Benchmarking Tools

| Benchmarking Tool | Year Developed | Input data | Output data | Process | Reference |
|---------------------------------|--|--|---|--|---|
| U.S. EIA – CBECS | First released 1981, latest release 2003, 2013 version anticipated | Building characteristics and energy use | Energy Use Intensity (EUI = kBtu/sqft./yr.) | Not weather normalized, no adjustment for use | (U.S. Energy Information Administration 2013) |
| U.S. EPA – Energy Target Finder | | Building type | Median source and site EUI (kBtu/sqft) and average (%) electricity use | Not weather normalized, no adjustment for use | (U.S. Environmental Protection Agency ENERGY STAR 2013) |
| U.S. EPA - Portfolio Manager | First released in 2000, latest version in 2013 | Energy bill data and operating characteristics | Energy Performance Rating (1-100) | Statistical algorithm to CBECS data, normalized for weather, operating hours, building size, occupancy and # of computers | (U.S. Environmental Protection Agency 2013) |
| DOE PNNL - EnergyIQ | First released in 2008, latest update in 2013 | Data from Portfolio Manager or filter with building type, location, vintage, floor area/size | Depends on level of input (whole facility, end use, end use component/system) | Statistical algorithm to CEUS (California Commercial End-Use Survey) and CBECS data, normalized for weather and operations | (Lawrence Berkeley National Laboratory 2013) |

Table 1. Continued

| Benchmarking Tool | Year Developed | Input data | Output data | Process | Reference |
|---|--|--|---|---|--|
| Itron's – DrCEUS | First released in 2005 | On-site survey data (building shell, equipment inventories and operating schedule), technology data tables, weather data, billing data | Annual end-use energy intensity, end-use peak load factors, 16-day results by end use, monthly end-use peak loads, energy and gas usage, 365 days whole bldg. gas sendout, 8760 electric whole bldg. energy usage | Use Itron's SitePro software + eQUEST + DOE.2, database from CEUS | (Robert et al. 2005) |
| DOE PNNL – Facility Energy Decision System (FEDS) 6.0 | Released 2008, previous version 5.0 released in 2002 | Building type, vintage (construction year), size, number of buildings in a set if applicable, operating hours and end use service provided by lighting technology, heating fuel type, cooling technology and service hot water fuel type | First year (energy, demand) saving, life-cycle (energy, demand, O&M) savings, estimated capital cost, annualized capital cost and net savings | Database inferred from NBECS (Nonresidential bldg.. energy consumption survey) and RECS (Residential bldg.. energy consumption survey), ELCAP (end use load/bldg. characteristics) and ASHRAE standard design and construction practices, normalized for weather, operating hours | (Pacific Northwest National Laboratory 2008) |

The U.S. Department of Energy's Energy Information Administration (EIA) has been collecting data on building characteristics and energy consumptions for commercial buildings across the United States since 1979. These survey results are referred to as Commercial Building Energy Consumption Survey (CBECS), which have become the foundation for many web-based benchmarking models (U.S. Energy Information Administration 2013). With these data, the U.S. Environmental Protection Agency (EPA) also created energy performance targets for various building types. EPA's Energy Target publishes the median source EUI (kBtu/sqft), average percent (%) electricity use and median site EUI (kBtu/sqft). Using these indices, a user can simply identify whether a building is above or below the median EUI compared to its peers by determining the appropriate building category based on the EPA's descriptive function (U.S. Environmental Protection Agency ENERGY STAR 2013).

One of the most widely used energy benchmarking tools for commercial buildings in the United States is EPA's Portfolio Manager (Skolnik 2011). An energy performance rating in the Portfolio Manager is developed by applying statistical algorithms to the existing CBECS data (Skolnik 2011). So, unlike the CBECS EUI's, the ratings are normalized for weather and adjusted for building characteristics such as size and activities (i.e., operating hours, occupancy and number of computers) that can affect the energy use. At a minimum, the following information is required: building address, year built, general information about the space (i.e., gross floor area, occupants, percent of heated and cooled spaces), minimum of twelve consecutive months of energy use, and cost data for all fuel types. The output is a performance rating expressed on a

scale of 1 to 100. This scale represents the percentile of performance relative to the other buildings in the national CBECS data set. A rating of 75 means that the particular building outscored 75 percent of its peers and that it fell within the top quartile of their building type. According to the program, any building above 75 is a “passing” grade and is eligible to earn an ENERGY STAR label. According to the rating interpretation, a score of 1 to 49 typically means that the building may need to invest and replace existing equipment to further enhance the performance even after aggressively applying low-cost operational changes. A building rating between 50 to 74 means there is significant opportunity for energy savings. In these cases, any operational and maintenance practices in combination with equipment upgrades could yield meaningful savings (U.S. Environmental Protection Agency 2013).

EnergyIQ is a second generation tool, which is based on CalArch. CalArch is a benchmarking tool that was developed by LBNL, which was originally developed for California consumers (Lawrence Berkeley National Laboratory 2013). Although CalArch required less input data, it did not allow weather normalization for year-to-year variations (Matson and Piette 2005). EnergyIQ represents a major advancement beyond the original CalArch tool. EnergyIQ allows benchmarking against the buildings in California by using the California End Use Survey (CEUS) (Lawrence Berkeley National Laboratory 2013). CEUS datasets are an improvement in the quality of data from most self-reporting surveys because it includes on-site surveys of building characteristics and monthly utility billing data. In addition, some sites included short-term data logging and/or interval metering data (Itron Inc. 2006). For benchmarking

buildings outside of the state of California, a national dataset, the CBECS provides an alternative reference point.

The main difference between the Portfolio Manager and the EnergyIQ is that the EnergyIQ allows “features benchmarking.” Features benchmarking allows a user to input end-use energy data such as equipment efficiencies (e.g. kW/ton) or product type (e.g. chiller type). The assumption is that there is value in knowing whether certain features exist to estimate savings and identify possible follow-up actions. The next edition of this tool will allow examining the impact of implementing a selected group of measures. These measures are those available with eQUEST models. The measures will be simulated using Itron’s DrCEUS Energy Efficiency Measure Analysis module (Lawrence Berkeley National Laboratory 2012). DrCEUS is a simulation tool that translates site-level survey data into language eQUEST can read to perform building simulation with surveyed data in conjunction with existing simulation platforms such as eQUEST and DOE 2.2 (Lawrence Berkeley National Laboratory 2012). The input and output for performance metric can be at the facility level, end use by fuel type or end-energy-use by system or components. The output depends on the input that was selected for benchmarking. For the whole building total site energy (kBtu/sf-yr.), the output is the median value with a range that represents percentiles.

Facility Energy Decision System (FEDS) is another example of a user friendly program for evaluating potential retrofits for facilities ranging from buildings to multi-building campuses geared for large Federal installations (Pacific Northwest National Laboratory 2008). The FEDS focus on evaluating retrofits using life cycle cost analysis.

At the minimum, FEDS require the following inputs: building type, vintage (construction year), size, number of buildings in a set if applicable, operating hours and end use service provided by lighting technology, heating fuel type, cooling technology and service hot water fuel type. A typical process starts with identifying groups of buildings that can be categorized into one set. Once the set is identified, a minimum set of inputs (as indicated above) are inserted into FEDS. This provides a minimum analysis that gives a gross indication of needed investment with preliminary screening of which retrofit opportunities may be most promising. With this information, the user can gather additional data focusing on the trade-offs between the costs of gathering additional data to the quality of the output analysis. The ultimate goal is to gather sufficient data to override the default parameters that are set by the FEDS. The user also has the option to review and modify the optimization parameters. However, prior to optimizing any of the parameters, it is recommended that the user initially run the model to determine the baseline consumption. The baseline output can be checked against real data for any discrepancies and adjusted as necessary. The output file includes first year energy and demand savings due to retrofits, present value of life-cycle energy, demand, and O&M savings (present value considering the lifetime across the entire installation), total estimated investment required for retrofits, present value of capital investment (annualized investment cost), and net present value of retrofits (net savings). In addition, estimated installation annual energy savings is the difference between the estimated current installation energy use and the estimated post-retrofit installation energy use. In addition to the summary report of retrofit resource potential, more

detailed information are available including an echo of the input data and detailed breakdown of selected retrofit analysis (Pacific Northwest National Laboratory 2008).

In summary, benchmarking is a process of comparing a building's energy use with the energy use of similar buildings. It is the most fundamental step to understanding how a building is performing (consuming energy) relative to its peers. The process and type of benchmarking determines the selection of benchmarking metrics and also influences the output. Clear and definable benchmark metrics determine the success of the entire benchmarking effort and is therefore important for quantifying savings. There are existing tools and strategies that allow benchmarking using local and national database. At the minimum these tools typically require building characteristic information and monthly utility bills. Recently developed tools not only identify retrofit strategies but also aim to address the impact of those retrofits.

2.2 Commercial Building Energy Audit

Organizations seek energy audit services for various reasons. The need for an energy audit can result from increasing utility costs, a competitive real estate market (peer pressure), state/local/federal regulations mandating energy efficiency (Swick 2011) and occupant discomfort. The energy audit prior to committing to the work should be of an investment type grade. The owner should thoroughly review the audit for completeness, accuracy and unbiasedness. The more thorough the audit is performed, the less risk for the stakeholders which reduces the chances of conflict (Mozzo 2000).

Waltz (2002) emphasize that one of the difficulties of using ESPCs is that savings can no longer be measured. When retrofit measures are put in place, the savings represents energy use that no longer exists and therefore, it becomes physically impossible to measure the pre-retrofit use in the post-retrofit period. Consequently, investment grade audit becomes the foundation to the performance contract. It surveys and documents the technical problems in the facility and identifies the opportunities to develop feasible solutions. Investment grade audits also serve as documentation to resolve change orders and other potential disputes that may occur later. Waltz (2002) stress that the rigor of the energy audit is “no better insurance” and therefore, is a foundation for a successful project.

Unfortunately, contrary to how much emphasis is put on standardized and transparent auditing process, according to Singh et al. (2009) there is no universal definition of an energy audit. Energy audits can be interpreted differently depending on individual auditors. In most cases, the definition of an energy audit is subjective and can vary from organization to organization and even across different countries. In fact, procuring performance-based energy efficiency services has been difficult because of this very reason where companies and auditors stumble over variations in definitions of how to conduct energy audits and how to carry over the findings into scoping retrofit projects.

At its core, energy audit should be a process of evaluating where and how the building consumes energy to identify energy saving opportunities (Thumann 2008). It is conducted in order to identify modifications that will reduce energy use and the cost of

operating the building. The audit reports should be presented so that the decision-makers can decide which of the recommended modifications should be implemented and how it should be implemented and monitored (Swick 2011). How one goes about actually performing the audit will vary depending on how much the owner is willing to spend on the audit and based on individual experience of the auditing firm. Typically, the selected qualified energy auditor will lead the effort. However, it is critical that the facility owner, operations and maintenance staff and occupants are engaged in the process. With more complicated ESPC projects, involving legal and financial staff in the process is beneficial (Beachler et al. 2011).

Pacific Northwest National Laboratory (PNNL) describe that regardless of the level of audit, the audit typically requires the following activities. The first and foremost step includes the selection of the qualified auditor and development of a contract. Subsequent phases include preliminary review of the energy use, site assessment, energy and cost estimates and completion of the audit report with findings and recommendations. The preliminary review includes collecting and analyzing utility data, benchmarking with EUIs, and developing a rough list of energy efficiency improvement projects. The site assessment includes interviewing the building staff, visually inspecting the building, and collecting data. Finally, the auditor should summarize the findings and present the recommendations to the owner so that these recommendations can assist with setting improvement project requirements (PNNL and PECO 2011).

Although there is no single national audit standard for commercial buildings, ASHRAE, International Energy Conservation Code (IECC), US Green Building Council (USGBC) and the U.S. DOE provide a mix of energy codes, standards and energy audit guidelines to assist building owners evaluate energy consumption in commercial buildings. With so many different codes and standards available, there is a need to review the guidelines to develop a comprehensive understanding of how the commercial building energy audits compare among different resources. ASHRAE's Procedure for Commercial Building Energy Audit is the most prominent and widely accepted guideline by organizations such as USGBC in Leadership in Energy and Environmental Design (LEED) Existing Building: Operations and Maintenance (EBOM) and U.S. DOE's Commercial Property Assessed Clean Energy Program. A detailed discussion is provided below on the various processes.

In general, energy audits fall into three basic categories which are, walk-through, preliminary, and investment grade. Walk-through audits are the simplest form of assessment. It encompasses a brief on-site inspection of the facility to evaluate the potential energy cost saving measures. Walk-through audits are sometimes referred to as screening audits or initial diagnosis. The next phase includes a preliminary assessment which typically includes a description of the building conditions, energy consuming equipment, and occupancy schedule. Preliminary audits are sometimes conducted by invited bidders to develop technical reports. It is also a way to confirm what was found in the walk-through audits. Finally, an investment grade audit is a detailed energy

survey of the energy cost savings potential, which includes economic and cash flow analysis (Singh et al. 2009).

Regarding the procurement of the ESPC, all three audits are applicable. Each project is unique and will require a different level of energy audit, which is perhaps why the “three-tiered auditing process” is necessary. In many instances, the walk-through audit serves as an objective and an unbiased evaluation prior to the ESCO’s preliminary and investment grade audit. While walk-through and preliminary audits tend to yield similar results, investment grade audits can vary depending on the ESCO’s experience. This has to do with the firm’s technical capabilities, strength, and risk sharing policy. Since these documents are part of a business model, they are typically confidential documents.

Concerning public procurement of energy audits, there are publically available guidelines that help federal and state agencies in the energy audit process. Regarding guidelines and training in the United States, the Federal Energy Management Program (FEMP), which is a part of the U.S. Department of Energy (DOE), helped over ten agencies and provided a combination of energy and water efficiency assessment, training, template, and worksheets to help with streamlining the auditing process (U.S. Department of Energy 2010).

In selecting and prioritizing facilities that warrant energy audits, the U.S. DOE guideline offers a basic decision process. In general, newer (less than 5 years old), renovated (within last 4 years) facilities or facilities that have been commissioned recently (last 4 years) typically do not offer a big return on investment. According to the

U.S. DOE, newer, renovated and recently commissioned facilities assume that deficiencies have been identified and corrected. In general, if energy bills are low and if the equipment has not reached its useful life, an energy audit may not be a good investment. On the other hand, high energy bills usually warrant an investigation. According to this document (U.S. Department of Energy 2011), there are three types of audit. A Type I audit is a preliminary, walk-through audit which will typically uncover the most noticeable problems. The biggest advantage of a Type I audit is that it can be completed with fairly limited budget and in a short amount of time. In addition, by identifying no-cost to low-cost opportunities such as changed procedures, the financial returns are immediately realized. A Type II audit includes additional data collection (i.e., correlated to historical weather data) and an energy profile analysis. Additional energy monitoring devices may be installed to collect specific end-use energy use information for major building systems. The Type II audit requires more resources than a Type I energy audit, and although it has a greater degree of accuracy than Type I energy audit, it lacks energy modeling detail. Therefore, Type II audit has a limited ability to perform “what-if” scenarios. A Type III audit is by far the most expensive and comprehensive study. In a Type III audit, building model is calibrated to actual utility and weather data to create a realistic baseline. Unlike the Type II audit, a Type III audit considers interactions between multiple improvements, which helps prevent overestimating the savings between multiple, combined improvements. A Type III audit often considers improving indoor air quality and may consider recurring issues in the facility. Many times, sub-meters and data loggers are included in a Type III audit to

provide valuable information to create sophisticated building energy simulations.

Typical instrumentation in a Type III audit for determining end-use energy use includes utility sub-meters, data from existing building automation system or energy management and control system, and temporarily installed data loggers. A Type III energy audit may lead to finding ECMs that may not be so obvious. Table 2 summarizes the candidate building selection process and different auditing types as mentioned by U.S. DOE *Energy Savings Assessment Training Manual*.

Table 2. Summary of U.S. DOE *Energy Saving Assessment Training Manual*

| Category | Description |
|--|---|
| Title of the building energy auditing standard | <i>Energy Savings Assessment Training Manual</i> U.S. DOE |
| General guidance | Older buildings (5 or more years) Has not been commissioned or renovated recently (4 or less years) High energy bills Equipment has reached its useful life |
| Phases: | Type I, II, and III |
| Type I | Walk-through audit Identify most noticeable problems |
| Type II | Requires more resources (historical weather data) Perform energy profile analysis Use of devices to collect specific end-use energy data |
| Type III | Calibrated building model to actual utility and weather data Quantifies interactions between multiple improvements Use of sub-meters and data loggers to collect data |

According to Krarti (2011), short on-site, walk-through visits can provide an immediate assessment of potential operation and maintenance (O&M) measures.

Operation and maintenance measures identified in the reference included setting-back heating thermostat temperatures, replacing damaged windows, and insulating hot water,

steam and cold water pipes. With a basic understanding of the building characteristics, the auditor can analyze the utility bills to identify energy use patterns and weather effects for further analysis. Subsequently, in addition to the walk-through audit, Krati identifies a utility cost analysis as a follow up to the walk-through audit to analyze the operating cost of the facility. This requires collecting utility data over several years to study patterns, peak demand and weather effects that may identify potential saving opportunities. During this stage, the auditor can determine whether the building is a good candidate for an upgrade by comparing to similar facilities and by comparing various indices either for the whole-building or for its end use systems. Much of what is described after the walk-through audit is a benchmarking effort that can provide the owners with a go or no-go decision on further audits.

A standard energy audit requires developing a baseline for the energy use to evaluate energy saving potentials. Simplified tools are used to develop a standard audit in these cases. Tools include degree-day methods and linear regression models. At the minimum, a simple payback analysis can provide the owner with a basis for more intense auditing efforts.

The final, most detailed level of energy audit involves measuring energy use for the entire building or for large systems within the building. In the most detailed energy audits, sophisticated computer simulations are used to model the dynamic thermal performance of the building systems. However, this requires a high level of competency in use of various energy simulation software and a significant increase in the systems

information, set-points, equipment efficiencies, and schedules. Table 3 summarizes the auditing process and steps as proposed by (Krarti 2011).

Table 3. Summary of *Energy Audit of Building Systems* by Krarti (2011)

| Category | Description |
|--|--|
| Title of the building energy auditing standard | <i>Energy Audit of Building Systems An Engineering Approach</i> , Second Edition Moncef Krarti |
| Phases: | Walk-Through Audit / Utility Cost Analysis Standard Energy Audit Detailed Energy Audit |
| Walk-Through Audit | Identify O&M measures |
| Utility Cost Analysis | Analyze operating cost of the building Collect utility data Similar to a benchmarking effort |
| Standard Energy Audit | Develop baseline energy use Use simplified tools such as degree-day methods and regression models Simple pay-back method economic evaluation |
| Detailed Energy Audit | Use of instrument for whole-building or end-use energy Consideration of building simulation models Life-cycle cost analysis of economic evaluation |

Lastly, ASHRAE’s “Procedures for Commercial Building Energy Audit” released an updated guidance for conducting audits in 2011 (Deru et al. 2011). Depending on the need, an energy audit is categorized as a: preliminary energy analysis (Level 0), walk-through analysis (Level I), energy survey and analysis (Level II), and detailed analysis of capital intensive modifications (Level III).

The preliminary analysis includes understanding the corporate or organizational goals, obtaining building drawings, maintenance policies, previous energy conservation projects, facility schedules, reviewing the utility billing data, and benchmarking using

EPA Energy Star Benchmarking tools. The preliminary energy use analysis report should contain a general description of the facility and usage, results of the benchmarking and preliminary list of potential O&M and energy efficiency projects. A Level I analysis should involve an increased interaction with the building operators to compare the actual drawings to actual facility conditions. Existing building surveys are performed to capture information related to building envelope components, heating ventilation and air conditioning (HVAC) systems, lighting fixtures and controls and to confirm the occupancy information. The auditor should focus on identifying low to no-cost measures such as lighting retrofits, control strategies, obvious energy waste operating practices and conduct a cost analysis including any appropriate utility rebates. In addition to the results from the preliminary energy usage analysis, a Level I energy audit should report the savings potential of changing fuel rate structures, any special problems identified in the O&M procedures and a preliminary end-use energy use breakdown estimate for major energy using components in the building. The Level I analysis report should refine the list of potential capital improvement projects and include an initial estimate of savings and implementation costs.

After completing the Level I analysis, the auditor meets again to start the Level II analysis with the owners or facility managers to discuss the potential retrofits and anticipated changes. This is also a time to validate the drawings and other documents related to the building envelope, HVAC systems, lighting fixtures and equipment. With such a breakdown of energy end-use within a building, the auditor can conduct a crude energy analysis with simulation softwares. During this step, more capital intensive

improvements that require further data and analysis should be included. These include investigating building envelope features, HVAC retrofits requiring complete replacement of existing systems and building automation controls or potential for alternative generation systems like geothermal, solar photovoltaic, solar hot water, and wind energy. The report should include the results of the simulation analysis such as annual/monthly breakdown of usage, monthly peak load report, an anticipated monthly fuel report, and provide high level summary of recommended retrofit strategies. All proposed retrofit strategies should have, at a minimum, a simple payback analysis with recommended measurement and verification methods.

The Level III energy audit requires further interface with the owner. For a Level III analysis, the owner should provide the financial criteria for a life cycle cost analysis and facility managers should discuss potential contractors that can assist with a detailed cost estimate analysis. In a Level III energy audit, a more rigorous energy analysis is conducted by collecting and verifying building envelope information, detailed system component and control strategies, accurate lighting counts, and schedules.

Recommended measures are presented based on a full life cycle cost evaluation of all alternatives. A Level III report should include detailed estimates from prices quoted by potential contractors, financial evaluation of the projected savings from recommended actions and analysis including owner's chosen techniques and criteria in those recommended actions. Table 4 summarizes the auditing process and steps as proposed by ASHRAE's guideline.

Table 4. Summary of ASHRAE's *Procedures for Commercial Building Energy Audit*

| Category | Description |
|--|---|
| Title of the building energy auditing standard | <i>Procedures for Commercial Building Energy Audit</i> ASHRAE |
| General guidance | Audits in 3 phases (pre-site, on-site, post-site visits) Audits in 3 levels (Level 1, 2, and 3) |
| Phases: | Level 0 – preliminary energy analysis Level I – walk-through analysis Level II – energy survey and analysis Level III – detailed analysis of capital intensive modifications |
| Level 0 | Understand goals Review building drawings Review utility bills Benchmark |
| Level I | Walk-through audit Identify O&M, low-cost savings measures |
| Level II | More analysis of operational characteristics On-site measurement and testing of systems and equipment Engineering calculations for economic evaluation |
| Level III | More data collection on building characteristics, Detailed equipment information and operational data Involves building energy simulations |

In summary, the energy audit is the most fundamental process of understanding how and where a building uses energy to reduce energy consumption. It is a service that is usually paid by the owner using capital funds, money from O&M budgets, government grants, utility company, rebates or it is repaid through an ESCO performance contract. The motivation to conduct an energy audit can stem from various regulations, incentives, peer pressure, rising cost in utility bills or can be driven by occupants. The current literature indicates that although there is consensus on the varying levels of detail in energy audits, there is no agreement about the distinctive boundaries between the levels. As a result, it is difficult to define specific activities or

requirements for the different levels and it is left for the individual auditor's decision (Ganji and Gilleland 2001).

In general, the prevailing theory is that each audit builds upon the previous audit. As the complexity of the audit increases, the cost and effort increases which is supposed to translate into potentially higher energy savings. Yet, detailed energy audits may not always provide additional savings. In 2001, Ganji and Gilleland (2001) investigated ten investment grade energy audits for institutional facilities and found that major shortcomings included: a lack of consistency in energy costs, building schedule, and equipment inventory which lead to overestimating the savings.

Likewise, in a recent report (Shapiro 2011), items building energy audits most frequently failed to include were appropriate life-cycle costing method and missed improvements. The author also speculated that lack of training, insufficient time spent in the building, lack of proper budgets, and owner directives were other possible shortcomings. On the other hand, best practices in energy audits were identified as those audits that provided: clear standards; strong energy audit data collection protocols; auditor training and certification; a strong quality control; adequate funding to ensure the quality; proper measurement and verification of actual savings; and feedback regarding how well predicted savings matched actual savings.

2.3 Energy Conservation Measures

There has been much discussion about the effectiveness of energy conservation measures (ECMs) in reducing building energy use in the past decade. Energy conservation measures refer to the installation, modification or remodeling of an existing

building in order to reduce the building's energy consumption and building operation costs. In general, in the articles reviewed²³⁴⁵, there was no single universal set of measures or ranking of ECMs that produced an optimal solution. Many opportunities (i.e., potential ECMs) were site specific making the evaluation often difficult to generalize (Shipley and Elliott 2006). In addition, ECMs evolved over time as energy programs, market conditions, building codes and technologies changed which implies they have a shelf-life (National Action Plan for Energy Efficiency 2008).

Most studies recommended a preliminary selection of potential ECMs for an individual building or program based on energy goals and financing availability. Energy saving goals were commonly defined as implementing measurements that meet the economic, technological, and/or feasibility goals. The literature also revealed that the effectiveness of various ECMs can vary across different building types (Shipley and Elliott 2006). For example, in the industrial sector, there was greater focus on reducing electricity use by improving the combustion system, thermal system, and motor system (Shipley & Elliott, 2006).

Regarding commercial or office type buildings, there was a consensus on a group of most commonly applied ECMs. Commercial office retrofit measures were largely divided based on which building system(s) it affected. The key categories of office

² PNNL, and PECO (2011). "Advanced Energy Retrofit Guides office building." Pacific Northwest National Laboratory, Richland, WA.

³ Belzer, D. (2009). "Energy efficiency potential in existing commercial buildings: review of selected recent studies." Pacific Northwest National Laboratory, Richland, WA.

⁴ Effinger, J., Friedman, H., Morales, C., Sibley, E., and Tingey, S. (2009). "A study on energy savings and measure cost effectiveness of existing building commissioning." PECO, Portland, OR.

⁵ Yu, P. C. H., and Chow, W. K. (2007). "A discussion on potentials of saving energy use for commercial buildings in Hong Kong." *Energy*, 32(2), 83-94.

building systems included lighting, plug loads, building envelope, and mechanical system (i.e., HVAC air-side or HVAC water-side system) (PNNL and PECI 2011). According to PNNL and PECI (2011) report, a rather comprehensive list of ECMs was identified.

In summary, the most successful adoption of ECMs targeted the following key waste areas in buildings: envelope, lighting, and HVAC systems (Saidur 2010). Within these areas, lighting retrofits by far had the greatest energy saving potentials, were the most cost effective, and were often implemented in retrofitting commercial buildings (Crawley et al. 2008; Krarti 2011). In Europe, preliminary audits on a sample of 12 representative small business enterprises in Greece, prioritized energy conservation in mechanical systems (air conditioning followed by space/water heating) and then building envelope (Markis and Paravantis 2007). Studies have also shown that simple periodic adjustments, operational practices, and control strategies alone can lead to 20 percent reduction in HVAC energy consumption (Johnson Controls Inc. 2012). Within the building envelope, using more insulation on roofs and walls as well as enhanced glazing performance was also an effective measure although it sometimes had a long payback (Miyazaki et al. 2005).

2.4 Whole-Building Energy Simulation

Initially, building energy simulation models were mainly used for design purposes (Lebrun & Liebecq, 1998) and are still frequently used to support decision making in design (Augenbroe, 1992). More recently, the area of application of building simulation models have extended to building operation optimization, technical and

economical evaluation of ECMs (Kaplan, McFerran, Jansen, & Pratt, 1990) (Chen, Pan, Huang, & Wu, 2006) (Cho & Haberl, 2008) (Cho & Haberl, 2008), commissioning and functional performance testing (Visier & Jandon, 2004), and energy audit (Krarti, 2010).

Prevailing public domain whole-building energy analysis programs in the U.S. for evaluating energy consumption in existing buildings included DOE-2.1e (LBNL, 1998), eQUEST/DOE-2.2 and EnergyPlus (DOE, 2001). A list of other available free software regarding whole building analysis for retrofits included Cool Roof Calculator, Federal Renewable Energy Screening Assistant (FRESA), Home Energy Efficient Design (HEED), LCA in Sustainable Architecture (LISA), Rehab Advisor, Retrofit Energy Savings Estimation Model (RESEM), and Star Performer (DOE Energy EERE, 2011). However, these tools were not applicable for this study. Cool Roof Calculator was used for roof application, FRESA for renewable energy technology, HEED and Rehab Advisor for residential housing, RESEM for institutional buildings and Star Performer for Australian office buildings. Finally, LISA was a decision support tool for construction.

Most recently, a study by Oh (2013) assessed the genealogy and the analysis method for the prevalent whole building energy simulation programs providing a plethora of information on describing the capability of six common whole-building energy simulation programs. In principle, the prevalent whole-building energy simulation programs quantify the hourly energy consumption generated by the entire building over a one year period. These energy simulation model programs consider the interaction between weather, building's internal loads, occupants, and building systems.

The mechanisms to simulate the whole-building energy use vary among different programs. The two predominant methods used by the programs are the weighting factor method and heat balance method. For example, the DOE-2 programs (DOE-2.1e & eQUEST/DOE-2.2) use the weighting factor method while the EnergyPlus program uses the heat balance method.

DOE-2.1e is a free software for analyzing and predicting building energy use and cost implication for all types of buildings. The input information includes identifying the building characteristics, HVAC description, operational schedules, and utility rate structures. By providing the hourly weather information, the input information is used to perform an hourly simulation of the building and estimates the utility costs. DOE-2.1e is composed of command lines using the building description language (BDL). In essence, the user creates an input file with a text editor. The building geometry in the DOE-2 input and output files are viewed in the Draw BDL program developed by the Joe Huang and Associates.

EnergyPlus is a software for analyzing energy and thermal load. The user provides the building description, associated building systems to predict precise space temperature. This program is beneficial for designing system and plant sizing and maintaining occupant comfort. EnergyPlus is also a code based program that combines the features of both Building Loads Analysis and System Thermodynamics (BLAST) and DOE-2. This program is available from U.S. DOE as well for modeling building heating, cooling, plant and electrical systems

Finally, eQUEST is a fairly easy to use freeware for building energy use analysis with the same simulation capability of DOE-2. The results are compatible to DOE-2 yet by combining a building creation wizard and an energy efficiency measure (EEM) wizard, the user could simulate the building without the extensive experience required to model building energy simulation (Crawley, Hand, Kummert, & Griffith, 2005). Nevertheless, eQUEST requires collecting project specific data to improve the accuracy of the analysis and manipulating specific parameters may be limited as compared to the DOE-2.1e. eQUEST is equipped with an Energy Efficiency Measures (EEM) Wizard that allows the user to test alternative design strategies. The following categories are available from the EEM Wizard: roof insulation, side and top daylighting, high performance daylight glass, high efficiency lighting, fan variable speed drive (VSD) and low static, chilled water (CHW) pump VSD, high efficiency water-cooled chillers and high efficiency packaged variable air volume (VAV).

2.5 Building Energy Simulation Calibration

Calibrated models are frequently used to support selection of investment-grade ECMs as well as to identify contractual baseline (Reddy A. T., 2005). A calibrated building simulation model should be able to closely represent the actual behavior of the building under investigation. The fine-tuning of a simulation model to an existing situation involves using as-built information, observations, and monitored data to iteratively adjust the parameters. This fitting is called “calibration.” Early identification of ECMs involved the use of utility bill analysis, which involved no additional cost of metering. However, large commercial building systems were found to be too profound

to rely on monthly utility bill analysis. This lead to development of more data-driven models such as specialized inverse models.

In fact, Ahmad and Culp (Ahmad, 2003, Ahmad & Culp, 2006) found that uncalibrated simulation does not reflect the real operations of a building. The comparison between a model mainly based on available design data and a model including as-built and operating information obtained from the maintenance personal for two different weather conditions revealed that there was too much variability between individual buildings. Discrepancies of +/- 30 percent were observed when comparing recorded and simulated total energy uses for four individual case-study buildings. This study emphasized that a good practice is to obtain information on operational data and occupancy when calibrating building simulation models. Furthermore, defining envelope details and the exact layout of the buildings was found to be important to minimize the errors that can occur from the default parameters built into the simulation program.

Previous studies have developed techniques and general process to calibrate building energy models with measured data. Bronson et al. (1992) developed graphical tools that plotted simulation output and measured energy consumption as a function of day and time. The plots aided in visualization of the comparison between the simulated values and the measured data to support the calibration process. In this study, it was found that schedules for occupancy and HVAC equipment that reflect the real operation of the building was important for calibrating the building energy simulation models.

Soebarto and Degelman (2008) developed an improved calibration method using short-term monitoring and disaggregated energy use data. Systematic data collection included obtaining building's physical data, HVAC data, operation data, weather data, and monthly utility records. In particular, building operation data was observed more in detail and included observing and collecting data in the field by visiting the site during the day-time and night-time period. Space temperature was obtained by measurements with portable temperature loggers. An operating schedule was derived using the "on-off tests" and "short-term monitoring" techniques. The on-off tests included segregating and obtaining different type of electrical load in the building (i.e., lighting, receptacles, fan motors) by turning them off and on consecutively and recording the reduction in load by a data logger that is connected to the electrical panels. The results were used to derive 24-hour use profiles for the whole building electric, lighting, receptacles, and fan motors. The on-off tests and the short term monitoring showed to be an effective method to calibrate the model when long-term monitoring was not practical.

Norford et al. (1994) calibrated office buildings by first addressing the occupancy energy consumption and HVAC schedule. The subsequent phase included addressing HVAC equipment and the building shell performance. Parameters that had a major impact on the as-designed to the as-calibrated model included the variability in the lights and equipment use, HVAC operation beyond the normal scheduled hours, and the actual thermostat setting. The recommended process to calibrate the building energy model included a process to measure occupant loads, part-load performance of major HVAC equipment, indoor space temperature, and outside weather data.

Pedrini et al. (2002) proposed a three step process to calibrate building energy models. The first step was to gather information about the building without any prior site visits. Architecture drawings and existing documentation was used to build the model. The second step was to conduct a walk-through audit with direct measurements using portable hand held instruments to check lighting levels, space temperature, and power in circuits for equipment and lighting. Information obtained from this phase was used to calibrate the lighting power density, equipment power density, cooling set point, and schedules. Finally, the third step was to split the aggregated energy use into end-use by lights, equipment, and air-conditioning circuits. This method was applied to six different buildings. The study showed that for the commercial building, occupant schedule and building operation had the greatest effect on the actual energy consumption. Evidently, measured energy consumption by end-use was shown to have a great impact on sufficiently calibrating the building energy simulation model.

In summary, calibration methods were largely categorized as being manual and iterative, based on informative graphical comparisons, based on specialized tests, and or based on analytical and mathematical methods (Agami Reddy 2006). The calibration process was a combination of approaches.

The manual and iterative process showed that a good practice was to identify the building parameters with information that were readily available by obtaining existing documentation first (i.e., drawings, specifications). Then conduct an on-site audit and perform short term measurements of existing building systems and temperatures to develop occupancy and equipment profiles to tune the model. Finally, measured data

along with actual weather data was used to investigate and match the simulation to measured end-use consumption (Kaplan 1992).

Informative and graphical comparison method by Haberl and Abbas (1998) included special tool-kit that showed 3D surface plots of energy use and juxtaposition binned box and whisker and mean plots. Simpler plots included plotting monthly and hourly time series using spreadsheets (Waltz 2000).

More advanced techniques included the adoption of special tests such as intrusive blink tests (Soebarto and Degelman 2008) and use of mathematical algorithms developed by Sun and Reddy (2006) that screened the most influential parameters, designating a range of realistic values for the sensitive parameters leading to numerical optimization of calibration.

2.6 Measurement and Verification Methods

The measurement and verification (M&V) process involved the process to determine actual energy savings where the measures have been implemented. Verification involved visual inspections and use of engineering calculation to determine potential savings. The measurement process involved metering and collecting data to confirm the hours of use parameter. Recommendations included extensive detail on processes, cautions, use of and pitfalls of meters and data loggers.

Three prominent guidelines for conducting measurement and verification activities in energy-efficiency retrofit projects were the ASHRAE Guideline 14, *Measurement of Energy and Demand Savings* and The International Performance Measurement and Verification Protocol (IPMVP) (IPMVP Committee, 2002) (Deru &

Torcellini, 2005). Much of the foundations for these guidelines were rooted in Texas A&M University's LoneSTAR project (Haberl, Lopez, & Sparks, 1992) (Haberl, et al., 1996). The U.S. Department of Energy's Energy Efficiency and Renewable Energy (EERE) also developed M&V guidelines associated with federal energy savings performance contracts (ESPCs) (Nexant, Inc., 2008). This guideline followed the IPMVP concepts and options.

Accurate determinations of savings were particularly important for energy-efficiency retrofit projects. The IPMVP included a framework for conducting M&V and outlined four savings verification options for various applications. The IPMVP effort was first initiated in 1994 to encourage energy efficiency investments. This first development contained methodologies that were accumulated by technical committees with industry experts mainly from the North American regions. The updated versions, officially renamed to International Performance Measurement and Verification Protocols (IPMVP) in 1997, was the first collaborated effort with international countries. This version was also the first version to include M&V for water saving opportunities. It was also the first time to include the Option D, which included using energy simulation tools to determine energy savings. The four Options (A, B, C and D) have since become the industry standard. In 2001, a third version was published. The third version was published in two volumes. IPMVP Volume 1 contained concepts and options for determining energy savings from building retrofits and Volume 2 contained practices for improving the indoor environmental quality (IEQ) (Efficiency Valuation Organization,

2012) (IPMVP, 2002) (IPMVP, 2002). In 2003, Volume III was published for determining energy savings in new construction (IPMVP, 2003).

The IPMVP provided four options to measure and verify savings. All of the options required some level of actual measurement. Option A was the simplest method and best applied when interactions between energy conservation measures (ECMs) could be measured or assumed not significant. Partial measurement was used with some parameters stipulated rather than measured. Option B was similar to Option A, however, no stipulations were allowed. Option B required either a short term or continuous measurement. To determine the collective savings from all of the ECMs, Option C used utility meters or whole building sub-meters. Option C was best used with projects where individual ECM savings was difficult to distinguish or when short period of random variation in savings did not affect the project. It is best used when the energy performance of the whole facility needed to be assessed. Option C requires developing an appropriate model for the base year energy data. Finally, Option D involved the use of computer simulation software to determine energy savings at whole-building level. Option D allowed estimating the savings attributable to individual ECM within multiple ECMs in a project. It was particularly useful when post-retrofit energy use data were unavailable (IPMVP Committee, 2002). However, Option D could not be used when the ECMs could not be readily simulated or when no data existed.

ASHRAE Guideline 14-2002 contained standard methodology for calculating energy and demand savings for residential, commercial and industrial retrofit projects. It was designed to calculate savings in individual or a few buildings served by a utility

meter. The creation of ASHRAE Guideline was motivated by ECMs that are influenced by other factors such as weather and occupant schedules. These ECMs included replacement of heating, cooling or lighting equipment. The analyst would first project the energy use or demand patterns of the pre-retrofit period to the post-retrofit period. Then, the projected energy use or demand would be adjusted for different conditions such as weather, occupancy or other influential variables on the energy consumption. Savings were determined as the difference between the baseline energy use projected to post-retrofit conditions and post-retrofit energy use. ASHRAE Guideline 14-2002 contained three approaches to determine energy savings. These approaches were: whole-building metering; retrofit isolation metering; and whole-building calibrated simulation. The calibrated simulation approach included the use of computer simulation program. This approach was most beneficial when accounting for multiple energy end-uses and when the interactions needed to be determined. It could not be used when the retrofits could not be simulated in the program or when the evaluation process was too complex to cover the cost. ASHRAE Guideline 14 also contained supplementary information to provide guidance on how to determine the uncertainty in savings (Haberl, Culp, & Claridge, 2005).

According to the U.S. Department of Environmental Protection Agency, typical ESPC projects employed IPMVP guideline with substantial use of Option A. The trend was to rely on stipulated savings rather than the costly alternative, which required rigor and continuous, long-term monitoring. For owners, this arrangement maximized their investment by expanding the budget to spend as much as possible on the front end of the

project rather than reserving their capital for long-term M&V. In turn, owners implemented projects that were perceived as less risky, meaning they had a tendency to be conservative in adopting technologies. By stipulating the savings, ESCOs were able to reduce their long term performance risk and third-party financing companies were able to minimize the risk of owners' reluctance to pay financing charges due to unmet savings (ICF International, 2007).

3. SIGNIFICANCE OF THE STUDY

3.1 Significance of the Study

The existing literature reveals the need for energy service projects and the complexity of quantifying savings. There were a handful of publications and general guidelines available for improving benchmarking, energy auditing, and measurement and verification of energy savings. However, since the business process of selecting and quantifying energy conservation measures (ECMs) can many times be qualified as a confidential and competitive advantage for energy service companies, there were very few published articles about how the current industry is actually performing the business tasks of identifying clients, selecting retrofits and quantifying the future savings. By conducting an interview with the subject matter experts and by investigating a recent utility assessment report from an energy performance contract, the significance of this study is that it will help reveal or confirm existing business practices as well as potentially new processes.

In addition, this study will perform a comparative evaluation of a selected number of different energy conservation measures (ECMs) using industry methods to an as-built calibrated whole-building simulation model. The objective is to assess the similarities, differences and opportunities to improve the selection and quantification of savings. As part of this work, this research will develop a step-by-step procedure giving general guidance about how to develop a calibrated energy simulation model by identifying data and available tools in a phased process.

3.2 Limitation of the Research

Regarding the limitation of this study, this study will not test the generalizability of deploying or implementing the proposed method to other organizations or situations. Secondly, this study will not test the accuracy of the predicted savings by physically conducting an experiment by implementing and changing the equipment or operation to the current case-study building.

4. METHODOLOGY

This research employed a combination of ethnographic study (e.g., expert interviews) and a review of publically available documents (e.g. existing Energy Service Performance Contract and Technical reference manuals) to better understand the current investment decision process of selecting retrofits and quantifying and verifying savings for energy efficiency upgrades in commercial buildings. Concurrently, a calibrated as-built whole-building energy simulation model was created using a phased data collection protocol. A comparison of savings from selected retrofits were made between current industry methods and the calibrated as-built whole-building energy simulation method.

The methodology is summarized into four tasks and are provided below:

- Task 1: To analyze and catalogue methodologies used to select and calculate predicted savings for selected energy conservation measures (ECMs) following investment grade audits.
- Task 2: To collect and document current industry practice of selecting and quantifying energy conservation measures by conducting a desk audit of an existing energy service performance contract (ESPC) and by interviewing subject matter experts (SMEs).
- Task 3: To lay out a comprehensive process of creating a calibrated as-built whole-building energy simulation model.
- Task 4: Compare and document the performance (predicted savings) between current methodologies (Task 1, 2) to the as-built calibrated whole-building energy simulation methodology (Task 3) for a case-study building.

Figure 1 shows the process of identifying the current industry practice of quantifying retrofits and the process of identifying candidate list of testable ECMs (Task

1 and Task 2). As seen in Figure 1, the research began with a full investigation of the existing body of literature on topics related to the ECM project delivery process, Technical reference manuals (TRMs), and interview methods. Efforts were also made to locate a typical Energy Service Performance Contract (ESPC).

To determine the current industry method, this research interviewed SMEs in the field, reviewed a typical ESPC, and investigated the selected TRMs. Interviewing experts required developing an interview protocol, submitting, and receiving approval from the Texas A&M University's Institutional Review Board (IRB). Once the permission was granted from IRB, interviews were conducted with six subject matter experts. Information gathered from the interviews, a typical ESPC, and selected TRMs were documented and compared to synthesize the current industry methods to quantifying ECMs. Concurrently, to investigate the current industry methods to quantifying ECMs, a preliminary list of testable ECMs were identified through the literature review. It was necessary to select ECMs that were applicable to the case-study building, had a corresponding current industry method of quantify the savings as well as have a method to quantify the predicted energy savings using the selected simulation program.

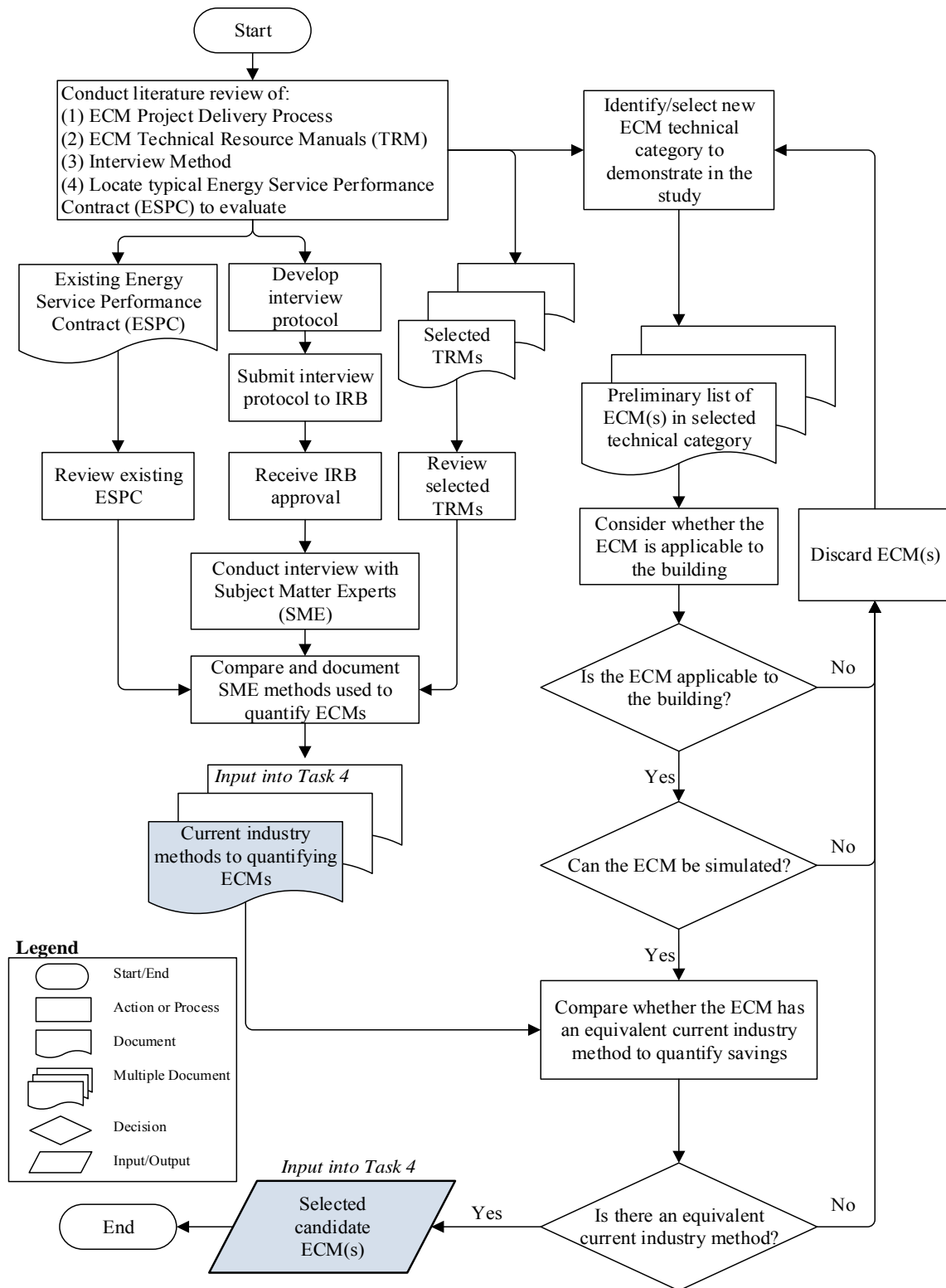


Figure 1. Methods to Select Candidate ECM(s) (Task 1) and Assess the Current Industry Practice of Quantifying Retrofits (Task 2)

Parallel to performing Task 1 and 2, the data collection and documentation for the case-study building was begun. Figure 2 shows the process of creating the as-built calibrated whole-building energy simulation model. Initially, by identifying the year the case-study building was constructed, relevant energy-code information was obtained to build a baseline code-compliant simulation input file. Further information was collected using the proposed, phased data collection toolbox. Measured data and information gathered from the building images, unassisted and assisted site visits and drawings were compiled in a text editor to create an input file for the DOE-2 building energy simulation program. The measured weather data was collected from the nearby Easterwood Airport weather station located in College Station, Texas, by the National Oceanic and Atmospheric Administration (NOAA) and merged with data from the Energy System Lab's solar test bench, which is located on the Texas A&M campus that is near-by to the case-study building. The measured weather data was processed and converted to DOE-2 weather file format to create a coincident weather file that was used to process the building simulation program. The coincident weather file, DOE-2 input file, and the DOE-2 materials library were used to process the building simulation program. DOE-2 building simulation program produced hourly output reports and standard output reports. Monthly report of the natural gas end-use (NG), hourly report of the whole building electricity end-use (WBE), and hourly report of the cooling end-use (CHW) were used to conduct statistical and graphical assessment of how well the simulated data matched the monitored data to create a calibrated as-built whole-building energy simulation model.

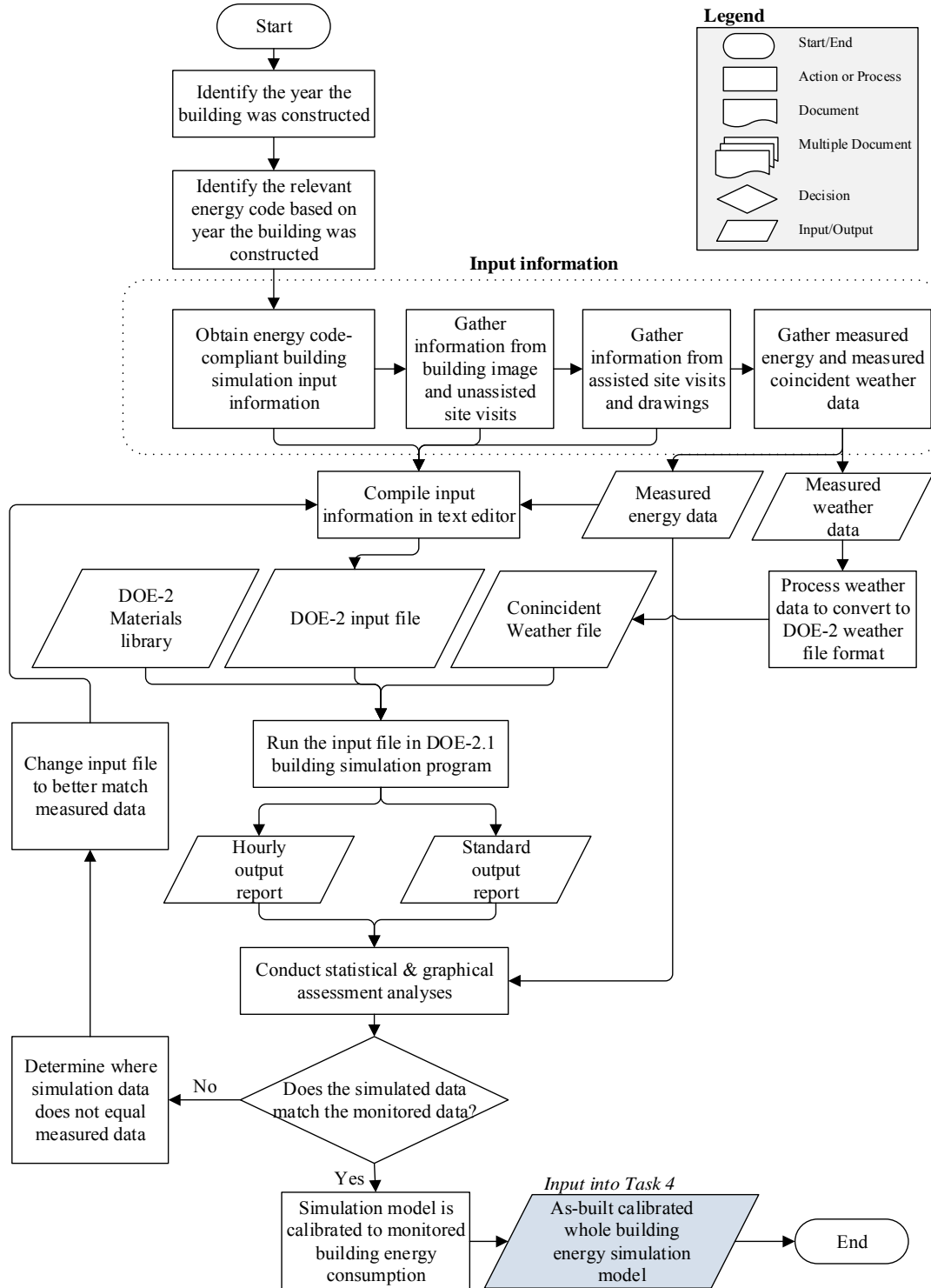


Figure 2. Calibrate the As-built Whole-building Energy Simulation Model Using the Phased Data Collection Toolbox (Task 3)

When the simulated data did not match the monitored data, the hourly and monthly output reports were further analyzed to determine where the simulation data did not equal the measured data. Based on the analysis, the input file was modified to better reflect the monitored data. This simulation model was carried over to Task 4 to compare the energy savings between the current industry methods.

As seen in Figure 3, the selected candidate ECMs list was carried over from Task 1 and Task 2. The selected ECMs from the list was quantified using the current industry method (output from Task 1 and 2) and the as-built calibrated whole-building energy simulation model (output from Task 3). The predicted savings from these two methods were cross-examined and compared. The final task involved documenting the findings and developing recommendations for the stakeholders.

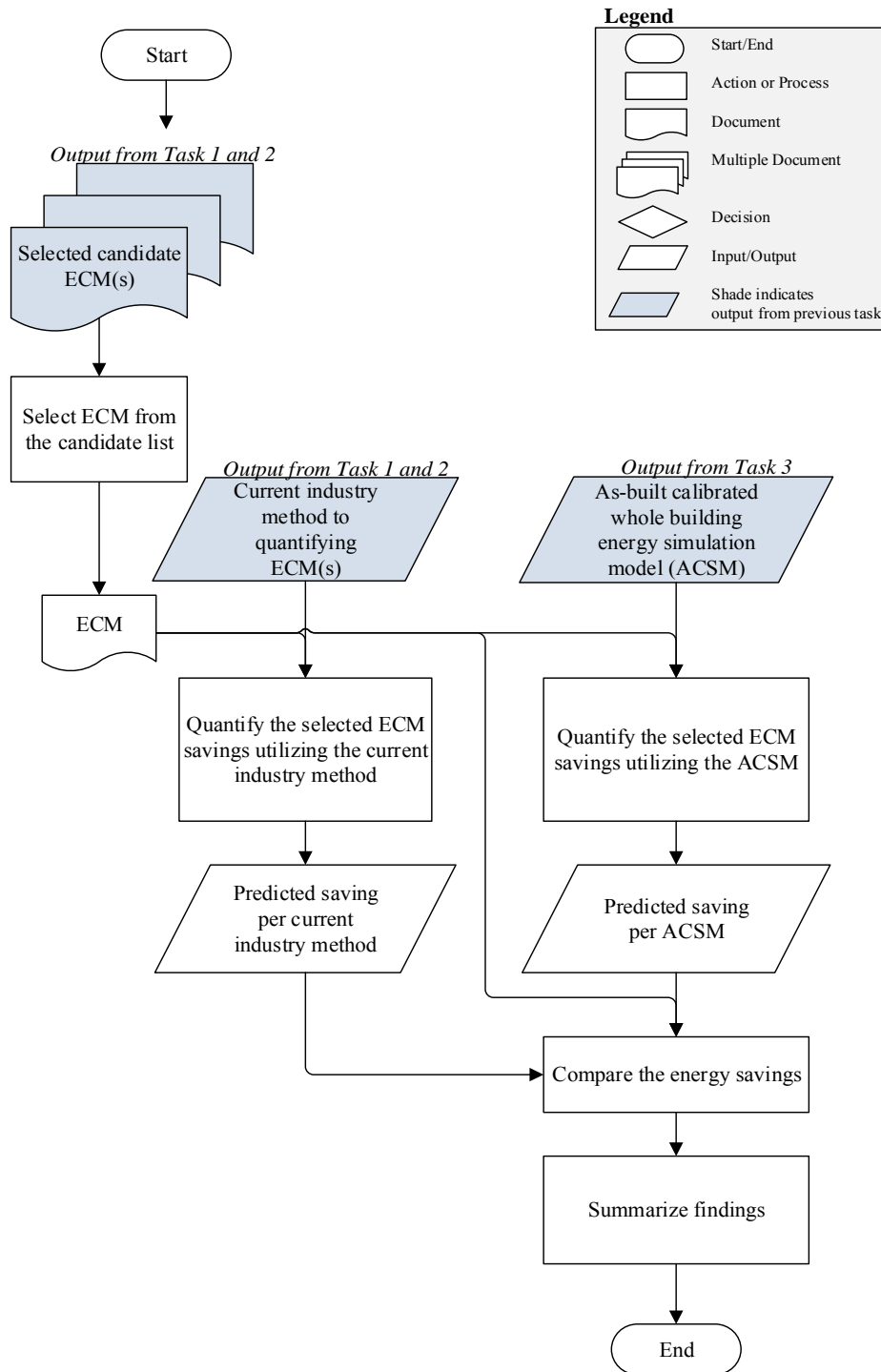


Figure 3. Compare the Savings Between Industry Methods and the As-built Calibrated Whole-building Energy Simulation Model (Task 4)

4.1 Interviews

According to Kvale (1996), qualitative interviewing is quite complex. The researchers should have significant knowledge about the interview topic and should be familiar with the interview techniques involved to produce knowledge through conversation. Unlike questionnaire surveys, which are pre-determined before the interview, the methodical decisions in qualitative interviews are frequently made during the interview process making the interview process even more challenging. Therefore, advance preparation was strongly encouraged and warranted to develop a quality study. In this research, the previous methods used to carry out the interview investigations were examined prior to the development of the interview questionnaires and were used as a guideline. Therefore, substantial amount of time was spent on investigating background information about the interview techniques in advance. The key references are discussed and cited in Chapter 5.

The following process was used to conduct and analyze the interviews; thematizing, designing, interviewing, transcribing, analyzing, verifying, and reporting. Thematizing refers to having a clear conceptual idea of the subject being investigated. The availability of resources was also considered during the thematizing stage. Although the interviews generally are not time-consuming, the subsequent step of transcribing the interviewees' responses requires significant effort. A balance between expert quality and interview resources was also necessary and therefore, six representative experts were selected.

4.2 Technical Reference Manuals (TRMs)

The rationale for the final selection of testable ECMs was based primarily on the popularity of each measure: measures that have at least one corresponding published stipulated savings methodology; or a current industry method identified from the expert interviews; and those that can be tested in the selected building simulation program. All must be applicable to the case-study building. Popularity was a criterion because it was important to select ECMs that had a major impact on whole-building energy consumption. In addition, these measures are commonly sought out by stakeholders meaning that they would have stronger implication to the community at large.

This research investigated the existing literature to find common ECMs that were implemented in existing commercial buildings. Energy conservation measures in the lighting and mechanical categories were found to be most widely applied because of their rapid payback, ease of installation and/or effectiveness in reducing the overall energy consumption, which was motivations to why this research chose to focus on comparing lighting and lighting control measures. In the next step, existing industry TRMs were reviewed to catalog the most common methods used to quantify the savings from lighting retrofits and lighting control retrofits.

The search included publications that described the quantification methods that are publically available at either the national or state level. The data collection included searching through websites and downloading PDF reports and spreadsheets. Information about the savings calculation methods was also sought-out during the expert interviews to cross-check the published industry methods to quantify the savings from lighting and

lighting control measures. Finally, both the lighting ECMs and lighting control ECMs identified in the study were checked to verify that the measure could be simulated using the simulation program selected for this research so they could be applied to the case-study building.

4.3 Desk Audit of a Utility Assessment Report

An independent desk audit was performed to gain additional insight into the current industry practice and issues on selecting and quantifying retrofits. The existing utility assessment report for an Energy Service Performance Contract (ESPC) was obtained from Texas A&M University's Utilities and Energy Management Department. This document was also available from the Texas State Energy Conservation Office (SECO) since it was a publically available document for review. The utility assessment report included savings calculation methodology associated with installing building automation systems and upgrading existing lighting systems on multiple campus facilities. In particular, in the utility assessment report, the current industry calculation methods for lighting and lighting control measures were investigated extensively for comparative purposes.

4.4 Calibrated As-Built Whole-building Energy Simulation Model

4.4.1 Simulation Program

The data collection process developed in this study was mainly driven by what was required to build the building energy simulation model. The simulation program considered and used in this study was DOE-2.1e which is a DOE-2 based software.

DOE-2.1e was used to develop the as-built calibrated whole-building energy simulation model.

DOE-2 software provides a whole-building performance analysis and thus considers the building to behave with interacting sub-systems in the building supplied with chilled water, hot water and service hot water from the building's own power plant. The building simulation model calculates the hour-by-hour building energy consumption for an entire year using hourly weather data from a weather station near the building location. To proceed, specific information needed to be obtained to develop the model. At a minimum, a whole-building energy simulation model required building site information and local weather data, building envelope information, operational characteristics, internal loads information such as people, lights and equipment, HVAC equipment, and performance data.

4.4.2 Case-Study Building

As part of this research, previously studied existing office building in a hot and humid climate was selected and analyzed to better understand and to demonstrate the proposed methodology. The case-study building selected for this study was the John B. Connally (JBC) building⁶ which is located in College Station, Texas. This building was selected for several reasons. First, this building was already equipped with calibrated sensors and an operational data logger that collected 15-minute consumption data. It was also located in an area that already had a nearby hourly weather station. Third, the

⁶ The name of this building changed during the study period from John B. Connally Building to Moore Connally Building on October, 18, 2013.

building was equipped with its own plant that is dedicated to providing chilled water, hot water and service hot water to the facility. These features made this building an ideal candidate to study.

4.4.3 Data Collection Process to Calibrate the Simulation Model

One of the objectives of this study was to present a tiered process of collecting the data to calibrate the model. The process of developing the data collection toolbox was driven by the simulation program. At a minimum, the most fundamental information to simulate the building included hourly weather data for an entire year and the physical location/address of the building. The building data collection followed the DOE-2 tutorial and user manual that is publically available from the DOE-2.com website (James J. Hirsch & Associates 2010). The building simulation input parameters were divided into five main categories which were: (1) building parameters; (2) building construction parameters; (3) space conditions; (4) HVAC systems; and the (5) plant equipment. The data collection effort was divided into four phases: Phase I-Code Compliant; Phase II-Simple Investigation; Phase III-Assisted Visits & Drawings; and Phase IV-Detailed Measured Data.

| INFORMATION SOURCE | Owner | Municipality / Utility | CBECs | ASHRAE Standard 90.1- Relevant Version | Huang & Franconi, 1999 | Abushakra et al., 2001 | Pre-existing Building Photographs | New Building Photograph - Google Street View | Visual Inspection - Building Exterior | Visual Inspection - Building Interior | Visual Inspection with Bldg. Proctor | Visual Inspection with Plant Manager | Meet with Design Engineer | Rough Floor Plans (Egress Plans) | Original Construction Documents | Current As-built Construction Documents | Lighting Logger | Temperature Logger | Humidity Logger | Energy Logger - WBE (Heating/Cooling) | Measured Coincident Weather Data |
|-------------------------------------|-------------------------|----------------------------------|-------|---|------------------------|------------------------|--------------------------------------|---|--|--|---|---|---------------------------|-------------------------------------|------------------------------------|---|-----------------|-------------------------|-----------------|--|-------------------------------------|
| ACTIVITY CATEGORY | Direct Contact | Reference (Code Compliant) | | | | | Building Image | Un-assisted Site Visit | | Assisted Site Visit | | | | Drawings | | Measured Indoor Environmental Data | | Measured Energy Data | | Weather Data | |
| PHASE | Phase I: Code Compliant | | | | | | Phase II: Simple Investigation | | | Phase III: Assisted Visits & Drawings | | | | Phase IV: Detailed Measured Data | | | | | | | |
| Building Vintage | | | | | | | | | | | | | | | | | | | | | |
| Monthly Utility Bills | | | | | | | | | | | | | | | | | | | | | |
| Building | | | | | | | | | | | | | | | | | | | | | |
| Building type | | | | | | | | | | | | | | | | | | | | | |
| Gross area (sq-ft) | | | | | | | | | | | | | | | | | | | | | |
| Dimension (ft. x ft.), Aspect Ratio | | | | | | | | | | | | | | | | | | | | | |
| Number of floors | | | | | | | | | | | | | | | | | | | | | |
| Floor to floor height (ft.) | | | | | | | | | | | | | | | | | | | | | |
| Orientation | | | | | | | | | | | | | | | | | | | | | |
| Construction | | | | | | | | | | | | | | | | | | | | | |
| Wall Construction | | | | | | | | | | | | | | | | | | | | | |
| Roof Construction | | | | | | | | | | | | | | | | | | | | | |
| Foundation Construction | | | | | | | | | | | | | | | | | | | | | |
| Glazing | | | | | | | | | | | | | | | | | | | | | |
| Window-to-wall ratio (%) | | | | | | | | | | | | | | | | | | | | | |
| Space | | | | | | | | | | | | | | | | | | | | | |
| Area per person (#2/person) | | | | | | | | | | | | | | | | | | | | | |
| Occupancy schedule | | | | | | | | | | | | | | | | | | | | | |
| Space Heating Set Point | | | | | | | | | | | | | | | | | | | | | |
| Space Cooling Set Point | | | | | | | | | | | | | | | | | | | | | |
| Lighting Power Density (W/#2) | | | | | | | | | | | | | | | | | | | | | |
| Lighting schedule | | | | | | | | | | | | | | | | | | | | | |
| Equipment Power Density | | | | | | | | | | | | | | | | | | | | | |
| Equipment schedule | | | | | | | | | | | | | | | | | | | | | |
| HVAC Systems | | | | | | | | | | | | | | | | | | | | | |
| HVAC system type | | | | | | | | | | | | | | | | | | | | | |
| Number of HVAC units | | | | | | | | | | | | | | | | | | | | | |
| Plant Equipment | | | | | | | | | | | | | | | | | | | | | |
| Chiller type | | | | | | | | | | | | | | | | | | | | | |
| Boiler type | | | | | | | | | | | | | | | | | | | | | |
| Boiler fuel type | | | | | | | | | | | | | | | | | | | | | |
| DHW fuel type | | | | | | | | | | | | | | | | | | | | | |

Figure 4. Data Collection Toolbox

Figure 4 shows the data collection toolbox that was developed to build the as-built calibrated whole-building energy simulation model. The Phase I activities were efforts necessary to create an energy code-compliant building simulation model. This code-compliant model was generated using existing statistical research reports or surveys (i.e., a relevant version of the energy code and/or CBECS information). Phase I activities did not include surveying the actual condition of the building. All of the simulation parameters were populated based on U.S. average building characteristics to minimize the effort in collecting information.

The Phase II activities included collecting additional, publically-available information related to the building envelope and construction. In Phase II, the building simulation model was enhanced by obtaining building images and by conducting un-assisted site visits. Building images were obtainable in one of two methods. The first and the most convenient method included investigating pre-existing building photographs using web-based tools which required no site-visits. The traditional method to obtaining building images included visiting the site to take photographs (e.g., un-assisted site visit, visual inspection – building exterior)⁷. The actual site visit allowed the researcher to examine the detached plant behind the main facility with two cooling towers outside the detached plant. Un-assisted site visit also included conducting a visual inspection of the interior without any escort. Information collected during Phase II were used to mainly refine the building parameters and building construction parameters in the data collection toolbox. Phase II activities did not include obtaining

⁷ See Figure 4 for details

information regarding the operational practices (i.e. space conditions) or the HVAC system and the plant equipment.

The Phase III activities included obtaining additional information about the space conditions, HVAC systems, and the plant equipment. Information was also gathered from conducting assisted site visits and from architectural and engineering drawings. Assisted site visits included surveying the building with the building proctor, plant manager and/or design engineers. Scheduling the visit required physically coordinating with the auditor, the escort and the building occupants. Phase III information was used to refine the space conditions, systems, and equipment. Space condition such as the maintained indoor temperature during the heating and cooling seasons, number of total occupants in the building, occupancy schedule(s) were specified by discussing with the building operators. Identification of air handling system and system performance was based on visual inspection, drawings and/or the manufacturing data. Phase III did not include any measured data.

Finally, the Phase IV activities were related to obtaining detailed measured energy use data and selected operational data from the building to further calibrate the as-built whole-building energy simulation model. Measured data included measured indoor environmental data, measured energy data, operational settings, and measured coincident hourly weather data. Measured indoor environmental data included gathering information on thermostat setting, humidity levels, lighting levels, and schedules. Measured energy data included collecting whole-building electricity use, natural gas use and selected end-use data during both the heating and cooling season. This data

collection tool provided a method to systematically collect information in a progressive manner.

4.5 Summary of Methodology

This research chose to perform a comparative study of the current industry methods versus the as-built calibrated whole-building simulation to develop an improved method of quantifying ECMs. Assessment of the current industry practice was accomplished through literature review, a desk audit of a typical utility assessment report from an energy service project, and by conducting interviews with the subject matter experts. The as-built calibrated whole-building energy simulation model was developed using the proposed data collection protocol. The selected simulation program and the influential parameters dictated the necessary information to develop the model. Since the as-built calibrated whole-building energy simulations are frequently reflected as being cost prohibitive and complex, the study developed a data collection toolbox that is systematic and transparent. The toolbox divides the complete data collection effort into four different phases. This entire process is demonstrated using a case-study building.

5. RESULTS: INTERVIEWS

The purpose of the interviews was to reestablish prevalent understanding of the energy service companies' (ESCOs) business procedures and to identify methods in quantifying energy savings from applying energy conservation measures (ECMs) in existing buildings. Subject matter experts (SMEs) were selected to participate in a semi-structured interview for this purpose. These SMEs were high-level decision makers of business organizations or research organizations that performed or reviewed energy service performance contracts (ESPC) with over 15 years of combined and diversified experience in the industry and the academia.

A total of six interviews were conducted over a six week period. Each interview was approximately one week apart from each other. This provided adequate time to document the findings after each interview and to consider other probing questions for the next round of interviews.

Interviewing human subjects required obtaining formal approval from Texas A&M University's Institutional Review Boards (IRB). A fully prepared IRB application with supporting documents was submitted and approved prior to commencing the interviews. Supporting documents included consent of waivers, recruiting email, and research information sheet. The outcome letter for the IRB application submission is included in Appendix M.

5.1 Methods

5.1.1 Subject Matter Experts

Identifying the proper respondents was essential since their input determines the quality of the data. For this reasons, experts were considered most suitable to answer interview questions pertaining to business strategies and practices. Regardless of their association, the prerequisites were that they all had to have extensive knowledge about the ESCO business practices with over 15 years of experience working with energy service projects. These experts were considered to be most familiar with their internal business practices and could elaborate on how the organization identifies clients and quantifies retrofits. Experts were recruited from three distinctive categories. These included, researchers from academic institutions that conduct studies related to energy efficiency projects, ESCOs, and consultants. Two subject matter experts (SME) from each of the three groups participated in the interview to provide multiple perspectives. The study anticipated to find commonalities and difference across the three groups. Table 5 lists the qualifications and expertise of the individual SMEs.

Table 5. Qualification and Expertise of the Subject Matter Experts

| Designation | Qualification |
|-------------|---|
| SME1 | A Consultant with over 37 years of experience in analyzing energy efficient building technologies, building energy modeling and analysis. Expert's expertise have been applied to projects worldwide. |
| SME2 | A Director at a large U.S. ESCO (over 500 employees) with experience in conducting building energy audit and energy service performance contracts. |
| SME3 | An Account Executive at a large U.S. ESCO (over 500 employees) with experience in conducting building energy audit and formulation of energy service performance contracts. |
| SME4 | A Researcher and a Consultant with over 30 years of experience in the Heating, Ventilation, and Air Conditioning (HVAC) field from both private and public sectors. |
| SME5 | A Researcher and a Consultant with over 30 years of experience in building energy simulation, commercial building energy audits and Measurement and Verification (M&V) of actual energy use. |
| SME 6 | A Consultant with over 20 years of experience in developing business to complete existing building commissioning and energy efficiency upgrades. |

The interview recruitment effort adopted strategies suggested by Brandl and Klinger (2006) to motivate potential interviewees and to encourage participation. The researcher offered access to research results and highlighted the experts' contribution to support young researchers for scientific advancement. In addition, the information about the research background and the interview instrument was shared with the experts at least a week prior to the interviews. This provided opportunities for the experts to discuss any questions or concerns prior to the actual interviews.

5.1.2 Interview Instrument

The interview instrument was developed based on the research questions. The draft interview instrument was discussed and pre-tested with an expert. The pilot interview provided an opportunity for checking the adequacy of the design and for the clarity of the questions. As a result, the interview instrument went through two

iterations and was revised based on the comments prior to finalizing the interview instrument. The comments that were addressed include: the questions were too detailed, making the interview lengthy; the questions did not capture the entire business process from identification to implementation of ECMs to M&V; and the questions should specifically address the use of building energy simulation models and lighting and lighting control ECMs, which will be demonstrated in this study. The interview instrument was revised to address these comments. A total of six questions were included in the interview instrument. The interview questions were largely divided into two parts. The first set of questions were related to identifying clients and the business process (questions 1, 2) and the second set of questions were intended to capture different methods of identifying and quantifying retrofits (questions 3-5). The last question (question 6) gave experts an opportunity to share pertinent information regarding the study topic. Subsequent probing questions were identified but customized during the interview process based on the previous interviewees' response. Table 6 shows the list of questions and standard probes asked during the interviews. The probing questions were not shared with the interviewees nor all of them used during the individual interviews. They were prepared to guide the interviews and to facilitate transition to the next topic of discussion. The complete and final version of the interview instrument is included in the Appendix N.

Table 6. Interview Instrument

| Question # | Question Type | Question |
|------------|---------------|--|
| 1 | Standard | How do you identify and approach potential customers? |
| 2 | Standard | What is the basic process once a potential customer is identified? |
| | Probe | <ul style="list-style-type: none"> • What information do you try to gather during this process? |
| | Probe | <ul style="list-style-type: none"> • When do you gather this information during this process? What information do you collect before you visit the site and what information do you collect after you visit the site? |
| 3 | Standard | How do you identify retrofits? |
| | Probe | <ul style="list-style-type: none"> • How do you identify lighting retrofits? |
| 4 | Standard | How do you calculate the savings from the retrofits? |
| | Probe | <ul style="list-style-type: none"> • How do you calculate savings from lighting and lighting control retrofits? |
| | Probe | <ul style="list-style-type: none"> • Do you use simulation programs to calculate the savings from retrofits? If so, what software do you use? |
| 5 | Standard | Do you perform actual measurement? |
| | Probe | <ul style="list-style-type: none"> • When or how often do you perform measurements? |
| 6 | Standard | Do you have anything else that you would like to share that may be pertinent for this study, which is to improve the current method of selecting and quantifying energy service projects? |

5.1.3 Interview Process

Prior to starting the interviews, interviewees were provided with an initial briefing, defining the context of this project. The briefing session included providing information about the researcher, the research organization, the interview process, the estimated length of the interview session, interview topics, and their right to refuse to answer any of the questions. The final publication process as well as the approval for note taking was discussed prior to the interview. Although this was included in the project information sheet and attached to the recruitment email as a PDF file, it was verbally communicated and reiterated at the start of each individual phone interview.

The final version of the interview instrument was sent at least one week prior to the interview date to encourage participation and to help experts prepare for the

discussion. Another tactic used in preparation of the expert interview was to gain contextual knowledge in the field which was going to be discussed with them. Literature related to the study topic was collected and reviewed over a 18 month period prior to the interviews to develop a sound theoretical basis. According to Bogner et al. (2009) investing in obtaining background knowledge will enable productive interviewing. In contrast, neglecting to prepare in advance runs the risk of being portrayed as an incompetent researcher. Interview sessions were conducted in a manner to verify the interpretation of the subject's comments during the course of the interview when it was unclear. The intent was to conduct an interview that could be self-explanatory without much clarification to minimize the risk of having to re-contact the expert for further explanation.

All of the interviews were conducted individually over the telephone in a private office space. Timing of these individual interviews was deliberately separated. This provided adequate intervals for the researcher to perform the initial step of the analysis which was to transcribe the interview notes. This study did not audio tape the interviews. Given the short estimated timeframe to conduct and complete the interviews, this study relied on notes taken during the interview sessions. All sessions were conducted using a phone that had a hands-free capability, which allowed the interviewer to concentrate, listen and take notes freely using both hands. Notes were assembled, typically within the week the interview was performed. Once the transcriptions were compiled, a draft copy of the transcription was sent to the respective interviewees for concurrence via email.

The estimated time to conduct the interview was 45 minutes. However, the actual interview duration varied across the respondents. The duration ranged from 40 minutes to 60 minutes. A debriefing session followed at the end of each interview. The conclusion posed opportunities for further discussion by asking the final question (Question 6).

5.1.4 Interview Transcriptions

The transcription itself was not verbatim but rather it summarized the main areas of interest based on broad patterns of common themes. If the experts did not comment on the draft transcriptions, this was considered as their concurrence. Four of the six experts provided feedback. Feedback included minor changes such as, clarification or modification to terminologies used in the transcriptions, omitted information, and rephrasing of the sentences used in the transcriptions. Corrected transcriptions were sent back to the respective respondents afterwards.

5.1.5 Data Analysis

The corrected transcriptions were used to conduct the data analysis. The data analysis required multiple steps and included both deductive analysis to confirm the literature findings and also inductive analysis to discover new information emerging from the data. The first step was to arrange all of the six final transcriptions side-by-side for a comparative analysis. Each of the responses for individual questions were extracted and compiled into a single document. For example, responses to interview Question 1 for all of the six interviewees were compiled into a single document. The second step included reducing the text by placing brackets around what appeared to be

important or interesting information. As Marshall (1981) and Mostyn (1985) indicate, making judgment about the important portions of the transcription is equivalent to responding to a common text. While conducting this activity, the researcher may have doubt regarding the legitimacy of one's "winnowing" process. However, as Marshall (1981) indicates, this is a natural concern that the researcher learns to endure and overcome with time. As a matter of fact, when multiple researchers were given significant flexibility on marking interesting materials in a transcription, Seidman (1998) found considerable overlap among the different examiners. Hence, to systematically guide this process, a list of cues was developed for this study to identify interesting text. These cues were a list of anticipated responses from the interviewees. Table 7 shows the key cues/indicators considered for identifying interesting text for the individual questions.

Table 7. Indicators for Analyzing the Interview Data

| Q # | Question | Cues for identifying interesting text |
|-----|--|---|
| 1 | How do you identify and approach potential customers? | <ul style="list-style-type: none"> • Different sectors or organizations • Reasons why these groups/organizations are targeted |
| 2 | What is the basic process once a potential customer is identified? | <ul style="list-style-type: none"> • List of activities • List of information sought at each step of the process • Activities not considered during this process • Standards/Reference guideline |
| 3 | How do you identify retrofits? | <ul style="list-style-type: none"> • Pre-determined list • Information/resources required to identify the retrofits |
| 4 | How do you calculate the savings from the retrofits? | <ul style="list-style-type: none"> • List of methods • Specific guideline or standards • Use or adaption of building simulation • Information and parameters required to constructing a building energy simulation • Advantages and disadvantages of using building energy simulation approach • Parameters/guidelines used to quantify the savings from lighting and lighting control ECMs |
| 5 | Do you perform actual measurement? | <ul style="list-style-type: none"> • Yes/No with conditional explanation • Measurement parameters pertaining to lighting/lighting control measurement |
| 6 | Do you have anything else that you would like to share that may be pertinent for this study? | <ul style="list-style-type: none"> • List of other references or sources • Current industry challenges • Future improvements and developments |

The third and final step was to identify major themes across the six interview questions. Although loosely termed, themes have general characteristics. According to King (2010), themes are repetitive and are typically mentioned multiple times across the different interviews. Yet, themes are distinctive features of the participant's experience and require the researcher's judgment regarding what is relevant to the study. The thematic analysis included clustering similar themes to form meaning and to derive overarching themes.

5.2 Interview Results

The methodology to analyzing the individual interview questions was identical to each other. The process and details of the interview results are included in Appendix A through L for further information.

5.2.1 Q1: Identifying and Approaching Potential Customers

Regarding the first interview question, five of the six experts indicated that the main customers of energy efficiency projects were in the public and institutional sectors. Three experts indicated that this process is competitive, nevertheless there were occurrences (mentioned by two out of six experts) where the clients approached the energy service companies as well, based on previous experience. Hence, building a creditable reputation was important in expanding the network and for repeat clients (mentioned by three experts).

Three of the six experts also mentioned why these particular group of clients were favorable. First, the ESCOs target large owners in the public sector because the projects with those particular clients were financially justifiable. However, since public work requires a competitive bidding process, large amount of effort was spent during the front-end of the project. Efforts included developing client relationships, becoming acquainted with the facility by reviewing documents and by conducting site visits, developing energy analysis reports, and making presentations to the client as they responded to the request for proposal (RFP). In order to compensate for these earlier efforts, the proposed ECM work packages typically involved comprehensive upgrades to the existing facility. Consequently, the projects were large (one expert mentioned that

the magnitude of the project can easily exceed 10 million dollars) with longer payback periods (10-25 year) which often times discouraged private sector participation. For that reason, one of the experts (SME 1) noted that because of this business structure, there were many opportunities in small buildings that were overlooked. It was also mentioned that, identifying opportunities in small buildings required additional skillsets and experience (SME 6).

5.2.2 Q2: Basic Process

Regarding the second interview question, five out of six experts discussed the business process once a customer was identified. The level of detail each expert provided varied but the generic process corresponded to what was found in the literature. The first step included activities in relationship to identifying project needs and determining whether the building was a good candidate for an ESPC. Once the facility was determined to have some opportunity for saving energy through various retrofits, the next step was to conduct a preliminary audit for a quick confirmation. The third step involved a post-audit meeting to come to an agreement on the scope of the work and financial arrangement between the different parties. Once the agreement was in place, the energy service company proceeded to conduct a full investigation of the building by performing an investment grade audit.

Two experts, both associated with large ESCOs, emphasized several activities that needed to be addressed and resolved before the project actually materialized into a profitable investment for all of the stakeholders. From the ESCO's perspective, the activities related to communicating and negotiating a feasible contract and agreement on

the financial terms appeared to be a major step in the process. Contrast to the ESCOs, for consultants and the researchers working as the owner's representatives, the business process were almost identical yet the steps to developing the contract were not extensively mentioned or discussed. This group of experts indicated that they typically worked on projects that did not require a long term performance contract. Instead, they worked on projects mostly based on time and material (T&M), or that they provided 3rd party services such as measurement and verification (M&V) of energy savings from a retrofit project that was supported by the state Utility-sector energy efficiency programs. Therefore, for the consultants and the owner's representative, there was no need and effort required to arrange the finances for the client.

In order to understand what information was most relevant to identifying and accessing the candidate energy conservation measures (ECMs), the researcher asked experts to discuss the information collected during various stages of the project development process. Regarding the information collected during each period, the consensus was that there was a toolbox or a spreadsheet that was developed internally by the organization. These tools assisted the engineers in identifying candidate ECMs. The experts described some of the major activities in these toolboxes that can help with quickly identifying candidate ECMs when knowledge about the building was limited. However, regardless of the superiority or comprehensiveness of these tools that were available to the engineers, experts mentioned that identifying promising ECMs were highly dependent on the individual auditors. Three of the six experts emphasized the importance of having senior level engineers with extensive experience in successfully

identifying potential ECMs. According to the experts, senior level engineer are most equipped to understand that each building is unique posing distinctive challenges and opportunities.

To further simplify the information gathered at different phases of the project development and to identify patterns, a code tree was created based on major categories of themes. Themes included information related to building energy consumption, finances and contracting, benchmarking with national and internal databases, documentations and drawings, physical building characteristics, owner's initiatives, risk assessment, and operational characteristics. All of the respondents indicated that energy usage, financial condition, building characteristics, and operational characteristics were important in determining the feasibility of a project. In addition, benchmarking the project using internal and national databases and collecting existing documents such as construction drawings and specifications were sought out to assist with the ECMs selections. However, based on one of the expert's past experience, approximately 75 percent of the projects that the expert has worked on did not have an adequate level of documentations to assist with this process. Hence, this expert indicated that there was a need to alternatively and rapidly gather information regarding the energy usage, building characteristics and operational characteristics to come to a reasonable selection of ECMs in a relatively short timeframe. As such, internal database with historical performance data and internally developed tools and checklists were used to develop intelligence on the different types of buildings. Beyond these major categories of information, understanding the client's long term goals in improving energy efficiency and

conducting a risk assessment by identifying obstacles early on in the project development process was mentioned by a couple of experts as well.

In summary, this finding was consistent with the findings from the literature review. Regardless of the process, experts specified that having the “right” personnel and a systematic data collection protocol were crucial to successfully identifying ECMs. According to the experts, skilled senior engineers were (mentioned by three of the six experts) superior to any master checklist when screening and selecting potential ECMs. The experts also listed the most fundamental information that was required to identifying potential ECMs. At the minimum, the building energy auditors should collect information regarding current energy consumption, financial requirements, physical characteristics of the building, and the operational characteristics of the building.

5.2.3 Q3: Identifying Retrofits

Interview Question 3 focused on how ESCOs initially select the preliminary list of ECMs and how this list evolves through the multiple layers of the building energy audit process. The intent of this question was to identify favorable ECMs that are frequently proposed for large office buildings and to identify factors that drive or determine the selection of these ECMs.

According to the experts, the best retrofits were ones that address the client’s concerns. Thus, all of the experts indicated that the first step to identifying potential retrofits involved investigating any issues or problems the building was experiencing. A successful investigation of the current conditions required engaging and discussing with the building owners and operators (mentioned by three experts) to determine what can be

improved in the building to deliver a better indoor environmental quality and also result in saving energy. Input from the building owners and operators become important since this can significantly reduce the effort necessary to determine the final selection of ECMs. For example, one expert indicated that some owners required an evaluation of a specific set of retrofits to consider for their projects. The benefit of using such a list was that it limited the scope of the work and the effort necessary to evaluate various energy saving options. Building owners and operators also identified the problem areas in the building and accelerated the site investigation process. Since each building was unique with a different set of problems and budgets, the final selection of ECMs were unique as well. Nevertheless, retrofits related to controls and sensors, lighting, and windows were often identified early on in the ECM selection process and the general practice was to identify these EMCs prior to replacing equipment. Experts also indicated that past project performance data was also used to screen out potential ECMs.

In summary, experts indicated that since individual buildings were unique and the needs were different, there was no single set of retrofits that satisfied every project. Selection of promising retrofits for any building started with engaging the owners and building operators to reduce the investigational efforts and to determine the scope of the work. In addition, it was important that all parties were cognizant of the time and resources necessary to collect data and to evaluate the various ECM options. In general, energy efficiency projects focused on the commissioning efforts prior to considering any large capital investments. Common retrofits that were universally reviewed in the earlier phase of project development included controls and sensors, lighting, and windows.

5.2.4 Q4: *Calculating the Savings from Retrofits*

Once the retrofits were identified the intent of the next question was to discover the various methodologies used to quantify ECMs, to discover how lighting and lighting control measures were quantified in particular, and to determine the practice of building energy simulation models in quantifying ECMs.

According to the experts, engineering calculation was by far the most frequently identified method to calculating the ECM savings. Other methods included quantifying savings using customized spreadsheets, experience (holistic method of calculation), actual measurement, and energy calculations using simulations. Over the years, companies have gathered intelligence on various buildings and savings from different ECMs. These performance data were being used to improve the existing engineering calculations. As such, the experts indicated that the industry was moving away from simple engineering calculations and was relying on more measurement-based methods. However, the extent of the measurement was relatively simple and the use of sophisticated measurement and verification or simulation was limited to analyzing complex buildings and in some instances seen as the last resort to quantifying savings.

Experts indicated that for lighting and lighting control measures, the use of customized spreadsheets and engineering calculations were most common. Experts indicated that simple replacement of the lighting system such as replacing T12 fluorescent lamps with T8 fluorescent lamps was well understood by the industry and was fairly predictable. Thus, all of the experts indicated that a simulation program was not warranted for quantifying lighting ECMs. However, quantifying the savings from

lighting and lighting control ECMs required taking measurements prior to and after the retrofit installation. Four of the six experts provided measurement parameters that were used to calculate the lighting and/or lighting control ECMs using engineering calculations and is summarized in Table 8.

Table 8. Parameters Used to Quantify Lighting and Lighting Control ECMs

| Activity or measurement parameter | SME1 | SME2 | SME3 | SME5 |
|--|------|------|------|------|
| Measure existing light level | | | ✓ | ✓ |
| Review specification - for lamps | ✓ | ✓ | | ✓ |
| Review specification - for ballasts / ballast + fixture | ✓ | ✓ | | ✓ |
| Measure spark reading of electric circuits for instantaneous power | ✓ | | | |
| Measure cumulative hours with run time loggers ⁸ | ✓ | ✓ | | ✓ |
| Measure time of use with time-of-use logger ⁹ | ✓ | ✓ | ✓ | ✓ |
| Measure power (for dimming) | ✓ | ✓ | | |
| Count lighting fixture in the building (all or spot measurements) | | ✓ | ✓ | |

Prior to identifying the lighting and lighting control ECMs, expert mentioned that they measured the existing light level to determine if the current light level is adequate for the intended space and occupants. Experts indicated that the existing lamps, ballasts and fixture specifications provided information to calculate the pre and post-retrofit energy use. Experts mentioned that the organizations had (coded) standard lighting tables that would provide information regarding what types of retrofits are possible with the existing lighting system and also the change in estimated fixture wattage. During the

⁸ Run time loggers operates on non-dimming lights, records only on-off conditions, and cannot determine lighting power with this sensor

⁹ Time-of-use loggers are similar to run time loggers but also records the time when the state changes

investment grade audit, the auditor also counted the total number of lighting fixtures and verified the lamps in the building. The baseline, pre-retrofit energy consumption was established by collecting spot measurement of lighting fixture power and fixture operating hours. All of the experts indicated that either a short term monitoring or information from the building proctor was required to determine the run time to develop a baseline occupancy schedule. One expert indicated that for office buildings, these loggers should collect at least one (1) weeks' worth of data with both weekday and weekend use while another expert recommended collecting three (3) weeks as an ideal period. Hence, consistently the experts mentioned that the change in total number of fixtures, fixture power, and the operating hours were used to calculate the baseline and post retrofit energy use of the lighting ECMs.

Alternatively, one of the experts indicated that quantifying savings from lighting control measures, such as occupancy sensors (OS), light sensors, and dimmers, cannot be easily quantified because the savings depended on other factors such as the orientation of the building, occupant schedule and behavior. In addition, lighting occupancy sensors need to be installed and tracked wherever an OS will be installed. Experts indicated that it is more difficult to accurately quantify savings from lighting control measures.

Regarding the quantification of demand savings, there was no consensus or mention of calculating the demand savings. According to one of the experts, this can be difficult to reproduce using engineering calculations. Most of the work that the expert has been involved in did not include the calculation of demand savings. The easiest way

to determine the demand savings for lighting measures would most likely include conducting a “blink” test. According to the expert, blink tests can be tested on a weekend with a data logger on the whole-building electric feed. The test starts out by turning on all the lights in the building and then incrementally turning off the lights until all of the lights are turned off. This is a controlled test used for a snap-shot picture of end-use measurement of lighting electricity use.

Experts indicated that building energy simulations were seldom used to select or quantify only lighting and lighting control ECMs. One expert indicated that building energy simulation models were only used when upgrading a large building, typically over 100,000 square feet with a sophisticated HVAC system. Another expert indicated that building energy simulations were applicable when replacing the entire mechanical plant or when installing complex and unique ECMs. The use of simulation was discouraged because of the additional effort and resources required to develop a calibrated model. In addition, the process of building a realistic model was complex and required skilled manpower.

Most experts indicated that they used the eQUEST program when it was necessary to develop a building energy simulation model. Information required to build an eQUEST building energy model included drawings, utility bills, peak demands, operating schedules, equipment name plate data, and some measured data. One of the experts noted that the industry typically relies on prototypical models that are readily available and recommended that if the industry uses techniques to fine tune the simulation to the actual building behavior then it would likely result in a powerful tool.

In summary, the use of engineering calculations with short term measurement based verification was most prevalent in the current industry. For quantifying lighting measures, spreadsheets and engineering calculations were found to be sufficient in predicting the energy savings. For quantifying lighting control measures, using engineering calculations required many assumptions and measurements. Use of building energy simulation models to quantify the savings was limited to unique measures and whole building plant retrofits.

5.2.5 Q5: Performing Measurements

All of the experts indicated that their organization performed some level of actual measurement. The frequency and the extensiveness of measurement depended on how the Contract was signed or structured. Typically, measures that were unique or unusual required a more rigorous M&V plan compared to the more popular and well-established measures by the industry and the state agencies. Stipulated savings, which are pre-determined savings, did not require any measurement or required a one-time measurement the first year. In contrast, complicated measures typically required multi-year measurements.

Regarding lighting retrofits, most experts indicated that a single measurement after the first year was adequate to quantify the savings. For lighting measures, pre-installment measurements included sample power and baseline occupancy schedule. For baseline occupancy schedules, loggers were used to determine the on/off schedule and the occupancy for one to three weeks. Once the measure was installed, a post-installment measure included obtaining a sample on a new fixture power. The baseline

occupancy and the operating schedule were assumed to be the same throughout the contract period.

5.2.6 Q6: Pertinent Information

The intent of Question 6 was to identify if there were other important issues related to this research. The experts discussed the weaknesses of the current business model, future opportunities in improving the management of energy efficiency projects, common mistakes found in analyzing ECM savings, and other helpful resources to improve the selection and implementation of ECMs. According to one of the experts, this expert observed that the current business model was not sustained by people that are actually managing the buildings. In other words, there was a need for better alignment between the governing agencies and the building operators to maximize the benefits of energy efficiency projects.

Some common mistakes found in quantifying the energy savings were not considering the uncertainties in savings and not considering the breakdown of total energy consumption. For example, if the total energy consumption for an existing facility was estimated at \$100,000 and the error margin of that total energy cost was 10 to 15 percent then this equates to \$10,000 to \$15,000 of uncertainty. If the estimated savings for this particular facility from the selected ECM package was 10 to 20 percent of the estimated total energy consumption (\$10,000 to \$20,000) then the predicted savings and the error margin is of the same magnitude. Thus, a better approach to quantifying the savings in this case would be to provide a reasonable estimate of the savings but to measure and to report how much saving is being realized rather than

negotiating a contract based pre-determined level of savings based on stipulation.

Another common error in predicting energy saving was not considering the breakdown of total energy consumption for the facility. For example, both parties should recognize the percentage of cooling vs. heating vs. lighting for the total energy consumption. If cooling only consists of 25 percent of the total energy consumption, it will be unlikely to achieve a 30 percent of energy savings for implementing ECMs that could supposedly reduce cooling energy consumption.

Finally, one of the experts emphasized the importance of being aware of what some of the large organizations such as Environmental Defense Fund, ASHRAE, National Association of Energy Service Companies (NAESCO) and Association of Energy Engineers (AEE) were doing in terms of promoting energy efficiency projects and reducing energy consumption.

5.3 Summary of Interviews

Throughout the process of identifying and selecting retrofits, experts noted the importance of having a senior level engineer lead the development of the energy efficiency projects. The experts also indicated that it is crucial to have all of the stakeholders participate and be involved in the retrofit feasibility, selection, and implementation and quantification process. Stakeholders were identified as owners, consultants, designers, construction contractors, building maintenance personnel, and occupants.

For the current industry the challenge still remains in developing a relatively accurate report in a short timeframe with limited data. Therefore, although the use of

simulations were encouraged for quantifying savings, this method was neither financially or physically justifiable. For lighting and lighting control ECMs, the current industry method relied on historical performance data to build a statistical database and to refine the engineering algorithms used to quantify the energy savings from retrofits.

6. RESULTS: TECHNICAL REFERENCE MANUALS/UTILITY ASSESSMENT REPORT

Through a review of the literature, common ECMs were identified for retrofitting existing commercial, office buildings. These included lighting, lighting control and Heating, Ventilation, and Air Conditioning (HVAC) measures. Lighting and lighting control measures were by far the most common in the industry. This was evident in a study by Larson et al.(2012) that looked at overall performance of project types and market activities of ESCOs in the United States from 1990 to 2008. According to this study, lighting and lighting controls measures were implemented in over 70 percent of the projects. Although the current trend is to apply more comprehensive energy retrofit packages by mixing ECMs in multiple technical categories, for the purpose of this study, only lighting and combination of lighting and lighting control measures were selected for further evaluation.

6.1 TRMs / Utility Assessment Report

This research cataloged and synthesized a list of available Technical reference manuals (TRM) by reviewing existing studies and reports (Cleff et al. 2011; Jayaweera et al. 2011; Jayaweera et al. 2012) . Technical reference manuals are guidebooks used by many state agencies and utility energy efficiency program managers to quantify deemed or estimated savings values for well-established energy retrofit measures. The review found that the methodologies to calculate savings are predominately pre-determined and agreed to ex ante (stipulated) or engineering algorithms and or combination of both. The manuals were typically developed by state agencies, by the

utility providers, or were developed at a national scale by the Federal government in conjunction with various consultants across the country.

Technical reference manuals are important in many ways. They provide consistency and transparency in the calculation of savings, allow energy efficiency program managers to quickly and easily evaluate the predicted savings for investing in energy efficiency projects. They also streamline the project management process by standardizing the reporting process (Cleff et al. 2011). According to a recent study in evaluating the consistency between various TRM's across the country, Jayaweera et al. (2012) found that in general, jurisdictions that develop TRMs for the first time, often create a modified version of (an) existing TRM(s). Unfortunately, when synthesizing multiple sources of TRMs, such reports failed to document the detailed procedure.

In the current study, a list of representative TRMs were selected from three different categories along with a recent, typical utility assessment report from an energy service company. The three distinguishing categories were TRMs developed by the utility companies, state agencies and the federal government in collaboration with energy consultants. The typical utility assessment report was developed by an energy service company and was adopted for this study to review the methods used to quantify lighting and lighting control ECMs. This study intended to select TRMs that also represented geographical distribution. Table 9 shows the list of TRMs reviewed and the typical utility assessment report investigated in this study. This study focused on investigating three areas of the TRMs which were, methodology used to estimate lighting and lighting control savings, identification of parameters within the engineering

algorithm and documentation of assumptions and cross references used. Table 9 summarizes the TRMs by organizations responsible for developing the document and the geographical territory.

Table 9. List of Technical Reference Manuals Investigated in this Study

| TRM ID | Developer | Reference | Geographical Territory |
|--------|-----------|--|------------------------|
| TRM 1 | Utility | CenterPoint Energy, 2013 Commercial Standard Offer Program, Program Manual v 13.1, Measurement and Verification Guidelines for Retrofit Projects (http://www.centerpointenergy.com/staticfiles/CNP/Common/SiteAssets/doc/2013%20CenterPoint%20Energy%20Commercial%20SOP%20Program%20Manual.pdf) | Southern |
| TRM 2 | Utility | Entergy Program Manual v 1.0, Measurement and Verification Guidelines (http://www.energy-texas.com/content/Energy_Efficiency/documents/sim-lighting.pdf) | Southern |
| TRM 3 | State | California Database for Energy Efficiency Resources (DEER) – 2005-2006, 2008 update, 2011 update (http://www.energy.ca.gov/deer/) | Western |
| TRM 4 | State | Colorado Technical reference manual (2011) (http://www.xcelenergy.com/staticfiles/xcel/Regulatory/2012-2013%20Biennial%20DSM%20Plan.pdf) | Western |
| TRM 5 | State | Massachusetts Technical reference manual (2011) (http://www.nationalgridus.com/non_html/ee/ma/10_MAE_EEAR_Pt_3.pdf) | Northeast |
| TRM 6 | Federal | U.S. Department of Energy, National Renewable Energy Laboratory, Uniform Methods Project: Methods for Determining Energy Efficiency Savings for Specific Measures, January 2012-March 2013 (http://www.nrel.gov/docs/fy13osti/53827.pdf) | All |
| UAR 1 | ESCO | Utility Assessment Report of a typical energy service project | All |

Within each manual or report, the following two energy efficiency measures were analyzed in-depth:

- Replacement of linear fluorescent (LF) fixtures
- Installation of occupancy sensors

Ultimately, two electricity energy providers with published TRMs or program manuals were selected. Both CenterPoint Energy and Entergy energy provided measurement and verification guidelines with associated lighting measure savings calculation method. The program manuals were downloaded from the website and the procedures for calculating energy savings from lighting and lighting control ECMs were extracted and further investigated. Three TRMs published by state agencies were selected and analyzed. The three states included California, Colorado, and Massachusetts. Many of the references developed by individual states had cross reference or link to Database for Energy Efficient Resources (DEER) which was developed by the California Public Utilities Commission (CPUC) and the California Energy Commission (CEC).

The California TRM was the most comprehensive in terms of references to measured data, number of updates and reviews based on impact evaluation studies, and included the use of building energy simulation. The Colorado TRMs borrowed existing TRMs developed by other states. For example, the Colorado TRM referenced Minnesota and Arkansas' TRM to determine lighting efficiency savings. Massachusetts TRM was developed by measured data from Western Massachusetts Electric Company. Hence, three state-level TRMs were selected to determine whether there would be

consistency in calculating lighting and lighting control savings given that their approach to developing their TRM varied.

More recently, the U.S. Department of Energy under the Uniform Methods Project (UMP) initiated the development of a framework for assessing the energy savings for most common residential and commercial retrofits that could be used throughout various energy efficiency programs across the U.S. The motivation for this project was spawned by the inconsistency in energy savings for identical measured determined by various M&V protocols. The protocols were released in two phases. The initial document for phase I outcomes, which included a selective number of energy efficiency measures, were released to the public on July of 2012 for stakeholder review. The final document was released after stakeholders' feedback was addressed in April of 2013. Finally, a typical utility assessment report from a recent energy performance contract was obtained to investigate the method for quantifying lighting and lighting control ECMs. A review of a representative state-level TRM (DEER) and a national level TRM (UMP) are described further below.

6.1.1 California Public Utilities Commission

In 2003, the California Public Utilities Commission (CPUC) and the California Energy Commission (CEC) commissioned the updated Database for Energy Efficient Resources (DEER). The Database for Energy Efficient Resources (DEER) provides commonly installed residential and nonresidential energy efficiency measures with estimated impacts, incremental cost and effective useful life. The project distinguished between non-weather sensitive measures and weather sensitive measures.

Savings for non-weather sensitive measures were estimated by utilizing engineering calculations and assumptions and results from Measurement and Verification (M&V) studies. Savings for weather sensitive measures were estimated by using an energy simulation model created in DOE-2. The DOE-2 model utilized building prototype defined in the form of individual eQUEST project file. There were 34 total DEER building prototypes where 23 of them were nonresidential prototypes. There were four office prototypes (Office – Large, Office – Large, Water-Source Heat Pump, Office – Small, GasPAC, and Office – Small, Heat Pump).

The project was carried out by four consulting firms; Itron, Inc., JJ Hirsch & Associates, Synergy Consulting, and Quantum Consulting. A separate contract supported by Summit Blue Consulting performed the measure cost analysis to update the measure cost information from the 2001 DEER measure cost study and to include new measures identified in the 2004-2005 DEER update study. The initial list of non-residential sector non-weather sensitive measures was adopted from the 1994 NEOS technology study (NEOS Corporation, 1994). The list included: interior lighting; interior lighting controls; exterior lighting; high efficiency office copiers; cooking measures; and hot water measures.

Overall, the DEER study evaluated over 400 energy efficiency measures. The project evaluated over 133,000 actual savings estimated from various California climate zones, building types, and building vintage. The report published two categories of estimated savings for individual measures. One scheme was to estimate the savings

using a baseline created from a statistical database. The other scheme was to estimate the savings using a minimum code baseline.

The study recommended continuous updates to be carried out every 3 years, develop guidance that lead to decision-making, provide additional baseline calibration especially as new California Commercial End-Use Survey (CEUS) becomes available, continue to improve the accuracy of the report and possibly investigate the difference in savings for other market segments. Regarding the non-residential updates only, in the 2008 DEER update, all nonresidential interior lightings were re-categorized as “weather sensitive” measures. The direct end-use and whole-building impact load shapes were updated from lighting logger studies for nonresidential interior lightings as well. This allowed the calculation of the interactive affects with heating and cooling systems. Primary peak demand period for various climate zones were revised. The updated DEER also provided weights for various building types based on climate zone and utility.

6.1.2 U.S. Department of Energy Uniform Methods Project

The development of UMP protocol was led by professionals and nationally recognized expertise on specific measures and technologies. The project was co-directed by the two offices within the Department of Energy (DOE) which are Office of Electricity Delivery and Energy Reliability and the Office of Energy Efficiency and Renewable Energy (EERE). The daily management was handled by the National Renewable Energy Laboratory (NREL). A consulting firm, Cadmus Group was in charge of organizing the development of the protocols in collaboration with technical

experts throughout the industry. The development of the guideline was also directed by existing standards such as International Performance Verification and Measurement Protocol (IPMVP), American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) *Guideline 14-2002* which deals with measurement of Energy and Demand Savings, DOE Office of Energy Efficiency and Renewable Energy *M&V Guidelines: Measurement and Verification for Federal Energy Projects Version 3.0*.

The first set of energy efficiency measures included commercial lighting, lighting controls, unitary air conditioning systems, and other residential measures. The framework was based on frequently adopted engineering and statistical methods. The guideline was intended to provide a foundation for determining the “deemed” savings on a gross scale based on unique and particular project conditions. The potential benefits to adopting the protocols included an increase in transparency, a reduction in M&V cost, and superior management of risk.

The guideline provided definitions for four methods of determining savings. The definitions were adopted from standard industry definitions. These were: projected savings; claimed (gross) savings; evaluated (gross) savings; and net savings. Projected savings referred to values determined by the program administrator before completing the energy-efficiency activities, typically calculated during planning phase. Claimed (gross) savings refer to values reported by the administrator after implementation of energy efficiency activities but prior to an independent, third-party evaluation of the savings. Evaluated (gross) savings referred to estimates stated by an independent, third-party evaluator after implementing the energy efficiency measures. Finally, net savings

refer to changes in energy consumption which is attributable to a specific energy efficiency program.^{10, 11} The UMP protocols predominantly concentrated on estimating gross savings unless the net savings originated as part of the same calculation method.

6.2 ECM Strategies

- ECM 1: Replacement of linear fluorescent (LF) fixtures
- ECM 2: Installation occupancy sensors

6.2.1 *Replace Linear Fluorescent Fixtures*

All of the TRMs investigated in this study included a methodology to quantify the savings from replacement of linear fluorescent fixtures and installation of occupancy sensors. The prevailing energy saving method included stipulated savings based on the following parameters: a baseline Wattage and the proposed energy efficiency lamp Wattage, hours-of-use, and interactive cooling and heating energy savings/penalty. Four of the six TRMs included methods to calculate electric demand savings as well.

The baseline Wattage and the proposed energy efficiency lamp Wattage assumptions varied across the TRMs. Although Wattages are often stipulated, individual

¹⁰ Net savings constitutes savings originating from sources other than just the program itself. These include energy consumption change due to free ridership, participant and non-participant spillover, induced market effects and rebound effects.

¹¹ A free rider refers to customers who receive incentive through participating in energy efficiency program who would have implemented the energy efficiency measures even in the absence of the program. Free riders can be total, partial, or deferred. Participant spillover refers to implementing additional energy efficiency measures due to program influence which do not include financial or technical assistance from the program. Non-participant spillover refers to implementing energy efficiency measures by non-participants due to the program's influence. Non-participants include groups such as design professionals and vendors who may influence product availability, product acceptance and customer expectations (**PA Consulting Group 2008**). Market-induced savings refer to development of energy-efficiency technologies and practices motivated by reasons other than the program such as higher energy price, macro-economic conditions and shifts in cultural norms (The Cadmus Group, Inc., 2011). The rebound effect is people's increase in consumption as a reduction in operating cost thereby decreasing the achievable energy reduction.

TRMs supplemented the use of standard Wattage tables developed by manufacturers specification and/or field collected data. The hours-of-use varied widely among the TRMs as well. The hours-of-use were assumed based on national database, as provided by the customer and building proctor, a recent impact evaluation (i.e., Massachusetts Impact Evaluation of 2010 Prescriptive Lighting Installation), or metered hours by physically sampling fixtures to determine pre-installation operating hours. The stipulated interactive factors for estimating cooling and heating energy savings/penalties varied across the TRMs. The method or logic to calculate the interactive cooling and heating energy saving/penalty factors was not traceable except in one TRM. The interactive factors were assumed as 80 percent of the lighting energy that is translated to heat which must be removed by the air conditioning system or added to the space by the heating system during the cooling and heating season. The interactive cooling energy saving factor is a positive value since efficient light fixture replacement assumed to produce less heat during the summer leading to less cooling. The interactive heating energy factor (i.e., a negative number) is a penalty factor since more heating is necessary during winter to make up for the inefficient fixtures that were replaced. Table 10 summarizes savings approaches for retrofitting commercial linear fluorescent fixture lamps with more efficient fixtures based on seven TRMs.

Table 10. List of Technical Reference Manuals and Calculation Methods for Installing Energy Efficient Light Fixtures

| TRM ID | Calculation Method/Engineering Algorithm |
|--------|---|
| TRM1 | $kW_{saved} = \sum_{i=1}^n (((N_{fixture(i)} \times kW_{fixture(i)})_{pre} - (N_{fixture(i)} \times kW_{fixture(i)})_{post}) \times CF_i \times ACfactor_1$ $kWh_{saved} = \sum_{i=1}^n (((N_{fixture(i)} \times kW_{fixture(i)} \times PAF_i \times Hours_{annual,i})_{pre} - (N_{fixture(i)} \times kW_{fixture(i)} \times PAF_i \times Hours_{annual,i})_{post}) \times ACfactor_2$ <p> kW_{saved} = Number of fixtures in line item i (pre or post) $N_{fixture(i)}$ = Number of fixtures in line item i (pre or post) CF_i = Coincident demand factor based on line item i (deemed, stipulated or metered) PAF_i = Power adjustment factor based on controls type on input in line item I (deemed, or metered) $ACfactor_1$ = If space is conditioned, value is 10% for interactive demand factor, 5% for interactive energy factor in office. If unconditioned, value is 1. $ACfactor_2$ = If space is conditioned, value is 10% for interactive demand factor, 5% for interactive energy factor in office. If unconditioned, value is 1. </p> |
| TRM2 | <p>Total Demand Saving (kW)= (CLLR + IHDS)* Coincident Factor</p> <p>Total Energy Savings (kWh)= LES + IHES</p> <p>Connected Lighting Load Reduction (CLLR) (kW) = Pre-lighting demand (kW) – Post lighting demand</p> <p>Interactive HVAC Demand Savings (IHDS) (kW)= Connected Lighting Load Reduction (kW) * 0.10</p> <p>Lighting Energy Savings (LES) (kWh) = CLLR * Annual Operating Hours (hours)</p> <p>Interactive HVAC Energy Savings (kWh) = LES (kWh) * 0.05</p> |

Table 10. Continued

| TRM ID | Calculation Method/Engineering Algorithm |
|--------|---|
| TRM3 | <p><i>Demand Impact</i> $\left[\frac{Watts}{unit} \right] = \left(\frac{\Delta Watts}{unit} \right) X (Peak Coincident Factor) X (Interactive Effects)$</p> <p><i>Energy Savings</i> $\left[\frac{kWh}{unit * year} \right] = \frac{\left(\frac{\Delta Watts}{unit} \right) X (annual hours of use) X (Interactive Effects)}{1,000 Watt hours/kWh}$</p> |
| TRM4 | <p>Electrical Demand Savings (kW) = (kW_Base - kW_EE) x HVAC_cooling_kWsavings_factor</p> <p>Electrical Energy Savings (kWh/yr.) = (kW_Base - kW_EE) x Hrs. x HVAC_cooling_kWhsavings_factor</p> <p>Natural Gas Savings (Dth) = (kW_Base - kW_EE) x Hrs. x HVAC_heating_penalty_factor</p> <p>Cooling kW Effects = 80% * Lighting kW Savings / Cooling System COP Heating kW Effects = -80% * Lighting kW Savings / Heating System COP kW_Base: Baseline fixture wattage (kW per fixture) kW_EE: High Efficiency fixture wattage (kW per fixture) HVAC_cooling_kWhsavings_factor: Cooling system demand savings factor resulting from efficient lighting from Table 1. Hrs: Annual Operating Hours HVAC_cooling_kWhsavings_factor: Cooling system energy savings factor resulting from efficient lighting from Table 1. HVAC_heating_kWhsavings_factor: Heating system penalty factor resulting from efficient lighting. Reduction in lighting demand results in an increase in heating usage, if the customer has gas heating. A value of -0.00088738 Dth/kWh given by (Reference: Arkansas Deemed Savings Quick Start Program Draft Report Commercial Measures Final Report, Nexant. CF and hours). (Partial Table 6, KW connected) Fluorescent T12 2 Lamp 40 watts (0.0865), 34 watts (0 .0720) Fluorescent T12 3 Lamp 40 watts (0.1410), 34 watts (0 .1060) Fluorescent T12 U Tube 1 Lamp 40 watts (0 .040), 34 watts (0.0360) Fluorescent T12 U Tube 2 Lamp 40 watts (0 .0097), 34 watts (0.0670)</p> |

Table 10. Continued

| TRM ID | Calculation Method/Engineering Algorithm |
|--------|--|
| TRM5 | $\Delta kW = \sum_{i=1}^n \left(\frac{Count_i - Watt_i}{1,000} \right)_{BASE} - \sum_{j=1}^m \left(\frac{Watt_j - Watt_j}{1,000} \right)_{EE}$ $\Delta kWh = \left[\sum_{i=1}^n \left(\frac{Count_i - Watt_i}{1,000} \right)_{BASE} - \sum_{j=1}^m \left(\frac{Watt_j - Watt_j}{1,000} \right)_{EE} \right] \times (Hours)$ <p> n = Total number of fixture types in baseline or pre-retrofit case m = Total number of installed fixture types Count_i = Quantity of existing fixtures of type i (for lost-opportunity, Count_i = Count_j) Watt_i = Existing fixture or baseline wattage for fixture type i Count_j = Quantity of efficient fixtures of type j Watt_j = Efficient fixture wattage for fixture type j 1000 = Conversion factor: 1000 watts per kW Hours = Lighting annual hours of operation </p> |
| TRM6 | <p>Energy Savings = (Baseline-Period Energy Use– Reporting-Period Energy Use) ± Adjustments</p> <p> kWh = [(Fixture wattage * Fixture quantity)/1000]*annual hours of use ES = kWh baseline - kWh energy efficiency CES = ES * (1 + Interactive cooling factor) HES = ES * (Interactive heating factor) </p> |

Table 10. Continued

| TRM ID | Calculation Method/Engineering Algorithm |
|--------------|---|
| UAR/ TRM7 | $(total\ kW)_{base} = \sum [(qty\ of\ fixture)_{base} \times (kW/fixture)_{base}]$ $(total\ kW)_{post} = \sum [(qty\ of\ fixture)_{post} \times (kW/fixture)_{post}]$ $(total\ kWh)_{base} = \sum_{\substack{\#\ of\ usage\ groups \\ 1}} [(total\ kW)_{base} \times (operating\ hours)_{base}]$ $(total\ kWh)_{post} = \sum_{\substack{\#\ of\ usage\ groups \\ 1}} [(total\ kW)_{post} \times (operating\ hours)_{post}]$ <p>CHW savings (MMBtu) = + [(Total kWh)savings * 0.0025] / equivalent to 73.3% with conversion HHW savings (MMBtu) = - [(Total kWh)savings * 0.00025] / equivalent to 7.3% with conversion</p> <p>(total kW)base = cumulative baseline electric power draw of lighting fixtures (qty. of fixtures)base = quantity of similar fixtures in the group represented by the sampling (kW/fixture)base = baseline fixture wattage determined from measurement or from Industry standard table of fixture Wattages (total kWh)base = cumulative baseline electric energy consumption of lighting fixture (Operating hours)base = number of stipulated annual operating hours as determined by building operating hours and occupant interviews</p> |

6.2.2 *Install Occupancy Sensors*

Six of the seven TRMs investigated in this study included methods to calculate the energy savings resulting from installation of lighting control equipment (e.g., lighting occupancy sensors). In this study, the lighting control measure for installing occupancy sensors was further evaluated. Five of the seven TRMs included engineering algorithms to calculate the demand savings from installing occupancy sensors. Four of the five engineering algorithms were evaluated further.¹²

The methods to quantify energy savings for installing occupancy sensor measures were similar to installing efficient light fixtures, which were the difference between the baseline-period energy use and reporting period energy use plus or minus the adjustments. The prevailing energy saving method for installing occupancy sensors included stipulated savings based on the following parameters: controlled fixture Wattage, the differences in hours-of-use due to lighting control measures, interactive cooling and heating energy saving/penalty and impact factors. Impact factors were generally a multiplier that is a variation of Power Adjustment Factors (PAFs). In some TRMs, PAFs were already incorporated into the hours-of-effect. Also, in two of the TRMs, the calculation included using a savings factors rather than a PAF. Finally, it was observed that one TRM used a realization rate¹³ rather than a PAF. Table 11 shows the various impact factors used in the TRMs evaluated in this study.

¹² TRM4 was removed from further evaluation in this study because the use of the value of Power Adjustment Factor (PAF) was not consistent with other TRMs.

¹³ Massachusetts Technical reference manual Description from Appendix F (Glossary) (2011): The ratio of measure savings developed from impact evaluations to the estimated measure savings derived from the

Table 11. Impact Factor for Technical Reference Manuals

| TRM ID | Impact factor | Reference | Values for installing occupancy sensors |
|--------|--|---|--|
| TRM 1 | Power adjustment factors (PAF) | ASHRAE Standard 90.1-1989 Table 6-3 | PAF = 0.7 |
| TRM 3 | Hours of effect = (Hours * power adjustment factor) | PG&E PY 2004/2005 working papers | Hours in effect is 1050 (Stipulated pre-retrofit hours for office is 2641) Energy Savings Factor (ESF) = 0.397 Power Adjustment Factor (PAF) = 0.603 |
| TRM 5 | Realization rate | Summit Blue Consulting, LLC. (2008). <i>Large Commercial and Industrial Retrofit Program Impact Evaluation 2007</i> . Prepared for National Grid. | RR = 0.76 |
| TRM 6 | Savings factor = (1- ratio of annual equivalent full load hours post to and prior to retrofit) | Not traceable | Did not indicate a value |
| TRM 7 | Hours of effect = (Hours * power adjustment factor) | Assumed from combination of project historical database and published references | Office PAF = 0.7 Hallway, bath, closet, break room PAF = 0.6 Lounge PAF = 0.975 |

The TRMs indicated that lighting control measures can also be metered by event logger, power logger or occupancy logger. In general, the TRMs reviewed showed that savings were primarily derived by using deemed hours of effect by building type values and used 30 to 40 percent for the PAF. Table 12 summarizes savings approaches for installing occupancy sensor measure.

TRM savings algorithms. This factor is used to adjust the estimated savings when significant justification for such adjustment exists.

Table 12. List of Technical Reference Manuals and Calculation Methods for Installing Occupancy Sensors

| TRM ID | Calculation Method/Engineering Algorithm |
|--------|--|
| TRM1 | $kW_{saved} = \sum_{i=1}^n (((N_{fixture(i)} \times kW_{fixture(i)})_{pre} - (N_{fixture(i)} \times kW_{fixture(i)})_{post}) \times CF_i \times ACfactor_1$ $kWh_{saved} = \sum_{i=1}^n (((N_{fixture(i)} \times kW_{fixture(i)} \times PAF_i \times Hours_{annual,i})_{pre} - (N_{fixture(i)} \times kW_{fixture(i)} \times PAF_i \times Hours_{annual,i})_{post}) \times ACfactor_2$ <p> kW_{saved} = Number of fixtures in line item i (pre or post) $N_{fixture(i)}$ = Number of fixtures in line item i (pre or post) CF_i = Coincident demand factor based on line item i (deemed, stipulated or metered) PAF_i = Power adjustment factor based on controls type on input in line item I (deemed, or metered) $ACfactor_1$ = If space is conditioned, value is 10% for interactive demand factor, 5% for interactive energy factor in office. If unconditioned, value is 1. $ACfactor_2$ = If space is conditioned, value is 10% for interactive demand factor, 5% for interactive energy factor in office. If unconditioned, value is 1. Deemed Control Savings – Adopt Power Adjustment Factor from ASHRAE Standard 90.1-1989, Table 6-3 PAF for Occupancy Sensor (OS) : 0.70 PAF for OS with Daylight Controls – continuous dimming: 0.6 PAF for OS with Daylight Controls – multiple-step dimming: 0.65 PAF for OS with Daylight Controls – On/Off: 0.65 </p> |

Table 12. Continued

| TRM ID | Calculation Method/Engineering Algorithm |
|--------|--|
| TRM3 | <p><i>Demand Impact</i> $\left[\frac{\text{Watts}}{\text{unit}} \right] = \left(\frac{\Delta \text{Watts}}{\text{unit}} \right) X (\text{Peak Coincident Factor}) X (\text{Interactive Effects})$</p> <p><i>Energy Savings</i> $\left[\frac{\text{kWh}}{\text{unit} * \text{year}} \right] = \frac{\left(\frac{\Delta \text{Watts}}{\text{unit}} \right) X (\text{hours in effect}) X (\text{Interactive Effects})}{1,000 \text{ Watt hours/kWh}}$</p> <p>Hours in effect: 1050 (PG&E 2004/2005 working papers) Energy interactive effects 1.17 Demand interactive effects 1.25 coincident factor 0.71 (based on 2008 update) **Assume control 2 lamp fixture w/T8-34 w EL ballast</p> |
| TRM5 | <p>ΔkW = (Controlled kW)</p> <p>ΔkWh = (Controlled kW)(Hours_{BASE} – Hours_{EE})</p> <p>Controlled kW = Controlled fixture wattage Hours_{BASE} = Total annual hours that the connected Watts operated in the pre-retrofit case (retrofit installations) or would have operated with code-compliance controls (new construction installations). Hours_{EE} = Total annual hours that the connect Watts operate with the lighting controls implemented. Realization Rate (energy) = 0.76 for OS CF summer peak = 0.3 CF winter peak = 0.19</p> |

Table 12. Continued

| TRM ID | Calculation Method/Engineering Algorithm |
|--------------|---|
| TRM6 | <p>Lighting Control Electric Energy Savings = $KW_{controlled} \times EFLH_{pre} \times CSF$</p> <p>Lighting Control Savings Factor (CSF) = $1 - (EFLH_{post}/EFLH_{pre})$</p> <p>Interactive Cooling Electric Energy Savings = $KW_{cool} \times IF_c \times Hours_{cool}$</p> <p>Interactive Heating Electric Energy Savings = $KW_{heat} \times IF_h \times Hours_{heat}$</p> <p>$KW_{controlled}$ = Sum (Fixture Wattage * Quantity Fixtures) for controlled fixtures $EFLH_{pre}$ = Annual Equivalent Full Load Hours Prior to Application of Controls $EFLH_{post}$ = Annual Equivalent Full Load Hours After Application of Controls KW_{cool} = Mean kW reduction coincident with the cooling hours IF_c = Interactive cooling factor, ratio of cooling energy reduction per unit of lighting energy $Hours_{cool}$ = Hours when the space is in cooling mode KW_{heat} = Mean kW reduction coincident with the heating hours IF_h = Interactive heating factor, ratio of heating energy increase per unit of lighting energy $Hours_{heat}$ = Hours when the space is in heating mode</p> |
| UAR/ TRM7 | <p>$(total\ kW)_{base} = \sum [(qty\ of\ fixture)_{base} \times (kW/fixture)_{base}]$</p> <p>$(total\ kW)_{post} = \sum [(qty\ of\ fixture)_{post} \times (kW/fixture)_{post}]$</p> <p>$(total\ kWh)_{base} = \sum_{\substack{\#\ of\ usage\ groups \\ 1}} [(total\ kW)_{base} \times (operating\ hours)_{base}]$</p> <p>$(total\ kWh)_{post} = \sum_{\substack{\#\ of\ usage\ groups \\ 1}} [(total\ kW)_{post} \times (operating\ hours)_{post}]$</p> <p>$Operating\ hours_{post} = Operating\ Hours_{base} \times Power\ Adjustment\ Factor$ Power Adjustment Factor by usage group: Office: 30%, Hall: 40%, Bath: 40%, Closet: 40%, Lounge: 2.5%, Break room: 40%</p> |

6.3 Summary of TRMs/Utility Assessment Report

As part of identifying the current industry methods for quantifying lighting and lighting control energy conservation measures, this study investigated six technical reference manuals and one typical utility assessment report (referred to as TRM 7). Regarding the analysis for the energy and demand saving, the analysis showed that there were major differences between methodologies, algorithms and assumptions. The specific measures that were investigated include:

- ECM 1: Replacement of linear fluorescent (LF) fixtures
- ECM 2: Installation occupancy sensors

All of the TRMs developed algorithms to calculate the predicted savings, which assumed stipulated parameters for many of these parameters. Energy savings included electricity savings due to reduction in fixture Wattage or hours-of-use (in the case of occupancy sensors), demand savings, interactive cooling savings, interactive heating penalty. In particular, the stipulated parameters varied significantly across different TRMs. Values for individual parameters are further discussed in Chapter IX.

7. RESULTS: CALIBRATED AS-BUILT WHOLE BUILDING ENERGY SIMULATION MODEL, DATA COLLECTION PROCESS

This study developed a data collection toolbox to assist with gathering pertinent information to create and to calibrate a whole-building energy simulation model. To accomplish this, the data collection process was divided into four phases. The information gathered in the first phase was used to build a code-compliant whole-building energy simulation model. In general, subsequent phases (Phase II to Phase IV) increased in the level of detail and in the level of effort. A case-study methodology was chosen to demonstrate the use of this toolbox. The results are presented in this chapter.

The case-study building selected for this project is the John B. Connally Building (JBC) located north of Texas A&M University's main campus which is in College Station, Texas. As seen in Figure 5, the building is separated from where most of the campus buildings (indicated as a dotted box in the figure) are and is surrounded by single-family residential, multi-family residential complexes and a large commercial hotel south of the building. Project background information, utility bills and building floor plans were collected by contacting the Office of Facilities Planning and Construction (OFPC), Utilities and Energy Services (UES) and Office of Facilities Coordination (OFC).¹⁴

¹⁴ OFPC provided the building's background information. UES provided the full years' worth of monthly utility bills for the whole building electricity and natural gas. OFC provided the building floor plans.

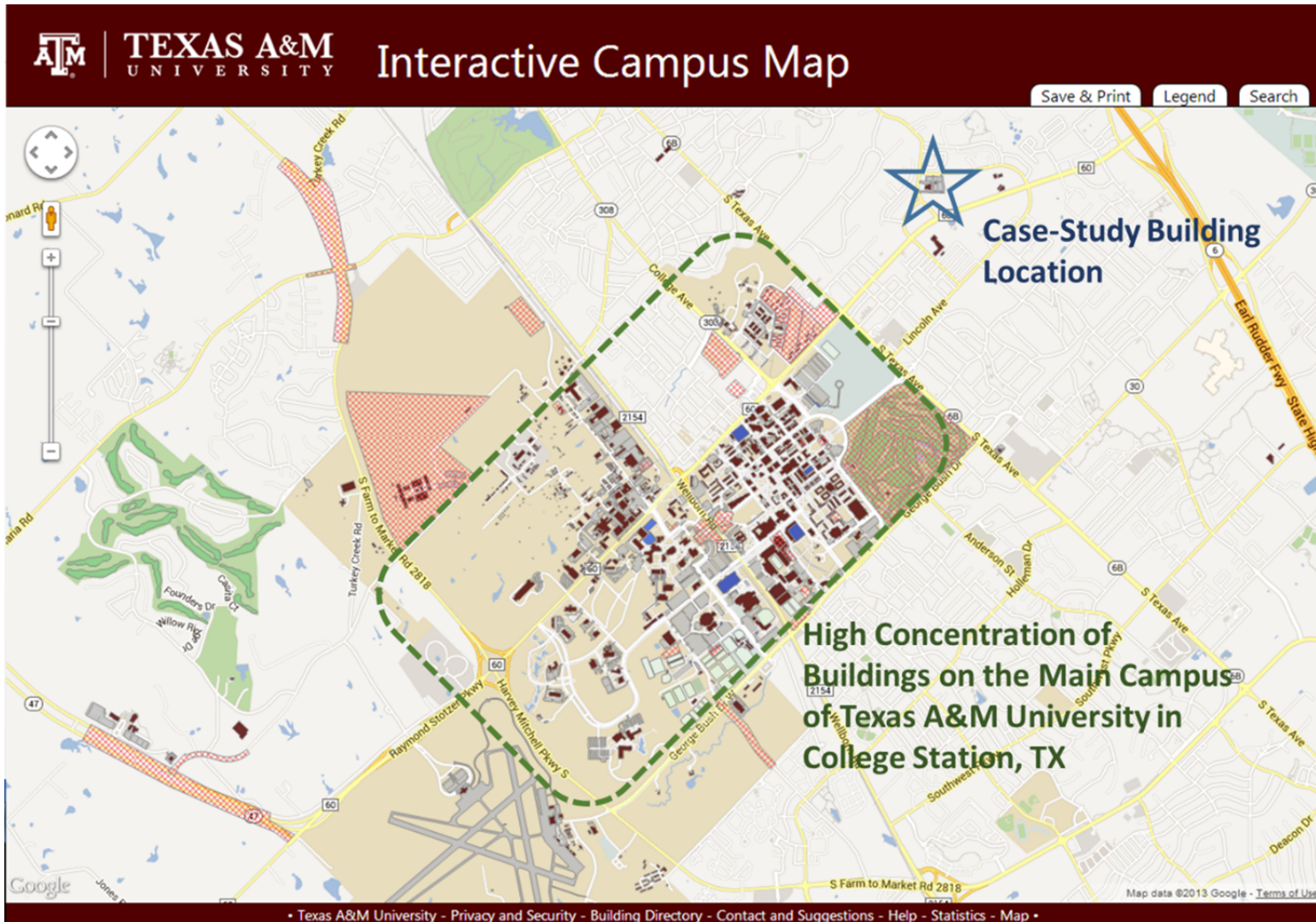


Figure 5. Texas A&M University Campus Map

7.1 Phase I: Code Compliant

7.1.1 Direct Contact

The first level (Phase I) of the data collection was performed to create a base-case, code-compliant, whole-building energy simulation model. The methodology for creating a code-compliant model included estimating the parameters to construct a representative model based only on known resources available at the Phase I level. The study accomplished this by first finding the year the building was built. This year was necessary to identify the relevant building codes, and to determine the prevalent technology and equipment available during the year it was designed and built.

For this study, the year the building was built was obtained by contacting the Texas A&M University's Office of Facilities Planning and Construction (OFPC).¹⁵ Typically, building information (i.e., year the building was built, building footprint, number of stories, primary use etc.) can be obtained by contacting the owner/owner's representative or the municipal building department.¹⁶ According to OFPC, the shell of this building was originally built by a private owner but later sold to Texas A&M University Systems (TAMUS). The original construction started in the mid-80's to

¹⁵ Office of Facilities Planning and Construction is responsible for maintaining and improving all physical facilities owned by the Texas A&M University System.

¹⁶ For example, in New York City, the Building Department has a web-based interactive Building Information System (BIS) (<http://www.nyc.gov/html/dob/html/bis/bis.shtml>). By providing the building address the BIS provides an overview of the property profile. In particular, by inspecting the Certificate of Occupancy records, it is possible to determine (1) the year the building was constructed, (2) the dimensions of the building, (3) the Engineer of Record for the facility, (4) the primary building classification, and (5) the use of the facility by each floor space. For states with a robust web-based system, the building information may be obtained by searching the internet.

house a bank and other lease office space called Woodbine Financial Center.¹⁷

Unfortunately, before the completion of the construction the owner went bankrupt. As a result, the facility was purchased by the TAMUS. The drawings to complete the remainder of the building components are dated June of 1990. Currently, the building is occupied by the Chancellor's office, General Counsel, Internal Audit among other TAMUS Departments. The building consists of 124,000 square feet of conditioned space in seven stories and has a detached thermal plant behind the building. The plant and thermal plant are surrounded by a parking lot.¹⁸

7.1.2 References

Next, based on the year the building was constructed, a code-compliant base-case model was developed. According to the OFPC, the original structure would have been designed to meet the City of College Station codes which would have been the Standard Building Code or Southern Standard Building Code from the early 1980s. Although there were no indications of any code references on the drawings, the University would have required compliance with the latest published edition of the Standard Building Code and Life Safety Code prior to 1990. In addition, effective June 1, 1989, the State Energy Conservation Office (SECO) adopted the first energy code for state-funded commercial buildings which was called the Texas Design Standard. This was modeled after the early 1989 version of the ASHRAE Standard 90.1.¹⁹ According to the State Energy Conservation Office, the Texas Design Standard was used until August 12, 2002

¹⁷ J. Davidson, Office of Facilities Planning and Construction (personal communication, March 07,2013)

¹⁸ J. Davidson, Office of Facilities Planning and Construction (personal communication, March 07,2013)

¹⁹ J. Davidson, Office of Facilities Planning and Construction (personal communication, March 07,2013)

(State Energy Conservation Office 2013). Effective August, 13, 2002 to August 31, 2005, all state-funded commercial buildings had to meet the ASHRAE Standard 90.1 1999. Presently, all state-funded commercial buildings in Texas has to meet the ASHRAE 90.1 2010. Based on the following information, the study developed a code-compliant base-case whole-building energy simulation model.

The selected references for this particular building included specifications of CBECS, ASHRAE Standard 90.1 and other sources. ASHRAE 90.1 was developed by American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE). This standard applies to all commercial buildings except low-rise residential buildings. It provides minimum requirements for energy efficient design and construction for commercial buildings. The standard is updated with input from committee members and public stakeholders (U.S. Department of Energy 2010). Other relevant sources included Huang et al. (1991), Huang and Franconi (1999), Abushakra et al. (2001), and Kavanaugh (2003). All of these documents were created to further refine the prototypical commercial building characteristics as defined by CBECS. In particular, Abushakra et al. (2001) developed a procedure to calculate the diversity factors, and published a library of typical load shapes of lighting and plug loads (e.g., weather independent loads). The library was developed based on measured data from 32 office buildings around the U.S. Since diversity factors are used in building energy simulation programs and internal heat gains from lighting and plug loads heavily influence the building's cooling load, this was an important parameter to estimate and to refine.

7.1.3 Phase I Summary

The Phase I data collection effort included contacting the owner to determine the year the building was constructed, the gross square footage, the building type and the number of floors. Utility bills were also obtained to benchmark the building's energy consumption to other comparable buildings and to use it to calibrate the building energy simulation model. Next, by discussing with the owner, the governing agency or the local jurisdiction was identified to determine the applicable building energy code and related references. Phase I activities were all conducted in the office and did not require any site visits. Information that came from the owner or the utility company was considered specific to the case-study building. For example, the year the building was built was obtained from the construction documents and university records. Monthly utility bills were obtained from the utility providers. Information gathered from this phase was useful as a starting point for developing and refining the building simulation model. Table 13 summarizes the code-compliant base-case building description. Relevant input parameters and sources are listed in Table 13.

Table 13. Code-compliant Base Case Building Description – Phase I

| CHARACTERISTIC | Phase I: Code-Compliant Base Case | SOURCES ²⁰ |
|---|---|--|
| Building | | |
| Building type | Office | |
| Gross area (sq-ft) | 90,000 | Prototypical office building size (Huang & Franconi, 1999, p.31) ²¹ |
| Dimension (ft. x ft.), Aspect Ratio | 0.67 | Prototypical office zone conditions (Huang and Franconi, 1991, P.4-47) ²² |
| Number of floors | 6 | Prototypical office building number of floors (Huang & Franconi, 1999, p.31) |
| Floor to floor height (ft.) | 13 | ASHRAE Standard 90.1-1989-13.7.1 (p.105) |
| Orientation | | |
| Construction | | |
| Wall Construction | Masonry | Prototypical office wall material (Huang & Franconi, 1999, p.31) |
| Roof Construction | Built-up | Prototypical office roof material (Huang & Franconi, 1999, p.31) |
| Foundation Construction | | |
| Wall absorptance | 0.7 | ASHRAE Standard 90.1-1989-13.7.3.3(p.106) |
| Wall insulation R-value (hr.-sq.ft-F/Btu) | R-13 | ASHRAE Standard 90.1-1999, Table B-5 (11.4.2(a)), (p.95) |
| Roof absorptance | 0.7 | ASHRAE Standard 90.1-1999-11.4.2(b)(p.58) |
| Roof insulation R-value (hr.-sq.ft-F/Btu) | R-15 | ASHRAE Standard 90.1-1999, Table B-5 (11.4.2(a)), (p.95) |
| Ground reflectance | 0.2 | ASHRAE Standard 90.1-1989-13.7.3.3(p.106) |
| U-factor of glazing (Btu/hr.-sq.ft-F) | 1.22 | ASHRAE Standard 90.1-1999, Table B-5 (11.4.2(c)), (p.95) |
| Solar Heat Gain Coefficient (SHGC) | 0.17 (0.44 for north) | ASHRAE Standard 90.1-1999, Table B-5 (11.4.2(c)), (p.95) |
| Window-to-wall ratio (%) | 50 | Average WWR of new construction (Huang & Franconi, 1999, p.31) |

²⁰ All ASHRAE Standard 90.1 sources indicated in Table 13 are adopted from Table 7.1.1 from Cho, S. (2010). "Methodology to develop and test an easy-to-use procedure for the preliminary selection of high-performance systems for office buildings in hot and humid climates." Ph.D. thesis, Texas A&M University, College Station, TX. Hence, it was assumed that ASHRAE Standard 90.1-1999 were used when there was no equivalent regulation for the ASHRAE Standard 90.1-1989.

²¹ Huang, J. and E. Franconi. (1999). Commercial Heating and Cooling Loads Component Analysis. Report LBL-37208. Lawrence Berkeley National Laboratory.

²² Huang, J. and E. Franconi. (1991). 481 Prototypical Commercial Buildings for 20 Urban Market Areas. Report LBL-29798. Lawrence Berkeley National Laboratory.

Table 13. Continued

| CHARACTERISTIC | Phase I: Code-Compliant Base Case | SOURCES |
|--|---|---|
| Space | | |
| Area per person (ft ² /person) | 275 (325 occupants) | ASHRAE Standard 90.1-1989, Table 13-2, (p.103) |
| Occupancy schedule | 8am-10pm (Mon - Sat) | ASHRAE Standard 90.1-1989, Table 13-3, (p.104) |
| Space Heating Set Point | 70F Heating | ASHRAE Standard 90.1-1989-13.7.6.2(p.110) |
| Space Cooling Set Point | 75F Cooling | ASHRAE Standard 90.1-1989-13.7.6.2 (p.110) |
| Lighting Power Density (W/ft ²) | 1.3 | ASHRAE Standard 90.1-1999, Table 9.3.1.1, (p.51) |
| Lighting schedule | ASHRAE RP-1093 Schedule | Abushakra et al., 2001 (ASHRAE RP-1093, p.61) ²³ |
| Equipment Power Density (W/ft ²) | 0.75 | ASHRAE Standard 90.1-1989, Table 13-4, (p.106) |
| Equipment schedule | 24 hours (Monday - Saturday) | Abushakra et al., 2001 (ASHRAE RP-1093, p.62) |
| HVAC Systems | | |
| HVAC system type | VAV with terminal reheat | ASHRAE Standard 90.1-1999, Table 11.4.3A, (p.59, System2) |
| Number of HVAC units | 7 | Assuming each floor is a zone |
| Supply motor efficiency (%) | 90 | Kavanaugh, 2003 (p.38) ²⁴ |
| Supply fan efficiency (%) | 61 | ASHRAE Standard 90.1-1989, Table 13-6, (p.108, System #5) |
| Supply fan total pressure (W.G) | 2.5 | Info. by ESL CC engineers |
| Plant Equipment | | |
| Chiller type | Centrifugal (280 ton cooling) | ASHRAE Standard 90.1-1999, Table 6.2.1C, (p.29) |
| Chiller COP | 5.55 (For 280 ton chiller) | ASHRAE Standard 90.1-1999, Table 6.2.1C, (p.29) |
| Boiler type | Hot water boiler | ASHRAE Standard 90.1-1999, Table 11.4.3A, (p.59, System2) |
| Boiler fuel type | Natural gas | ASHRAE Standard 90.1-1999, Table 11.4.3A, (p.59, System2) |
| Boiler thermal efficiency (%) | 75 | ASHRAE Standard 90.1-1999, Table 6.2.1F, (p.31) |
| DHW fuel type | Natural gas | ASHRAE Standard 90.1-1999, Table 7.2.2, (p.47) |
| DHW heater thermal efficiency (%) | 80 | ASHRAE Standard 90.1-1999, Table 7.2.2, (p.47) |

²³ Abushakra, B. 2001. Compilation of Diversity Factors and Schedules for Energy and Cooling Load Calculations. Final Report. ESL-TR-01/04-01. Energy Systems Laboratory, Texas A&M University.

²⁴ Kavanaugh, S. 2003. Estimating Demand and Efficiency. ASHRAE Journal. American Society of Heating, Refrigerating, and Air-Conditioning Engineers.

7.2 Phase II: Simple Investigation

7.2.1 Building Image

Building images are obtainable by one of two methods. There are several websites on the internet that may show pre-existing photographs of the building. In this case, it is possible to view and determine the building exterior characteristics without having to ever visit the site. For example, by inserting the name and geographical location of the building, couple of professionally taken photographs were available for purchase on the Emporis website for this specific case-study building.²⁵ The Emporis website collects and provides building information to a wide-range of building industry professionals. The data comes from a professional community, researcher as well as the public. By viewing the images on the website²⁶, it was possible to determine the general exterior characteristics of the building (i.e., general shape of the building, estimate the window to wall ratio based on available photographs, and number of floors).

Further, refinement to the building envelope information was obtained from the Google Maps Street View. In addition, it was also found that Google Earth has free software that can be down-loaded to a personal computer, plugged-in to view 3 dimensional (3-D) renderings directly from the web or to a mobile device.²⁷ For this study, Google Earth desktop was used. By typing in the physical address in the search

²⁵ <http://www.emporis.com/images/details/335557> & <http://www.emporis.com/images/details/335553> webpage accessed 9/25/2013

²⁶ <http://www.emporis.com/building/john-b-connelly-building-college-station-tx-usa> webpage accessed 9/25/2013

²⁷ <http://www.google.com/earth/explore/products/> webpage accessed 9/25/2013

box, Google Earth provided a clear view of the site plan and neighboring buildings as seen in Figure 6.

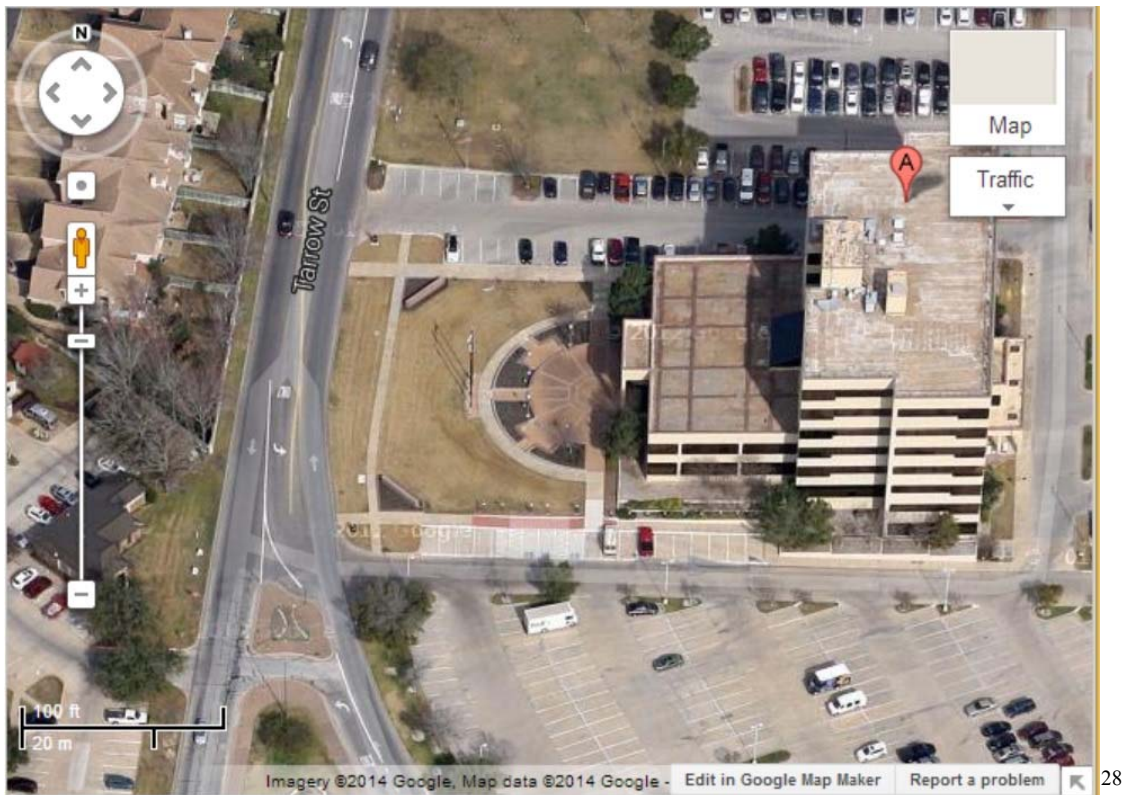


Figure 6. Site view of the JBC building with Google Earth

By zooming in using the mouse wheel, a synthetic 3 dimensional (3-D) rendering appeared. By viewing the 3-D rendering, certain parameters of the building characteristics became apparent. For example, by looking at the model, the general shape of the building, number of stories and building orientation was identifiable. The

²⁸ Imagery ©2014 Google and Map data © 2014 Google

windows were assumed to be the darker shade of strips and later verified by looking at a street-level imagery.

Next, the “3D Buildings” layer in the Layers panel was turned-off in Google Earth to measure and approximate the building square footage (Figure 7). Google Earth provides a ruler tool at the toolbars to measure distances. This tool was sufficient to determine the approximate length of the exterior walls. Finally, as shown in Figure 8 street-level imagery was obtained by dragging the Pegman icon that appear at the top right, under the navigation controls.

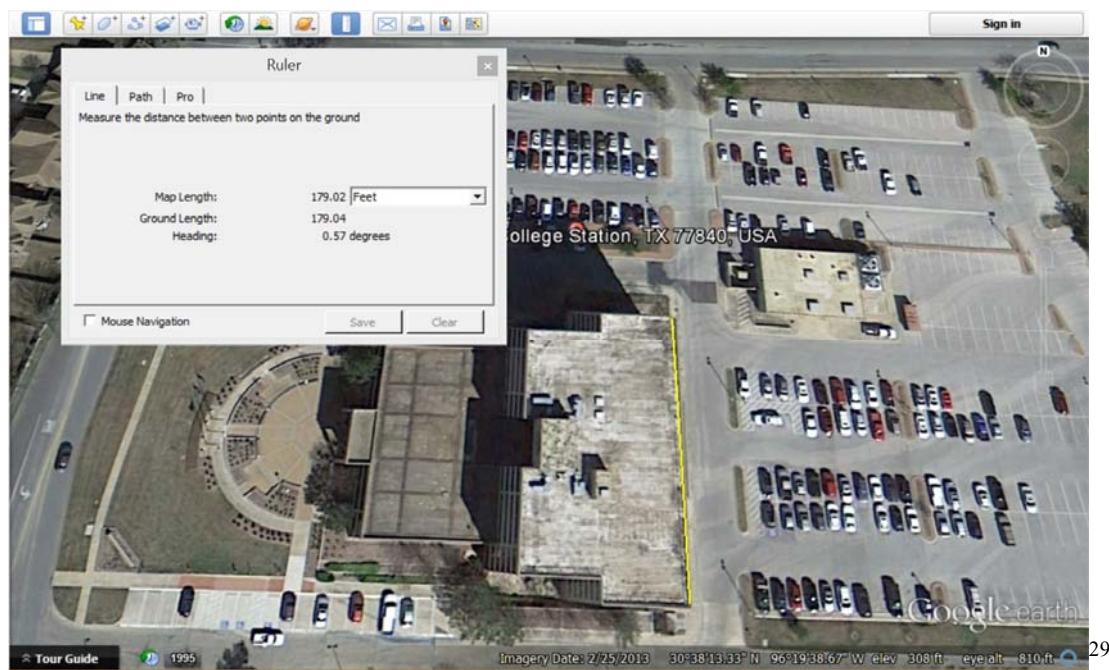


Figure 7. Use of Google Toolbars to Measure JCB Exterior Dimensions

²⁹ Imagery data © Google earth



Figure 8. Google Maps Street View Imagery of the JBC Building

³⁰ Imagery © 2014 Google and Map data ©2014 Google

The still images obtained from websites were useful in determining the general shape of the building and number of floors. It was only possible to estimate the window to wall ratio based on available photographs. Photographs from multiple angles are typically required to capture all of the different facades with windows to accurately estimate the window to wall ratio. The Google Street View was superior in terms of providing a better visual inspection with capability to zoom in and obtain 360° views of the building from a computer workstation. The Google Maps Street View allowed better estimate of the window-to-wall ratio, orientation of the building, and allowed rough measurement of the building footprint.

7.2.2 Un-assisted Site Visit

Un-assisted site visits included visiting and documenting information that are obtainable from the exterior and the interior of the facility without contacting the facility personnel. This was meant to represent the information that could be gathered by the general public. Un-assisted visits served couple of purposes. First, un-assisted visits aided with visually confirming the information that was collected in the office without ever visiting the site. Second, this was also an opportunity to locate utility meters and to determine what existed inside the building and on the site with minimal assistance. The exterior site visit consisted of day-time visits and night-time visits. The day-time activities included visually inspecting the building envelope, visually inspecting the exterior of the thermal plant, and locating and documenting the utility meters around the site. The visual inspection of the building exterior during the night-time provided an opportunity to confirm the window-to-wall ratio (WWR) and the number of glazing.

The interior site visit activities included checking the primary facility use, visually inspecting the general layout of the building and interior finishes and dimensions.

Exterior Inspection, Day-Time

By getting up-close to the exterior of the building, it was confirmed that the darker shades in the building exterior photographs were bronze shade of glazing. In addition, by walking around the site, a detached thermal plant was located to the east of the building. Two (2) cooling towers were placed just outside the thermal plant (Figure 9). This building also had a large parking lot with parking lot lighting.



Figure 9. Cooling Towers Outside the JBC Thermal Plant



Figure 10. Electricity Meter Adjacent to the Transformer

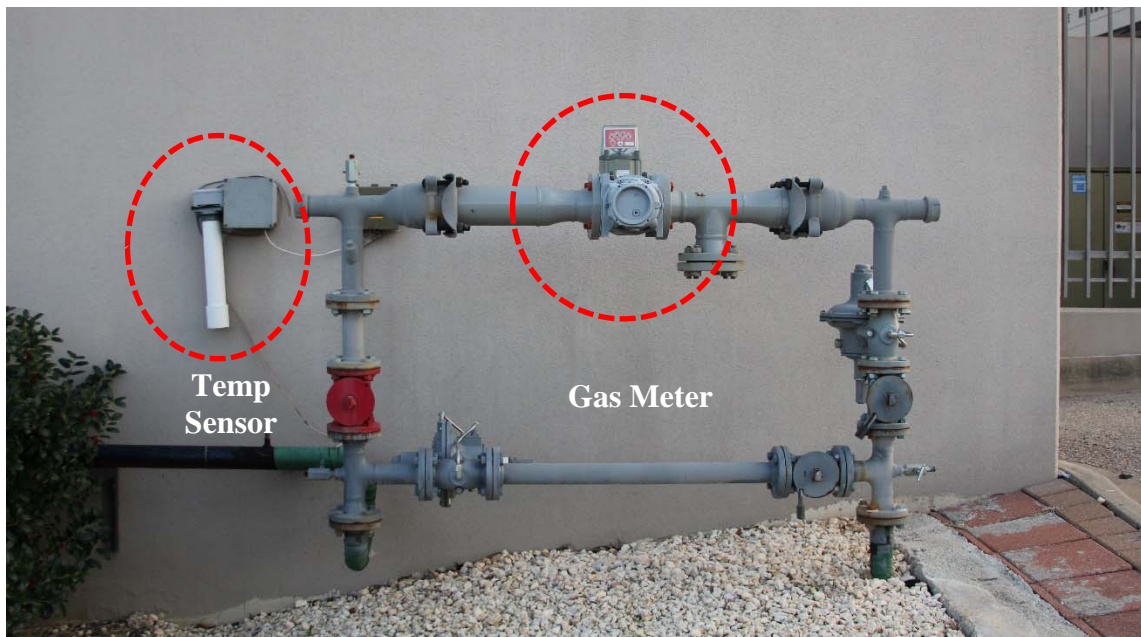


Figure 11. Gas Meter Outside the JBC Thermal Plant



Figure 12. Water and Sprinkler Utility Meters at the JBC Building

Next, electricity and gas meters were found and meter numbers were recorded to check against the actual utility bills. The electricity meter was located adjacent to the transformer which was placed on a concrete pad outside the thermal plant (Figure 10). The gas meters and the temperature sensors were attached on the north façade of the thermal plant (Figure 11). The water meter was located by contacting the City of College Station Utilities Department and by scheduling a site visit when the Utilities Department came out to do the utility meter reading (Figure 12).

There were two entrances to this building from the exterior. One was on the first floor and could be entered from the east side of the building. The main entrance was on the second floor, on the west side of the building. Public access to the building was only

possible by entering through the main entrance. The first floor entrance was secured and could only be accessed by employees with access cards (Figure 13). The entrance doors on both the first and second floors were arranged in an airlock configuration.



Figure 13. JBC Building Secondary Entrance – East Elevation

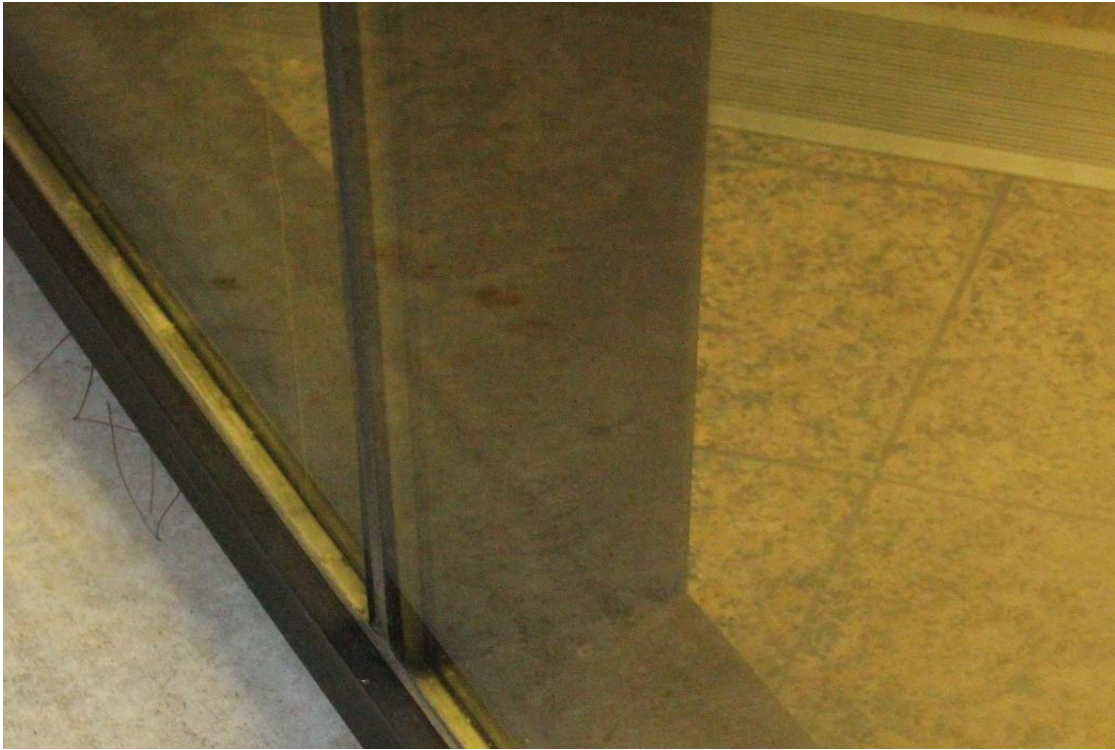


Figure 14. Close-up Photo of the JCB Entrance Curtain Window during the Night-time

Exterior Inspection, Night-Time

As seen in Figure 14, an up-close photograph of the window during the night time clearly showed that the building's glazing was a double glass, bronze tint outer pane with $\frac{1}{2}$ -inch of air-space. Accordingly, the U-factor of the glazing and the solar heat gain coefficient was modified to reflect the new information.



Figure 15. Night-time Building Exterior Photograph of the JCB

Comparison of day time photographs and night time photographs were also demonstrated to be useful when the WWR was difficult to distinguish from the Google Street View or if further confirmation was necessary. A comparison of a daytime picture and night time pictures would be beneficial in differentiating between the windows from the walls. As seen in Figure 15, photos taken during the night-time made windows more distinguishable and visible. The obstacle to this method is the need for a higher quality camera than the typical point-and-shoot digital camera. The camera used to capture the night-time image was with a digital single-lens reflex (DSLR) camera. For higher quality pictures like this a tripod was useful in taking the photographs.

Interior Inspection, Day-Time

The site visit of the interior space was conducted during the normal business hours. The building was locked to the public after 5 pm on weekdays and on weekends. By conducting a walk through audit it was observed that the general building shape was T-shape from floors one through three with an atrium in the core leading up into a smaller rectangular shape from the fourth floor to the seventh floor.



Figure 16. JBC Building Open Atrium with Floors 2 & 3 Shown



Figure 17. JBC Building Interior Landscaping and Indoor Planters (on Floor 1)

Figure 16 shows a view of the open atrium taken from the second floor of the building. On the first floor this atrium space had an interior landscaping and indoor planters. Figure 17 shows the landscaping on the 1st floor.

From both the entrances, the foyer led to the atrium and to the core of the building where there were conveying systems. The three passenger elevators serviced floors one through seven. The roof of the building was accessible by a stairwell on the seventh floor. The common areas such as toilets/washrooms, mechanical rooms, elevator lobbies, and public corridors were all located in the center of the building. From these large corridors, smaller corridors branched out to service the larger open floor plan office spaces and private office spaces.

The building was primarily used for offices and conference areas with drop ceilings and a floor-to-ceiling height of 9 feet. The typical lighting fixtures throughout the building were 2X2 recessed parabolic fluorescent lighting with return air as seen in Figure 18.



Figure 18. Main Entry with Typical Lighting Fixture inside the JBC Building

7.2.3 Phase II Summary

The Phase II data collection consisted of gathering building information by collecting existing and new building photographs and by conducting un-assisted site visits. The site visits included both day-time and night-time visits. Night-time visits can be particularly useful when the window-to-wall ratios are difficult to distinguish during the day. Table 14 summarizes the information that was gathered from the un-assisted site visits to the case-study building.

Table 14. Information Gathered from an Un-assisted Site Visit

| | Day Time | Night Time |
|---------------------|--|--|
| Exterior Inspection | <ul style="list-style-type: none"> • Confirmed shade of windows (bronze) • Located thermal plant • Located two cooling towers • Located parking lot with lighting (and poles) • Locate utility meters (gas, electricity, water) • Two entrances (east and west) | <ul style="list-style-type: none"> • Confirmed double pane windows • Confirmed lights mostly shut-off during the night • Confirmed that parking lot lights have sensors |
| Interior Inspection | <ul style="list-style-type: none"> • Mostly office spaces with common areas • Three story atrium • Interior landscaping on first level atrium space • Three passenger elevators • Typical floor to ceiling height (9 foot drop ceiling) • Lighting: various recessed parabolic fluorescent lighting with 2 or 3 T12 lamps and 1 or 2 T12 U bent fluorescent lighting lamps | |

The information gather in Phase II was used to refine and tune the code-compliant base-case model as seen in Table 15.

Table 15. Refinement of the Data Collection Protocol - Phase II

| CHARACTERISTIC | Phase II: Simple Investigation | SOURCES |
|---|--------------------------------------|--|
| Building | | |
| Building type | Office | Phase I, Visual inspection – Building interior |
| Gross area (sq-ft) | 124,260 ³¹ | Google Street View |
| Dimension (ft. x ft.), Aspect Ratio | T-shape ³² | Google Street View |
| Number of floors | 7 | Pre-existing Building Photographs, Google Street View |
| Floor to floor height (ft.) | 13 | Carry over from Phase I, Visual inspection – Building interior |
| Orientation | West | Google Street View, Visual inspection – Building exterior |
| Construction | | |
| Wall Construction | Masonry | Phase I |
| Roof Construction | Built-up | Phase I |
| Foundation Construction | | |
| Wall absorptance | 0.7 | Phase I |
| Wall insulation R-value (hr.-sq.ft-F/Btu) | R-13 | Phase I |
| Roof absorptance | 0.7 | Phase I |
| Roof insulation R-value (hr.-sq.ft-F/Btu) | R-15 | Phase I |
| Ground reflectance | 0.2 | Phase I |
| U-factor of glazing (Btu/hr.-sq.ft-F) | 0.62 ³³ | Visual inspection – Building exterior |
| Solar Heat Gain Coefficient (SHGC) | 0.49 ³⁴ | Visual inspection – Building exterior |
| Window-to-wall ratio (%) | 40 | Google Street View |

³¹ 124,260 sq. ft. (Floors 1-3: 66,660 sq. ft. + Floors 4-7: 57,600 sq. ft.)

³² Loads 1 (T-Shape, from Floors 1-3): X1: 160 ft., X2: 22.5 ft., X3: 115 ft., Y1: 158 ft., Y2: 68 ft. & Loads 2 (Rectangle, from Floors 4-7): X1: 160 ft., Y1: 90 ft.

³³ Source: 1993 ASHRAE Handbook: Fundamentals, Atlanta, GA: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Incorporated, 1993

³⁴ WINDOW 4.1 (a computer program for calculating the thermal and optical properties of windows), Lawrence Berkeley National Laboratory, Berkeley, CA, 1994.

Table 15. Continued

| CHARACTERISTIC | Phase II: Simple Investigation | SOURCES |
|--|--|--|
| Space | | |
| Area per person (ft ² /person) | 275 (325 occupants) | Phase I |
| Occupancy schedule | 8am-10pm (Mon - Sat) | Phase I |
| Space Heating Set Point | 70F Heating / 75F Cooling | Phase I |
| Space Cooling Set Point | 70F Heating / 75F Cooling | Phase I |
| Lighting Power Density (W/ft ²) | 1.3 | Phase I |
| Lighting schedule | ASHRAE RP-1093 Schedule | Phase I |
| Equipment Power Density (W/ft ²) | 0.75 | Phase I |
| Equipment schedule | 24 hours (Monday - Saturday) | Phase I |
| HVAC Systems | | |
| HVAC system type | VAV with terminal reheat | Phase I |
| Number of HVAC units | 7 | Phase I |
| Supply motor efficiency (%) | 90 | Phase I |
| Supply fan efficiency (%) | 61 | Phase I |
| Supply fan total pressure (W.G) | 2.5 | Phase I |
| Plant Equipment | | |
| Chiller type | 2 Centrifugal (280 ton cooling) | Phase I, Visual inspection – Building exterior |
| Chiller COP | 5.55 (For 280 ton chiller) | Phase I |
| Boiler type | Hot water boiler | Phase I |
| Boiler fuel type | Natural gas | Phase I |
| Boiler thermal efficiency (%) | 75 | Phase I |
| DHW fuel type | Natural gas | Phase I |
| DHW heater thermal efficiency (%) | 80 | Phase I |

7.3 Phase III: Assisted Visits & Drawings

7.3.1 Assisted Site Visit

Visual Inspection with Building Proctor

Next, a request was made to visit the building. The intent of this visit was to: verify if there are any issues with the operation of the building; to verify the building floor plans; to check the air handling equipment; and to become familiar with the operational practices. The meeting started out by asking about the building systems and questions regarding thermal comfort. The building proctor indicated that the building is maintained at 74 degrees for cooling and 72 degrees for heating. Most of the building was used for office spaces. The building equipment was “on” 24 hours a day 7 days a week. Most people on a typical weekday came in between 6:00-8:00 am and left the building around 5:00 pm. The building proctor was aware of the general process, location and operation of various equipment (i.e., air handling units, fans) and where various ductwork and piping, were located to transport the air and water throughout the building.



Figure 19. Air Handling Unit (AHU) on the 1st Floor of JBC Building



Figure 20.Outside Air Handling Unit (OAHU) on the Roof of JCB Building

This building was unique in that it brought in fresh outside air from two dedicated outside air handling units (OAHUs). These units were located on top of the roof and provided fresh outside air to individual mechanical rooms which were used as a mixing chamber. The building proctor indicated that the AHUs were single duct (SD) system equipped with variable air volume (VAV) terminal boxes and variable frequency drive (VFD) motors on the supply fans. Each floor was equipped with multiple AHUs that were dedicated for that floor. The return air came through a plenum from the roof to each floor through the mechanical rooms. From floors one to three there were three air handling units (AHUs) to cover a greater square footage than the upper floors. From the

fourth floor to the seventh floor there were two AHUs on each floor. According to the building proctor, all of the mechanical rooms were fairly identical to each other. Thus, the visit included verifying a few mechanical rooms throughout the building. During the site visit, one of the mechanical rooms on the 1st floor and one of the mechanical rooms on the 4th floor was observed. Figure 19 and Figure 20 shows the two different AHUs that are used in this building to supply air and to recirculate returned air.

Visual Inspection with the Plant Manager

After meeting with the building proctor, the separate meeting that was made was with the plant manager from UES. The tour started by visiting the outside transformer that lowers the voltage before it enters the building. Also outside the plant are the two cooling towers that are associated with the two chillers inside the plant.

Figure 21 shows the schematic floor plan of the JBC plant building.

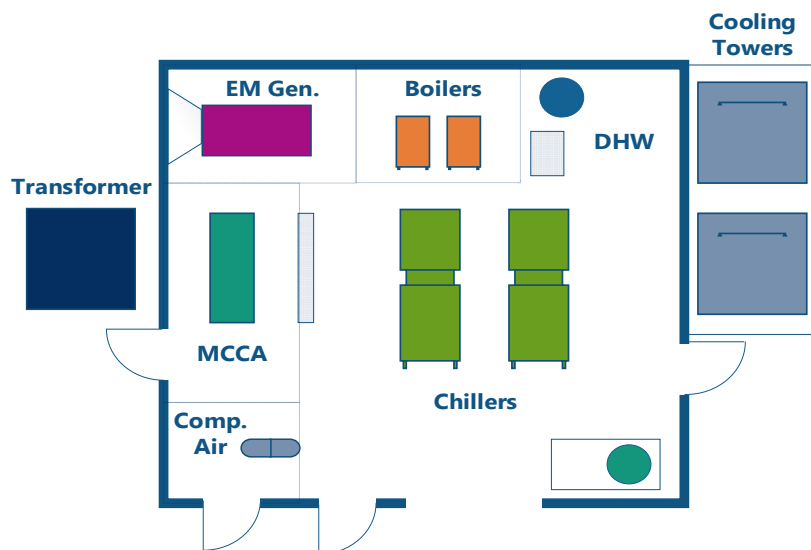


Figure 21. JBC Plant Schematic Floor Plan



Figure 22. MCCA in the Switch Gear Room of the JBC Plant Building

The MCCA is located inside the building in the switch gear room (Figure 22). The individual breaker controls for all of the equipment inside the plant is located just outside the switch gear room along the wall. Just outside the MCCA are individual breakers that can be turned-off for specific equipment when maintenance personnel are working on the individual pieces of equipment.

To the north of the switch gear room was the emergency generator in a separately enclosed space. This emergency generator provides electricity in case the powers for the JBC building became unavailable. The generator provides enough electricity for the

critical operations such as the lights for safely exit of the building. The emergency generator was tested every week on Wednesdays. Outside the emergency generator room in the main space is where the two chillers, domestic hot water tank, pumps, and the water treatment tanks are located.

According to the plant manager, the two centrifugal chillers are about 12 years old. The chiller controls were upgraded about 5 years ago. The chillers are water-cooled with a totally closed-loop condenser configuration. The motor to start the compressors are variable speed drive (VSD) which saves a lot of energy for the building. During typical conditions, the building only requires one 280-ton chiller to run to meet the building's maximum cooling loads. So the chillers were sequenced to run equal amounts each year. The secondary chiller was also necessary to serve the building when one chiller had maintenance issues. Heat is rejected to the atmosphere through the evaporative process in the cooling towers. This building has one cooling tower for each chiller. Both are closed (indirect) cooling towers where the chilled water does not come in direct contact with the outside air. At the top of the cooling tower, fans have VSD added to the fan motors to regulate the temperature of the water leaving the tower.



Figure 23. Cooling Towers (CT 901, 902) in JBC Building Plant



Figure 24. Chillers (CHLR-901, 902) in the JBC Plant Building

Figure 23 shows the two cooling towers located outside on the east side of the plant and Figure 24 shows the two chillers.

In the same space, the domestic hot water heater tank is located that provides hot water for the building. Directly opposite to the hot water heater tank is the water treatment tank for the cooling tower. Towards the center of the main space are the emergency fire pumps. These pumps will start if the automatic sprinkler in the building is activated. The plant has a compressor room on the southwest corner of the building that has an air compressor for the pneumatic controls. According to the plant manager, the compressed air is used to control (open/close) valves and for smaller tools.



Figure 25. Two Boilers (B901, 902) in JBC Plant Building

Finally, in the boiler room there are two gas-fired hot water boilers that supplied heat to the building. The two boilers inside the boiler rooms are shown in Figure 25

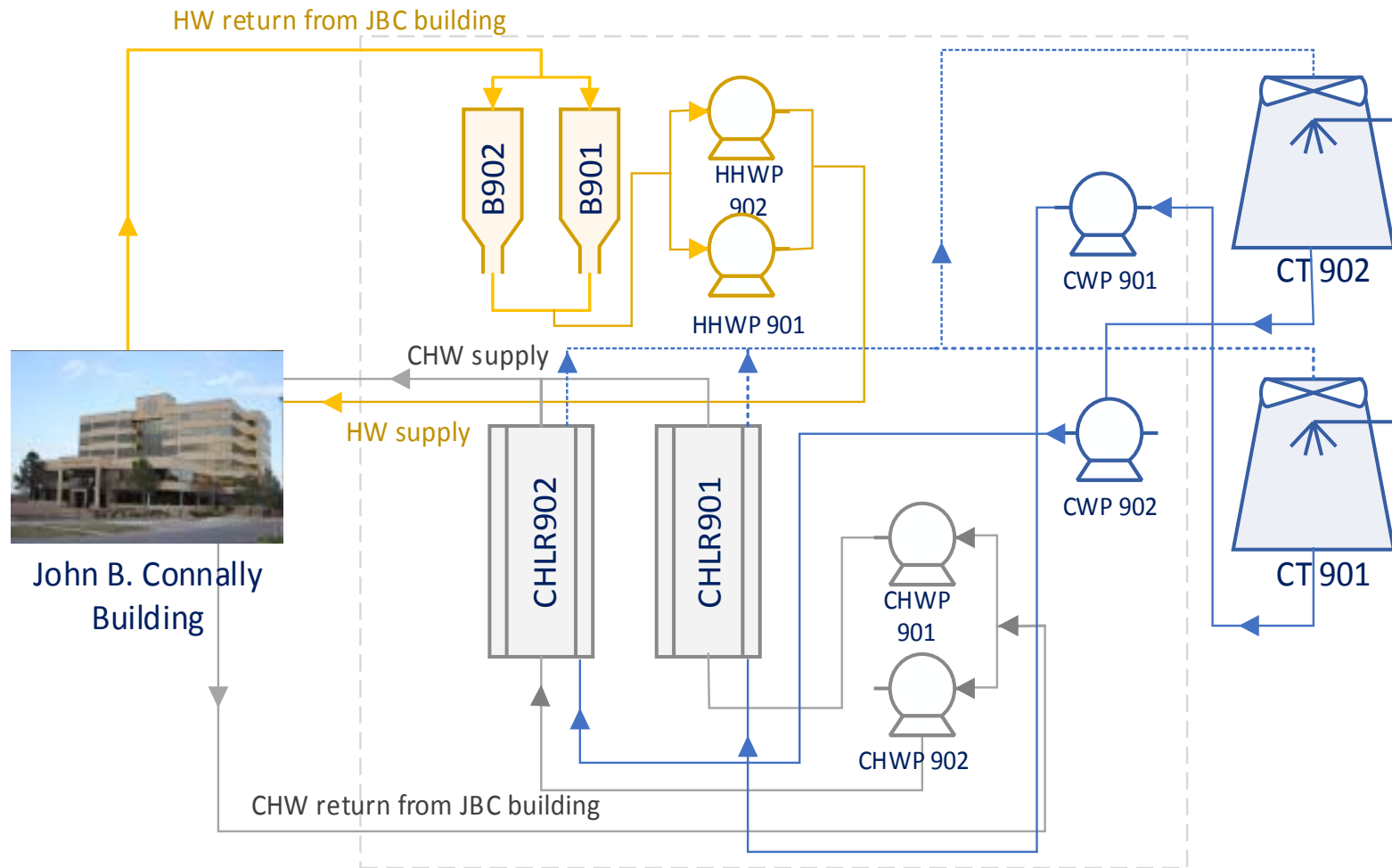


Figure 26. Simplified JCB Building Plant Diagram of the Heating and Cooling System

As seen in Figure 26, the overall illustration of how the hot water is supplied and returned to the JBC building can be traced by following the hot water piping that is connected to the two boilers (B901, B902) and the boiler pumps (HHWP 901, HHWP 902). The chilled water is supplied by the two chillers (CHLR 901, CHLR 902) and the associated pumps (CHWP 901, CHWP 902). The process water in the chiller is circulated into the cooling towers (CT 901, CT 902) to reject the heat and is pumped (CWP 901, 902) back into the chillers. The chiller basically has two components. One is the circulation of processed water and the other is the circulation of refrigerants.

Meet with the System Engineers

The final meeting was with the building's engineers (e.g., electrical and mechanical system engineers) to discuss the operation of this case-study building in more detail. The building engineers were able to discuss: the relevant codes; the operational issues; and other considerations to take into account when selecting energy retrofits in more detail. In particular, the emphasis was on understanding the building occupant comfort versus what is in the code or the standards. The advancement in technology provided more opportunities but this also meant that the people that operate the building must have adequate training to sustain the savings. According to the engineers, part of the problem with following the energy codes is that it is "designed for the masses". Therefore, applying the codes to an individual building is challenging. For example, in the economizer cycle, the outside air temperature controls the building air intake. However, in Texas, there is overwhelming humidity. Therefore, the economizer cycle is ideal but can realistically only be used during limited time periods in Texas.

Reducing light levels to recommended standard does not always meet the lighting needs of the occupants in the building. For example, the engineers need to consider older adults in the building when reducing light levels. LED lighting is becoming popular since it is known to be energy efficient. However, current LED lights are very directional making this inappropriate for the existing conference rooms in the JBC building. In addition, conflicting industry standards about the lighting colors further complicates the problem. The engineers also noted that retrofit efforts can defeat the purpose of saving energy if the maintenance people install the wrong color lamp which leads to a mix of colors. The engineers indicated that human involvement in the maintenance and operation of the building was still an integral part of reducing and sustaining the energy. Based on the engineer's experience, new technology did not always prove to be easy to maintain.

For this building, the three story atrium was noted to contribute to consuming more energy compared to similar type of office buildings. Unfortunately, the system engineers did not have the hourly building profile to analyze the building energy consumption in detail. However, they noted that the envelope was not as efficient. Windows in this building are not low-e glass although it has double pane glazing. As such, the building had a large amount of reheat load. Meaning, when excess air is released to the air it is replaced with warm moist air which needs to be treated. Without an energy recovery ventilation equipment it lead to wasted energy.

7.3.2 Drawings

The request for building plans and construction documents (CD) were made to supplement the site visits accompanied by the building proctor, plant manager and the systems engineers. Although the CD could not be released as instructed by the Chief Financial Officer and Treasurer of the TAMUS, the simplified building floor plans obtained from the Office of Facilities Planning and Construction (OFPC) showed the general layout of the building as seen in Figure 27.

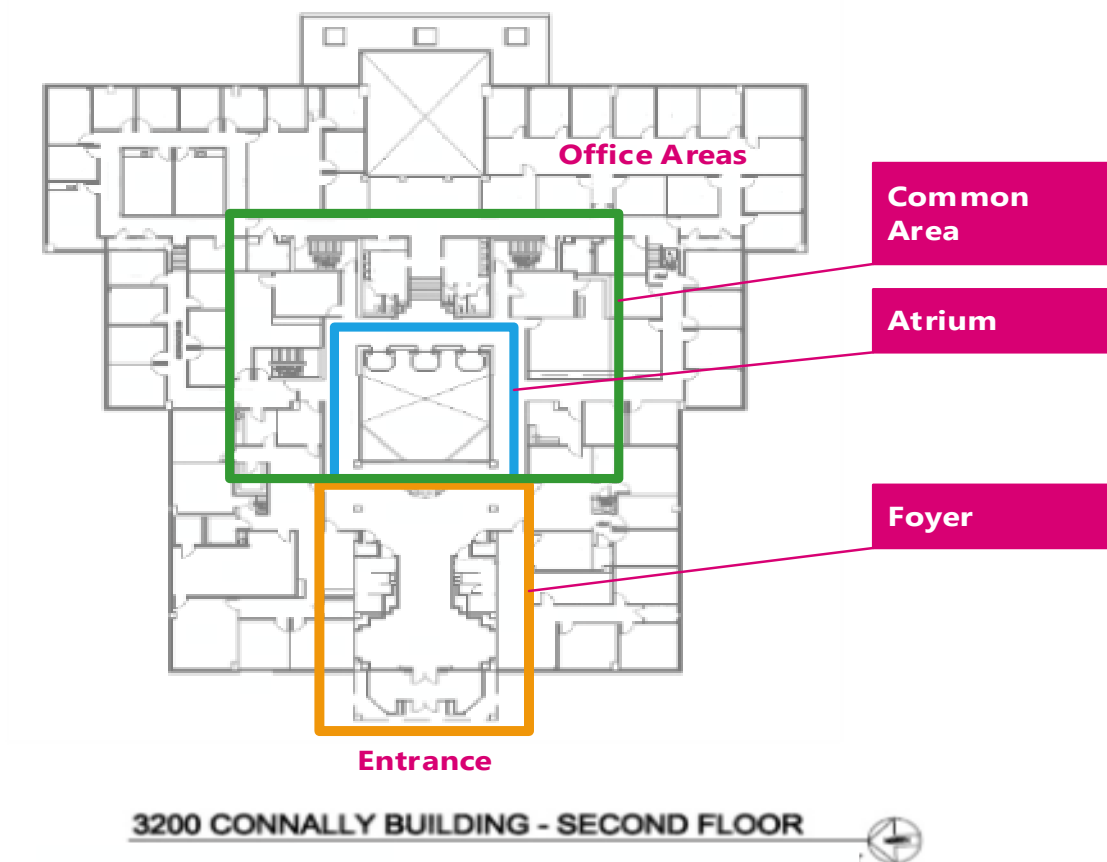


Figure 27. Typical Diagrammatic Floor Plan of JBC Building (Floors 1-3)

Glazing specification, existing air side equipment, plant equipment specification, were all extracted from a previous study (Cho, 2009). Lighting fixture schedule was also obtained by Office of Facilities Planning and Construction. These partial CD information was used to improve the model. The building component details showed that the roof was essentially a 4” sprayed urethane coating on a concrete roof with gravel ballast. When the researcher visited the site, the roof did not have any gravel ballast. The finishes were visually inspected to be a light-colored membrane on the surface. The exterior walls were composed of a mix of stone veneers, concrete panels and a glass air-lock entry. The interior walls were painted gypsum boards and the building had suspended ceiling panels. By removing one of the ceiling panels, the researcher was able to verify that the floors were concrete. These building component details (summarized in Table 16) were used to refine the whole-building energy simulation parameters.

Table 16. Summary of JBC Building Component Material Detail

| Building Components | Materials | Values | Units | General Description |
|----------------------------|-----------------------------|---------------|----------------|---|
| Roof | Roof Total R-Value | 29.03 | Hr.-Sqft-F/Btu | Urethane coating on concrete roof with gravel ballast |
| Exterior Wall | Exterior Wall Total R-Value | 9.52 | Hr.-Sqft-F/Btu | Concrete wall with metal studs and batt insulation |
| Floor | Floor Total R-Value | 4.34 | Hr.-Sqft-F/Btu | Concrete floor |
| Ceiling | Ceiling Total R-Value | 1.78 | Hr.-Sqft-F/Btu | Suspended ceiling with gypsum ceiling tiles |
| Interior Wall | Interior Wall Total R-Value | 2.95 | Hr.-Sqft-F/Btu | Gypsum board on each side with metal stud wall |

The glazing product used throughout the JBC building was from obtained from the previous study (Cho, 2009). The detailed parameters were verified by searching on the web for the specific product literature. The performance data was downloaded from the PPG website and summarized in Table 17.

Table 17. Glazing Properties of the JBC Building

| Glazing Property: <i>SOLARCOOL</i> Glass (Reflective): <i>SOLARCOOL</i> (2) <i>Bronze</i>³⁵ | Description | Performance Data |
|---|----------------------|-----------------------------|
| Transmittance | Ultra-violet % | 6 |
| | Visible % | 19 |
| | Total Solar Energy % | 21 |
| Reflectance | Visible Light % | 14 |
| | Total Solar Energy % | 12 |
| U-Value | Winter Night-time | 0.48 |
| | Summer Day-time | 0.50 |
| Shading Coefficient (SC) | | 0.40 |
| Solar Heat Gain Coefficient (SHGC) | | 0.34 |
| Light to Solar Gain (LSG) | | 0.56 |

³⁵ © 2005 PPG Industries, Inc. and performance data calculated using LBL Window 5.2
(<http://www.ppg.com/corporate/ideascapes/sitecollectiondocuments/solarcoolearthtone.pdf>)

Next, the design specification of the AHUs were determined as shown in Table 18 and for the and plant equipment as shown in Table 19.

Table 18. AHU Schedule for the JBC Building

| AHU Schedule | | | | | | | |
|--------------|-----------|--------|-------------------------|------|-----------------------|-------------|----------|
| AHU ID# | Total CFM | OA CFM | SP ³⁶ (inWG) | HP | Unit Location | Area Served | Air Flow |
| 1-1 | 7610 | 500 | 2.5 | 7.5 | 1 st floor | N | VAV |
| 1-2 | 10445 | 1725 | 2.5 | 7.5 | | S | |
| 1-3 | 9385 | 1565 | 2.5 | 7.5 | | W | |
| 2-1 | 8000 | 500 | 2.5 | 7.5 | 2 nd floor | N | VAV |
| 2-2 | 8535 | 535 | 2.5 | 7.5 | | S | |
| 2-3 | 12170 | 670 | 2.5 | 10.0 | | W | |
| 3-1 | 6855 | 475 | 2.5 | 7.5 | 3 rd floor | N | VAV |
| 3-2 | 10775 | 575 | 2.5 | 10.0 | | S | |
| 3-3 | 8935 | 500 | 2.5 | 7.5 | | W | |
| 4-1 | 9520 | 560 | 2.5 | 7.5 | 4 th floor | N | VAV |
| 4-2 | 9850 | 560 | 2.5 | 10.0 | | S | |
| 5-1 | 9520 | 560 | 2.5 | 7.5 | 5 th floor | N | VAV |
| 5-2 | 9850 | 560 | 2.5 | 10.0 | | S | |
| 6-1 | 9520 | 560 | 2.5 | 7.5 | 6 th floor | N | VAV |
| 6-2 | 9850 | 560 | 2.5 | 10.0 | | S | |
| 7-1 | 10560 | 560 | 2.5 | 10.0 | 7 th floor | N | VAV |
| 7-2 | 10620 | 560 | 2.5 | 10.0 | | S | |
| OA 1 | 4215 | 4215 | 1.0 | 3.0 | Roof | Outside Air | VAV |
| OA 2 | 5075 | 5075 | 1.0 | 3.0 | | | |

³⁶ Static Pressure in Water Gauge

Table 19. Summary of Plant Equipment in the JBC Plant Building

| Equipment Type | Performance Data | | | | | | |
|---|------------------|-------------------|-----------------------|------------------------|----------|---------------|----------------|
| Boilers: 460V, 3Phase Blower Motor, Cleaver Brooks Model M4W-2000 | Fuel Type | GPM ³⁷ | EWT ³⁸ (F) | LWT ³⁹ (F) | HP | Input (MMBtu) | Output (MMBtu) |
| B-901 | N.G. | 80 | 150 | 190 | 1 | 2,000 | 1,6000 |
| B-902 | N.G. | 80 | 150 | 190 | 1 | 2,000 | 1,6000 |
| Chillers: York Centrifugal Chiller, Model: YT E1 E3 C1-CK FS | Tons | GPM | EWT (F) | LWT (F) | Delta-P | Input (kW) | Eff. (kW/ton) |
| CHLR-901 | 280 | 560 | 54 | 42 | 15 | 190 | 0.68 |
| CHLR-902 | 280 | 560 | 54 | 42 | 15 | 190 | 0.68 |
| Cooling Towers: VFD | Condenser Data | | | Amb. Twb ⁴⁰ | Fan Data | | |
| | GPM | EWT (F) | LWT (F) | (F) | HP | Volts | Phase |
| CT-901 | 840 | 96 | 86 | 80 | 15 | 460 | 3 |
| CT-902 | 840 | 96 | 86 | 80 | 15 | 460 | 3 |
| Pumps | GPM | Head Ft. | Min. Eff. | HP | Volts | Phase | RPM |
| CHWP 901: Aurora Series 410 | 560 | 90 | 75 | 20 | 460 | 3 | 1750 |
| CHWP 902 | 560 | 90 | 75 | 20 | 460 | 3 | 1750 |
| CTWP 901: Aurora Series 1110 | 840 | 40 | 81 | 15 | 460 | 3 | 1750 |
| CTWP 902 | 840 | 40 | 81 | 15 | 460 | 3 | 1750 |
| HWP 901: Aurora Series 360 | 80 | 80 | 60 | 2 | 460 | 3 | 1750 |
| HWP 902 | 80 | 80 | 60 | 2 | 460 | 3 | 1750 |

³⁷ Gallons of Water Per Minute³⁸ Entering Water Temperature³⁹ Leaving Water Temperature⁴⁰ Ambient Wet Bulb Temperature

The lighting schedule showed a variety of lighting fixtures used throughout the building. The majority of the lights were various sizes (i.e., 2'X4', 2'X2', 1'X4') of parabolic recessed fluorescent lights with return air troffer. Throughout the building there were also recessed fluorescent downlights, various display lighting and wall fixtures with halogen lighting fixtures. The parking lot fixtures were high pressure sodium (HPS) flood lighting fixtures on a pole. In addition, there were metal halide lighting fixtures on a pole for area lighting.

7.3.3 Phase III Summary

Phase III data collection process included gathering information by assisted site visits and by reviewing the drawings. Assisted site visits were conducted with the building proctor to gain information about the building system and space conditions. The assisted site visits with the plant manager was conducted mostly to inspect plant equipments such as chillers, cooling towers, boilers, service water heater and associated pumps. Although in this study, there was no site visit with the design engineers, the system engineers provided additional information and operational issues about the building's electrical and mechanical systems. The drawings were used to verify the equipment specifications and to confirm what was visually inspected from the previous data collection efforts. Accordingly, all of the information collected from Phase III was used to improve the whole-building simulation model. Table 20 shows the updated data collection protocol for Phase III.

Table 20. Refinement of the Data Collection Protocol - Phase III

| CHARACTERISTIC | Phase III: Assisted Visits & Drawings | SOURCES |
|---|---|---|
| Building | | |
| Building type | Office | Phase I, II, Assisted Site Visits |
| Gross area (sq-ft) | 124,000 | Phase II, Assisted Site Visits, Drawings |
| Dimension (ft. x ft.), Aspect Ratio | T-shape | Phase II, Drawings |
| Number of floors | 7 | Phase II, Assisted Site Visits, Drawings |
| Floor to floor height (ft.) | 13 | Phase I, II, Assisted Site Visits, Drawings |
| Orientation | West | Phase II, Assisted Site Visits, Drawings |
| Construction | | |
| Wall Construction | Masonry | Phase I, Drawings |
| Roof Construction | Sprayed Urethane | Phase I, Drawings |
| Foundation Construction | | |
| Wall absorptance | 0.7 | Phase I |
| Wall insulation R-value (hr.-sq.ft-F/Btu) | 9.52 | Phase I, Drawings |
| Roof absorptance | 0.7 | Phase I |
| Roof insulation R-value (hr.-sq.ft-F/Btu) | 29.03 | Phase I, Drawings |
| Ground reflectance | 0.2 | Phase I |
| U-factor of glazing (Btu/hr.-sq.ft-F) | 0.48-0.50 | Phase II, Drawings |
| Solar Heat Gain Coefficient (SHGC) | 0.34 | Phase II, Drawings |
| Window-to-wall ratio (%) | 40 | Phase II, Drawings |

Table 20. Continued

| CHARACTERISTIC | Phase I: Code-Compliant Base Case | SOURCES |
|--|---|--|
| Space | | |
| Area per person (ft ² /person) | 275 (325 occupants) | Phase I |
| Occupancy schedule | 6am-5pm (Mon - Sat) | Phase I, Assisted Site Visit |
| Space Heating Set Point | 72F Heating / 74F Cooling | Phase I, Assisted Site Visit |
| Space Cooling Set Point | 72F Heating / 74F Cooling | Phase I, Assisted Site Visit |
| Lighting Power Density (W/ft ²) | 1.3 | Phase I |
| Lighting schedule | ASHRAE RP-1093 Schedule | Phase I |
| Equipment Power Density (W/ft ²) | 0.75 | Phase I |
| Equipment schedule | 24 hours (Monday - Sunday) | Phase I, Assisted Site Visit |
| HVAC Systems | | |
| HVAC system type | VAV with terminal reheat | Phase I, Assisted Site Visit, Drawings |
| Number of HVAC units | 19 | Phase I, Assisted Site Visit, Drawings |
| Supply motor efficiency (%) | 90 | Phase I, Drawings |
| Supply fan efficiency (%) | 61 | Phase I, Drawings |
| Supply fan total pressure (W.G) | 2.5 | Phase I, Drawings |
| Plant Equipment | | |
| Chiller type | 2 Centrifugal (280 ton cooling) | Phase I, II, Assisted Site Visit, Drawings |
| Chiller COP | 5.55 (For 280 ton chiller) | Phase I |
| Boiler type | Hot water boiler | Phase I, Assisted Site Visit, Drawings |
| Boiler fuel type | Natural gas | Phase I, Assisted Site Visit, Drawings |
| Boiler thermal efficiency (%) | 80 | Phase I, Drawings |
| DHW fuel type | Natural gas | Phase I, Assisted Site Visit, Drawings |
| DHW heater thermal efficiency (%) | 85 | Phase I, Assisted Site Visit |

7.4 Phase IV: Detailed Measured Data

7.4.1 Measured Indoor Environmental Data

Both the system engineers and the experts recommended it is important to address any issues and occupant discomfort prior to selecting the retrofits. Although it was outside the scope of this work, it is recommended that the energy auditor verify the indoor environmental qualities (IEQ) prior to recommending ECMs. Common IEQ include thermal comfort, indoor air quality (IAQ), lighting, and acoustics. For the purpose of calibrating the whole-building simulation model and for testing the lighting and lighting control ECMs, the study considered and reviewed a previous study (Kim 2012) which investigated the IEQ performance of the JBC building by collecting both subjective measurements which were self-reported by the building occupants and corresponding objective spot measurement of various performance parameters⁴¹.

⁴¹ Of interest for this previous study was to see if there were any significant differences found between the dissatisfied group and the satisfied group with the thermal and visual comfort. The study found that in general, for the most basic level of IEQ (thermal comfort, IAQ, lighting and acoustics) measurements, there was no significant difference between the two groups of occupants. Spot measurements indicated that the air temperatures ranged from 71.8 to 77.0 (F) degrees in the summer and relative humidity of 39.1 to 51.3(%). In the previous study two of the 17 occupants were dissatisfied with the current lighting level and only one of those office spaces had a luminance level lower than the recommended value for task areas. Thus, in this study, it was assumed that the current temperature was maintained at 72(F) in the winter and 74(F) in the summer and that the current lighting level was assumed to meet the minimum national level lighting standard.

7.4.2 *Measured Energy Data*

The JCB building is equipped with a data logger in the thermal plant which provides sub-hourly (15 minute interval) data. This study used data collected from January 2009 to December 2009 on 15 different channels and monthly natural gas utility bills to calibrate the whole-building energy simulation model which was monitored by the Energy System Lab during those periods. An energy monitoring diagram and locations of individual sensors were obtained prior to visiting the plant⁴². The data acquisition system was also documented and photographed during the site visits. The output document for the 15 different channels was in a spreadsheet format and was compiled by the researchers at ESL. A separate meeting with the one of the researchers was conducted to gain intelligence on how the data was assembled and monitored.

⁴² Hyojin Kim and Jeff Haberl "Status Report of the John B. Connally Building on the Electric, Thermal, and Weather Data Loggers - Draft" Energy Systems Laboratory, March 2009. (ESL-ITR-09-03-02)

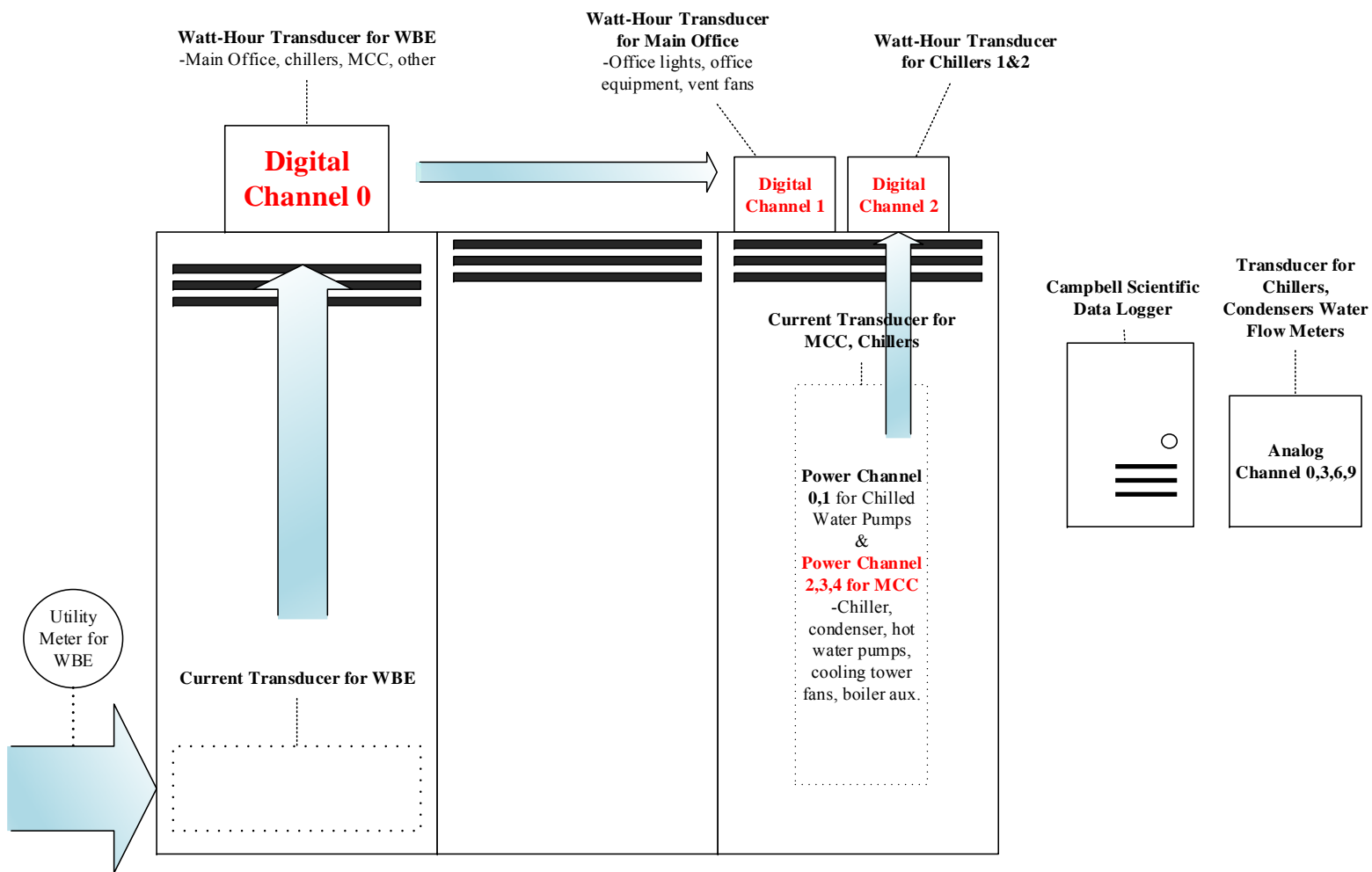


Figure 28. Schematics of the Data Acquisition System and Electric and Thermal Monitoring Instrumentation in the Switch Gear Room Inside the JBC Thermal Plant

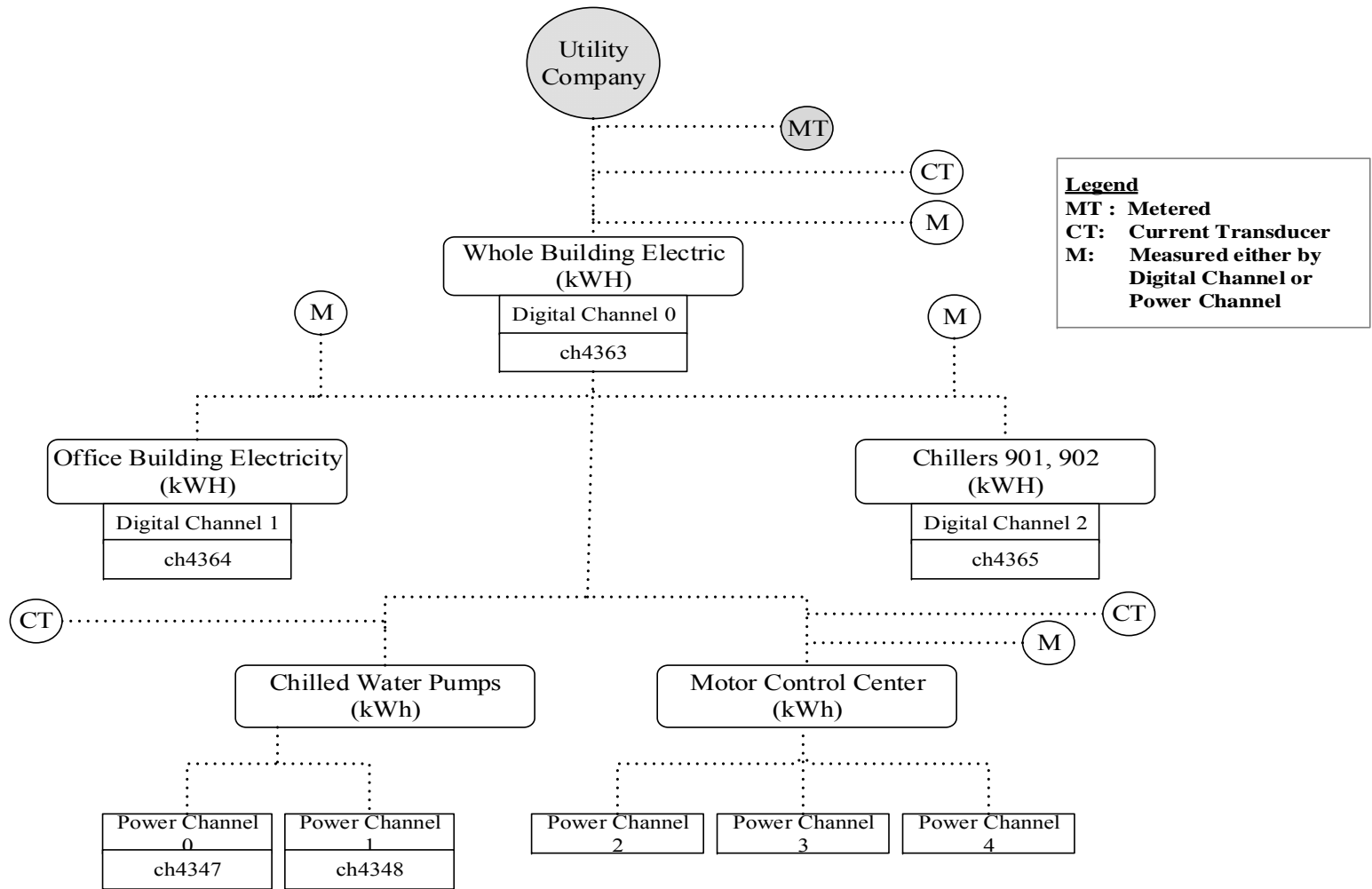


Figure 29. JBC Building Electric Monitoring Diagram

Figure 28 shows the schematic drawing of the electric monitoring system in the switch gear room inside the JBC thermal plant. The switch gear room is adjacent to the main transformer outside the thermal plant. The main electricity meter, which is managed by the utility company is located outside the thermal plant near this main transformer. When the electricity is supplied by the utility company, the electricity goes to the pad-mounted transformer with a fenced enclosure to step down the primary voltage to a lower secondary voltage for the building. The lowered voltage goes to the current transducer for the whole building electricity (WBE). To acquire the energy data, power channels were added to the chilled water pumps (power channel 0, 1) and MCC (power channel 2, 3, 4). Motor control center electricity included chilled water pumps, condenser water pumps, hot water pumps, cooling tower fans, and boiler auxiliaries.⁴³ To measure the WBE, a secondary watt-hour transducer was added to measure the current via electrical signals by installing a digital channel (digital channel 0). The WBE (digital channel 0) included main office building electricity (OBE), chiller electricity, MCC electricity and others.⁴⁴ Two other digital channels were installed to measure the Watt-hour for the chillers (digital channel 2) and OBE (digital channel 1). Office building electricity (e.g., main office electricity) included office lights, equipment and the vent fans.

⁴³ Hyojin Kim, "Methodology for Rating a Building's Overall Performance based on the ASHRAE/SIBSE/USGBC Performance Measurement Protocols for Commercial Buildings" Doctoral Dissertation, Department of Architecture, December 2012. (ESL-TH-12-12-01)

⁴⁴ The output document included WBE, OBE, electricity use for chillers, and electricity use for MCC. The electricity use for others were derived by subtracting the sum of OBE, electricity use for chillers, and electricity use for MCC from the WBE consumption.

Figure 28 also shows a data logger which collected the measured energy data from the building and transferred the data via internet connection. Adjacent to the data logger was a transducer for the chillers and condensers water flow. All of the measuring equipment and the data acquisition system was maintained by the Energy Systems Lab. Similarly, Figure 29 shows the electrical monitoring diagram. The main meter for the building, measured data from the sensors for both the digital channels and power channels, and locations of the current transducers are indicated in the diagram.

Figure 29 shows the thermal monitoring diagram of the JBC building. The supply and return water temperature ($^{\circ}\text{F}$) to the chillers and condensers along with the flow (GPM) measurements were used to derive the chiller and condenser output. Finally, Figure 31 through Figure 35 shows the installed electric monitoring instrument, sensors and flow meters throughout the JBC thermal plant. A partial output for the building energy performance spreadsheet is shown in Table 21 and Table 22. Once the information on the sensors were gathered, as a first step, a time-series diagram of the various sub-hourly building energy data was plotted for period of February 28, 2009 to March 6, 2009.⁴⁵ Weekly plots of the WBE (kWh/h), chiller output (MMBtu/h), condenser output (MMBtu/h), supply and return temperature ($^{\circ}\text{F}$) and flow (GPM) for both chillers and condensers were plotted against the date to verify that the information was reasonable.

⁴⁵ Weekly plots from February 28-March 6 was selected to cross-check against the weekly plots that were developed by the ESL. These weekly plots were published in Hyojin Kim and Jeff Haberl "Status Report of the John B. Connally Building on the Electric, Thermal, and Weather Data Loggers - Draft" Energy Systems Laboratory, March 2009. (ESL-ITR-09-03-02).

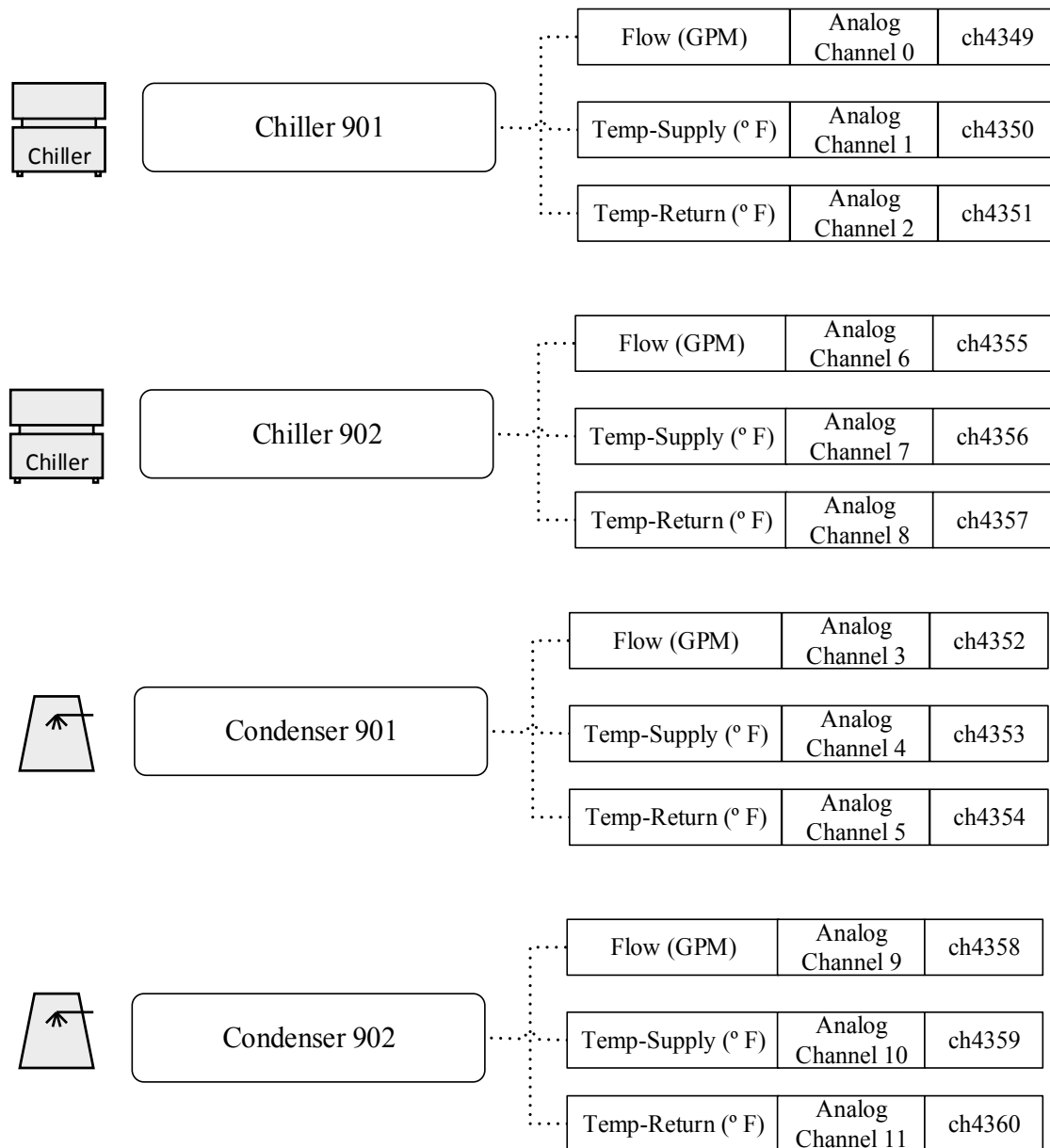


Figure 30. JBC Building Thermal Monitoring Diagram

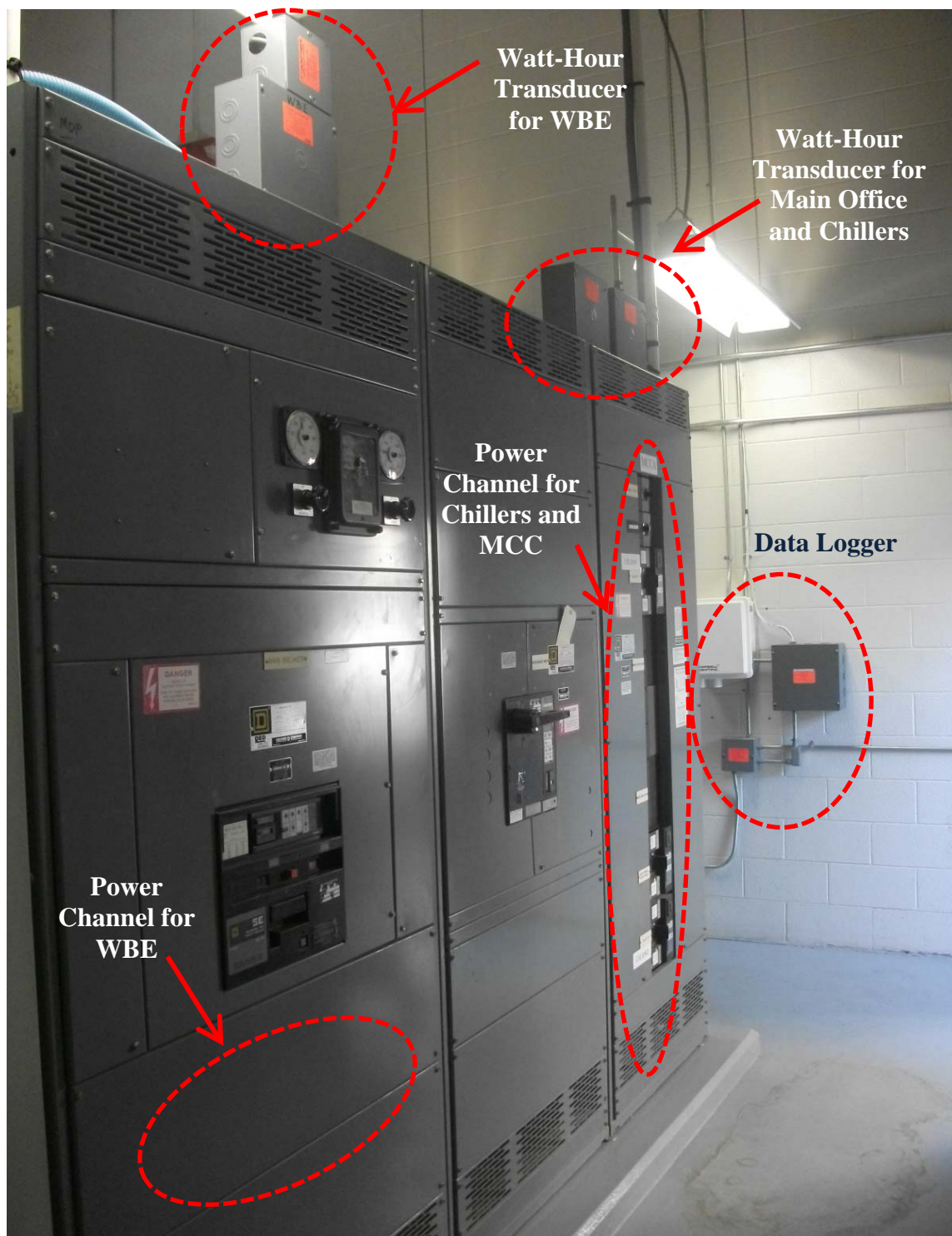


Figure 31. Electric Monitoring Instruments

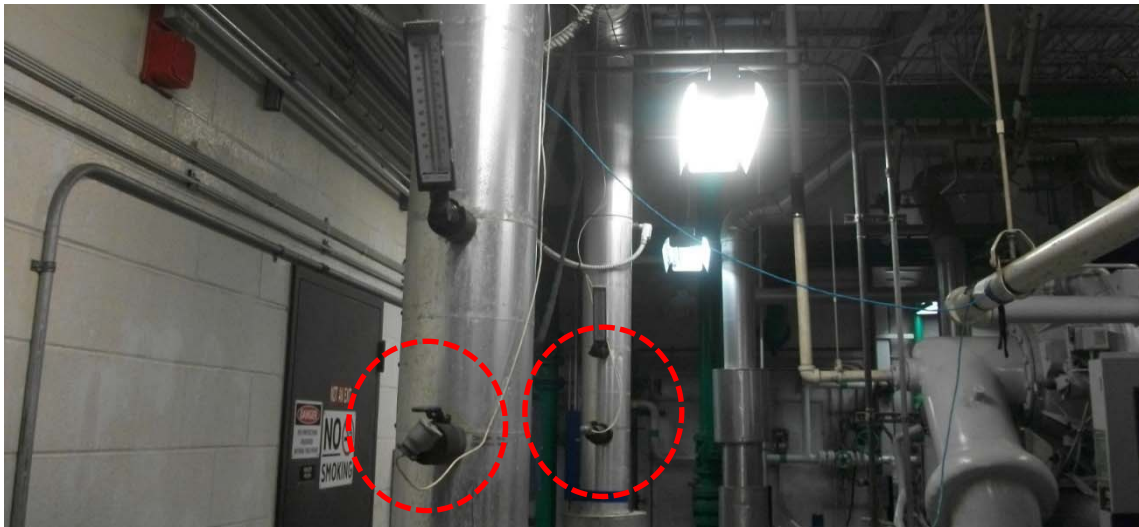


Figure 32. Sensors for Chilled Water Supply Temperature

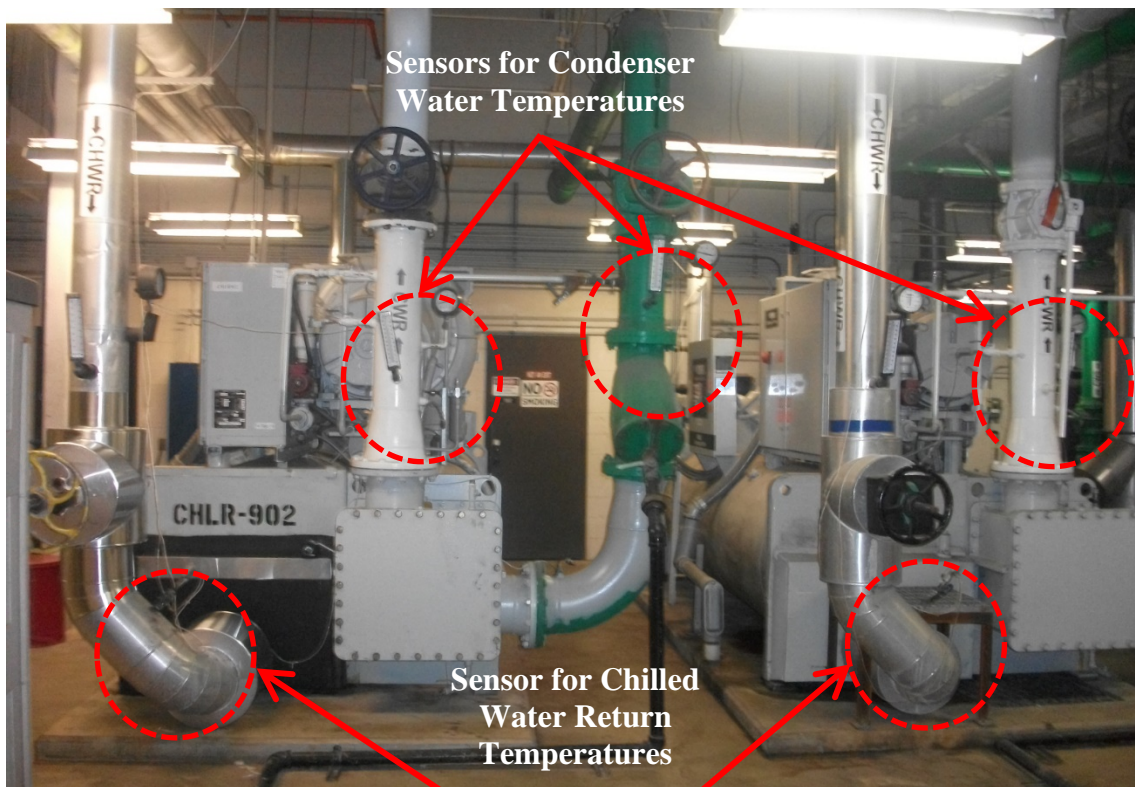


Figure 33. Sensors for Chilled Water Return Temperatures and Condenser Water Temperatures

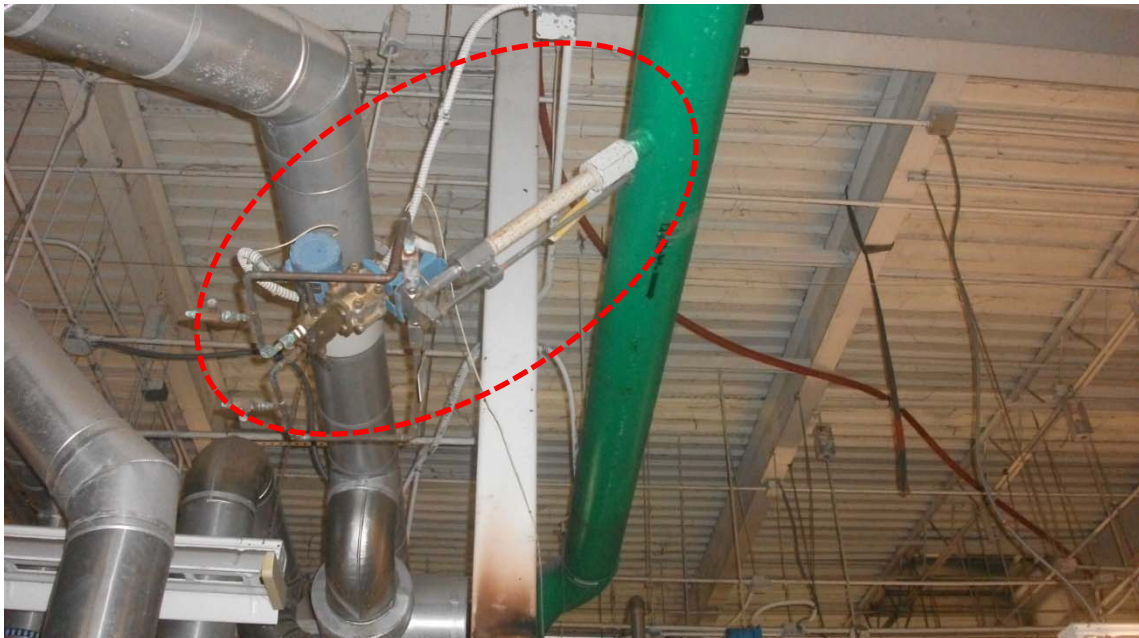


Figure 34. Flow Meters for Condenser Water



Figure 35. Flow Meters for Chilled Water

Table 21. Partial WBE Output of the Measured Sub-hourly Building Energy Performance Data

| TAMU3200 : State Headquarters Building (Sta) | | | | | | |
|--|------------------|---------------|-----------------|-------------|-------|-------|
| Site # 585 | | Logger # 2856 | | | | |
| Date & Time | Time Stamp (LST) | WBE | OFF. BLDG ELEC. | CHILLER 1&2 | MCC | Other |
| | | D 0 | D 1 | D 2 | | |
| | | (kW) | (kW) | (kW) | (kW) | (kW) |
| | | ch 4363 | ch 4364 | ch 4365 | | |
| | | WBE | OBE | CHW | MCC | Other |
| 2/28/09 0:00 | 0:00 | 219 | 154 | 29 | 18.24 | 17.96 |
| 2/28/09 1:00 | 1:00 | 216 | 154 | 28 | 18.22 | 15.78 |
| 2/28/09 2:00 | 2:00 | 213 | 152 | 28 | 18.09 | 14.91 |
| 2/28/09 3:00 | 3:00 | 216 | 150 | 27 | 18.18 | 20.62 |
| 2/28/09 4:00 | 4:00 | 213 | 152 | 27 | 18.18 | 15.62 |
| 2/28/09 5:00 | 5:00 | 216 | 152 | 29 | 18.36 | 16.84 |
| 2/28/09 6:00 | 6:00 | 255 | 184 | 34 | 20.72 | 16.68 |
| 2/28/09 7:00 | 7:00 | 267 | 202 | 32 | 21.10 | 11.90 |
| 2/28/09 8:00 | 8:00 | 255 | 196 | 31 | 20.99 | 6.81 |

Table 22. Partial Thermal Energy Output of the Measured Sub-hourly Building Energy Performance Data

| TAMU3200 : State Headquarters Building (Sta) | | | | | | | | | | | | | |
|--|------------------|---------------|---------------------|---------------------|---------|---------------------|---------------------|---------|---------------------|---------------------|---------|---------------------|---------------------|
| Site # 585 | | Logger # 2856 | | | | | | | | | | | |
| Date & Time | Time Stamp (LST) | ChW 1 | | | COND 1 | | | ChW 2 | | | COND 2 | | |
| | | A 0 | A 1 | A 2 | A 3 | A 4 | A 5 | A 6 | A 7 | A 8 | A 9 | A 10 | A 11 |
| | | (GPM) | (F) | (F) | (GPM) | (F) | (F) | (GPM) | (F) | (F) | (GPM) | (F) | (F) |
| | | ch 4349 | ch 4350 | ch 4351 | ch 4352 | ch 4353 | ch 4354 | ch 4355 | ch 4356 | ch 4357 | ch 4358 | ch 4359 | ch 4360 |
| | | Flow | T _{Supply} | T _{Return} | Flow | T _{Supply} | T _{Return} | Flow | T _{Supply} | T _{Return} | Flow | T _{Supply} | T _{Return} |
| 2/28/09 0:00 | 0:00 | 427.62 | 70.40 | 48.69 | 796.61 | 68.06 | 65.53 | 0.00 | 58.39 | 72.32 | 0.00 | 76.65 | 80.05 |
| 2/28/09 1:00 | 1:00 | 432.43 | 126.97 | 48.67 | 796.37 | 67.01 | 64.59 | 0.00 | 58.43 | 72.22 | 0.00 | 75.27 | 79.27 |
| 2/28/09 2:00 | 2:00 | 435.36 | 146.88 | 48.52 | 796.32 | 67.03 | 64.66 | 0.00 | 58.31 | 72.09 | 0.00 | 74.17 | 78.50 |
| 2/28/09 3:00 | 3:00 | 432.93 | 340.80 | 48.42 | 797.05 | 67.02 | 64.70 | 0.00 | 58.19 | 71.87 | 0.00 | 73.34 | 77.56 |
| 2/28/09 4:00 | 4:00 | 434.49 | 484.70 | 48.43 | 797.98 | 67.51 | 65.21 | 0.00 | 57.76 | 71.50 | 0.00 | 72.44 | 76.35 |
| 2/28/09 5:00 | 5:00 | 441.18 | 522.31 | 48.50 | 798.42 | 68.36 | 65.97 | 0.00 | 57.59 | 71.15 | 0.00 | 71.76 | 75.11 |
| 2/28/09 6:00 | 6:00 | 475.44 | 522.98 | 49.06 | 798.81 | 69.27 | 66.42 | 0.00 | 57.35 | 70.76 | 0.00 | 71.01 | 73.96 |
| 2/28/09 7:00 | 7:00 | 472.73 | 524.33 | 49.26 | 799.15 | 68.44 | 65.52 | 0.00 | 56.86 | 70.38 | 0.00 | 70.46 | 72.92 |
| 2/28/09 8:00 | 8:00 | 465.88 | 525.23 | 49.23 | 799.64 | 68.02 | 65.18 | 0.00 | 56.66 | 69.92 | 0.00 | 69.77 | 71.85 |

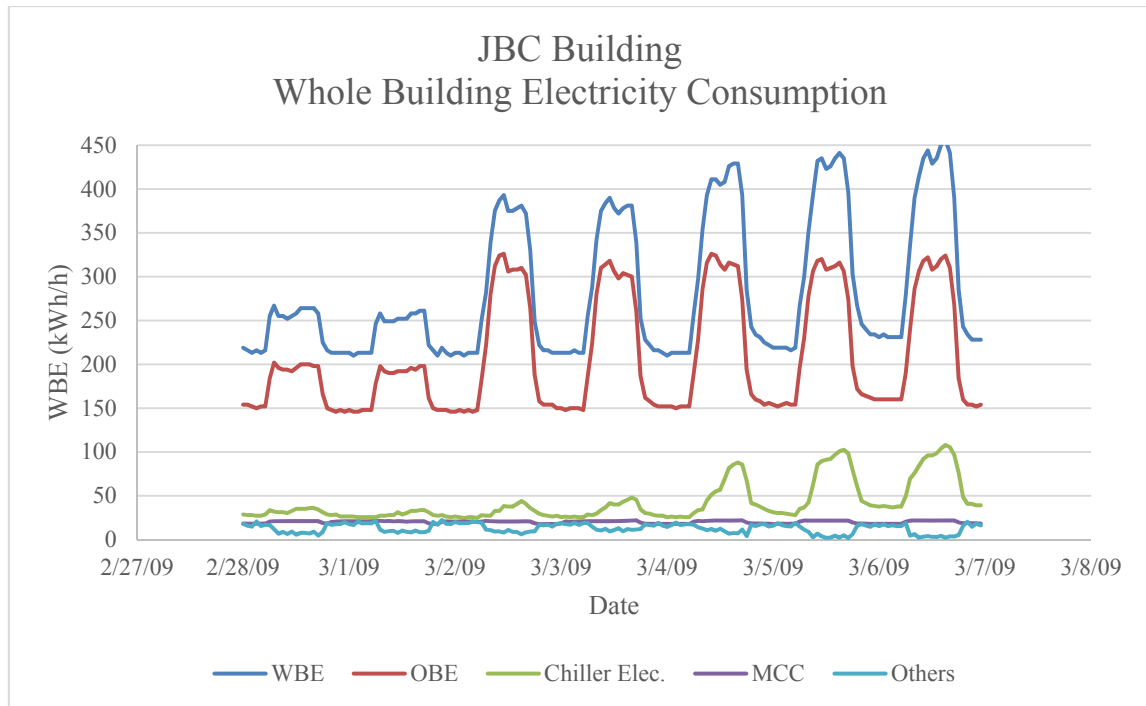


Figure 36. Weekly Plot of JBC Building WBE Consumption - 2/28/2009 to 3/7/2009

As seen in Figure 36, the WBE included the sum of OBE, chiller electricity, MCC electricity and others. Office building electricity use was much lower during the weekends (2/28/09-3/1/09) as opposed to weekdays indicating that there should be a separate OBE schedule for the weekday and weekends. Office building electricity use displayed a bi-modal distribution and was mainly consistent throughout the weekday (Monday-Friday). However, the chiller electricity use increased with more CHW energy use which was dependent on the outside conditions (i.e., outdoor dry-bulb temperature). Electricity use from MCC and others followed a consistent pattern.

Next, the chiller energy use for chillers 1&2 were plotted against time.⁴⁶ Chiller 1 displayed excessive amount of energy use. For example, on 2/28/09 12:00, the chiller use was over 100 MMBtu/hr., equivalent to over 8,300 ton. This indicated that the thermal energy data may be erroneous for this particular week since the chiller had a cooling capacity less than 300 tons. Since there was no flow detected in chiller 2, the chiller energy use was “0” meaning that chiller 2 was not in operation during this particular week.

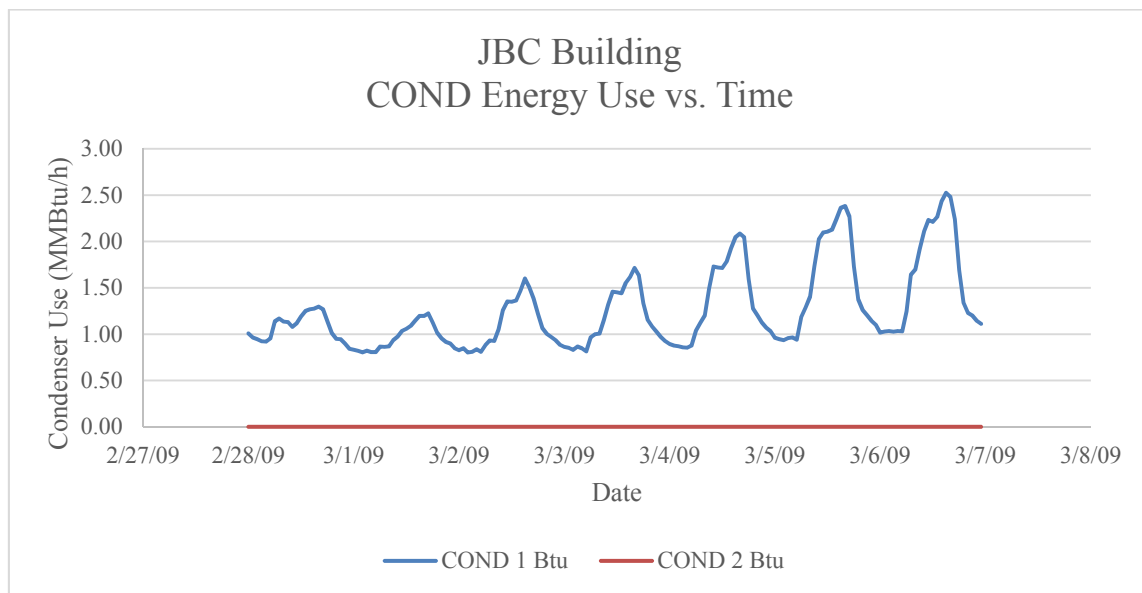


Figure 37. Weekly Plot of JBC Building Condenser Energy Use vs. Time - 2/28/2009 to 3/7/2009

⁴⁶ Chiller energy use (in tons) was calculated by taking the difference between the supply temperature to the return temperature and then multiplying by the flow and dividing the result by 24 $((T_s - T_r) * \text{Flow} / 24)$. The chiller energy use was then converted from Tons into MMBtu/hr. by multiplying by 0.012.

To validate that chiller 1 was running and 2 was off, the condenser 1&2 were plotted against time. Whenever a chiller is running the corresponding condenser should also be activated. Hence, the expected result was that if chiller 1 is operating then condenser 1 should be in operating as well. As seen in Figure 37, the condenser 1 was in operation while condenser 2 was in the off position. Correspondingly, the supply and return temperatures for the chiller1, chiller2, condenser 1, and condenser 2 were plotted against the date.

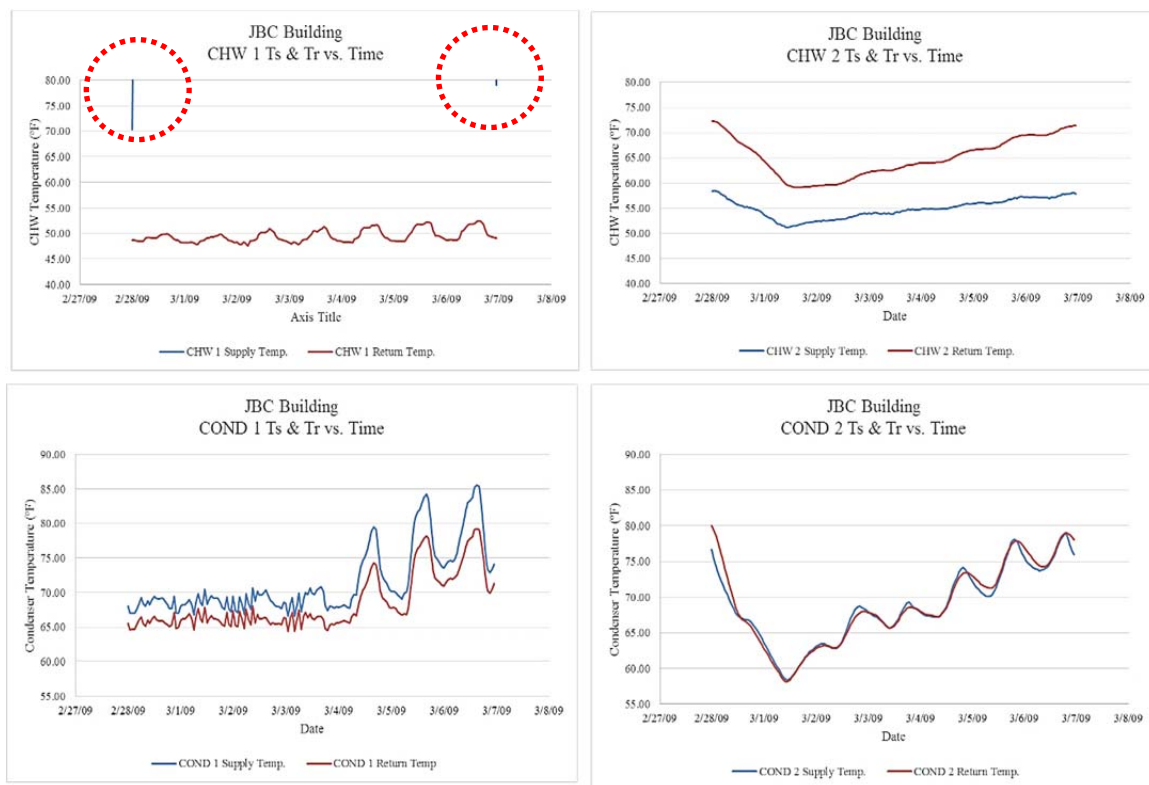


Figure 38. Weekly Plot of JBC Building Chillers, Condensers Supply and Return Temperature vs. Time - 2/28/2009 to 3/7/2009

As seen in Figure 38, the weekly plot indicated that the sensor for measuring the chiller 1 supply temperature was not properly collecting the data. Thus, the building's chiller energy use data from chiller 1 was considered useless.

The weekly plots were useful in determining the quality of the data. By investigating the weekly plots, it was possible to determine that one of the chiller's (chiller 2) sensor was not working properly⁴⁷. Next, the second step involved identifying and extracting the data that is needed to calibrate the whole building energy simulation model.

⁴⁷ More information is provided in Appendix O.

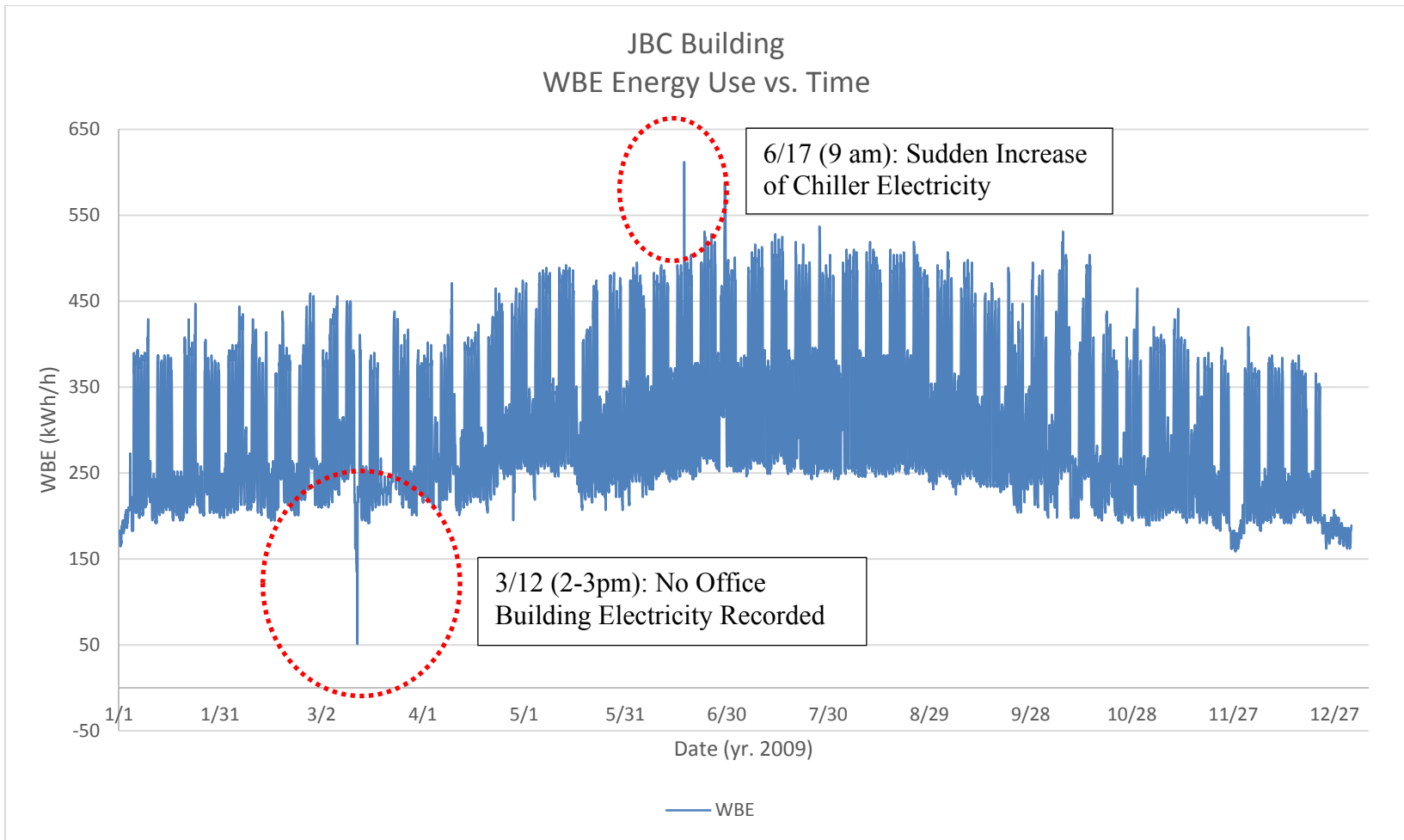


Figure 39. Time Series Plot of JBC Building WBE Consumption for Year 2009

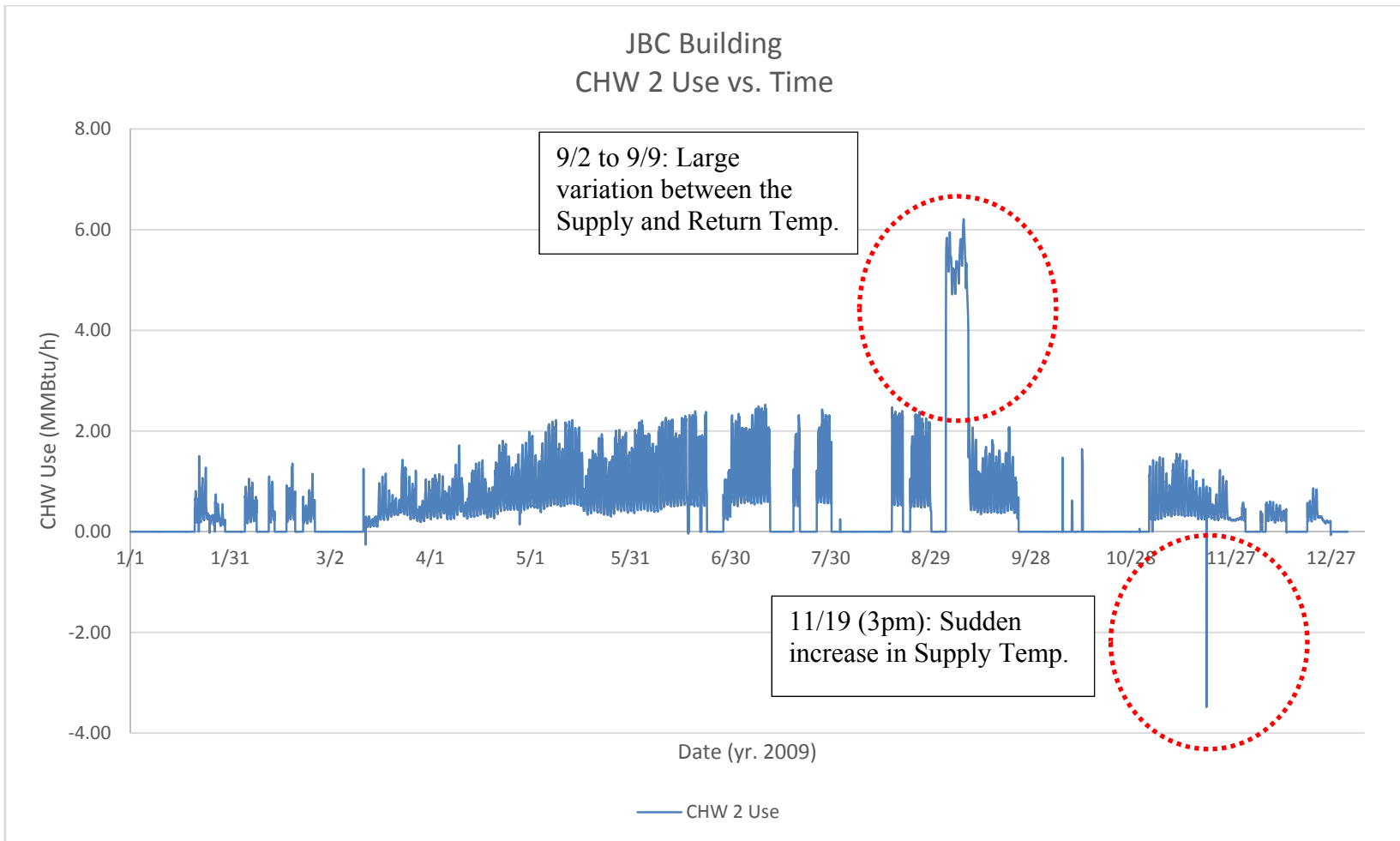


Figure 40. Time Series Plot of JBC Building Chiller 2 Energy Use for Year 2009

A time series plot of the WEB energy use and chiller energy was plotted against time to analyze the trend and to identify any abnormalities. As seen in Figure 39, there were a few points that were distinctively different from the rest of the data points. On March 12, 2009, the total WBE consumption was only 50 kWh/h. By looking at the data spreadsheet, it was identified that no office building electricity was recorded from 2:00 pm to 3:00 pm. On June 17, 2009, the chiller electricity dramatically increased by approximately three times (72 kW to 219 kW) from the previous hour suddenly increasing the electricity consumption. Regarding the chiller energy use, as seen in Figure 40, there was a sudden increase in the difference (approximately 15 degrees) between the supply temperature and the return temperature dramatically increasing the chiller use from September 2, 2009 to September 9, 2012. Finally, on November 19, 2013, the sudden increase in the supply temperature lead to a negative energy use. Also, since the two chillers were sequenced to run approximately same amount of the time each year, the “0” consumptions were considered to be the time when that particular chiller was in an off mode.

7.4.3 *Coincident Weather Data*

Coincident weather data corresponding to the measured energy use data was also obtained for the site. The coincident weather data for College Station, TX was obtained from a combination of three different sources. The key sources for creating a coincident weather data includes the: National Climate Data Center (NCDC) database; the ESL's Solar Test Bench (STB) database; and Texas Commission on Environmental Quality (TCEQ) database. The NCDC dataset provides information regarding: dry bulb temperature (T_{db}); dew point temperature (T_{dp}); wind speed; wind direction; precipitation; and station pressure. The STB provides information regarding: dry bulb temperature; solar radiation intensity; wind speed; wind direction; normal incidence solar radiation; and relative humidity. The TCEQ database provides the global solar radiation (GSR) information.

Nine parameters were combined into a single file to prepare a coincident weather data file that corresponds to the measured energy use. Some parameters were directly obtainable from the sources and others needed to be derived from given parameters. For example, the wet bulb temperature was calculated from the dry bulb temperature together with the dew point temperature and the station pressure which were available from the NCDC database. Table 23 shows the required weather parameters to pack the weather file and the associated relevant data source.

Table 23. Required Weather Parameters Needed to Prepare a Coincident Weather Data File

| Required weather parameter | Source | | | Comments |
|-------------------------------|--------|-----|------|--|
| | NCDC | STB | TCEQ | |
| Tdb | ✓ | ✓ | | |
| Twb ⁴⁸ | | | | Calculated from Tdb, Tdp, station pressure using psychrometric equations ⁴⁹ |
| Tdp | ✓ | | | |
| Wind speed | ✓ | ✓ | | |
| Wind direction | ✓ | ✓ | | |
| GSR | | ✓ | ✓ | |
| Normal Direct Solar Radiation | | ✓ | | Calculated from GSR data |
| Precipitation | ✓ | | | |
| Station pressure | ✓ | | | |

The ESL's Solar Test Bench⁵⁰ (STB), which is positioned near the case-study building, is on the roof of the Texas A&M University Langford Architecture Building. The ESL maintains the accuracy of the STB data using weekly inspection plots. The weekly inspection of the weather data is compared to similar data from the weather data from the near-by National Oceanic and Atmospheric Administration (NOAA) National Climate Data Center (NCDC) weather station at the College Station Easterwood Airport. The weekly inspection plots were used to find any discrepancies between the two datasets and also to identify malfunctioning sensors when there were large inconsistencies. The STB data were also used to fill in any missing data from the

⁴⁸ Wet bulb temperature

⁴⁹ Kim, K. and Baltazar, J. 2010. Procedure for Packing Weather Files for DOE-2.1e. Final Report. ESL-TR-10-09-03. Energy Systems Laboratory, Texas A&M University.

⁵⁰ Narayanaswamy, A., Do, S., Kim, K., Baltazar, J., and Haberl, J. 2010. Solar Test Bench Manual. Draft Report. Energy Systems Laboratory, Texas A&M University.

NCDC. The STB consists of fourteen sensors. The list of sensors are shown in Table 24. The wires from individual sensors meet at a junction box and from the junction box the cables run through a PVC piping which leads to an adjacent, enclosed mechanical room. The mechanical room stores the data logger powered by a battery backup. Data collected by the logger is transferred to ESL via an internet connection. Various software's at the ESL is used to retrieve the data from the logger and to display graphical images which can be shared over the web. Figure 41 shows the location of sensors and junction box for the Solar Test Bench.

Table 24. Sensors on the ESL's Solar Test Bench at Langford Architecture Building⁵¹

| Sensor Number | Sensor Type | Manufacturer | Measurements |
|---------------|--|--------------|---|
| 1 | Precision Spectral Pyranometer (PSP)-1 | Eppeley | Solar radiation intensity (global radiation) |
| 2 | PSP-2 | Eppeley | Solar radiation intensity |
| 3 | Li-Cor-4 | Licor | Solar radiation intensity |
| 4 | Li-Cor-1 | Licor | Solar radiation intensity |
| 5 | Li-Cor-2 | Licor | Solar radiation intensity |
| 6 | Li-Cor-3 | Licor | Solar radiation intensity |
| 7 | Anemometer | Metone | Wind speed, wind direction |
| 8 | Temp/RH sensor-Vaisala HMP 45A | Vaisala | Temperature, relative humidity |
| 9 | Temp/RH sensor-Vaisala HMP 45A | Vaisala | Temperature, relative humidity |
| 10 | Anemometer | Met one | Wind speed, wind direction |
| 11 | Normal Incident Pyrheliometer (NIP) | Eppeley | Normal incidence solar radiation intensity (direct radiation) |
| 12 | NIP | Eppeley | Normal incidence solar radiation intensity |
| 13 | B&W pyranometer-1 | Eppeley | Solar radiation intensity |
| 14 | B&W pyranometer-2 | Eppeley | Solar radiation intensity |

⁵¹ Narayanaswamy, A., Do, S., Kim, K., Baltazar, J., and Haberl, J. 2010. Solar Test Bench Manual. Draft Report. Energy Systems Laboratory, Texas A&M University.

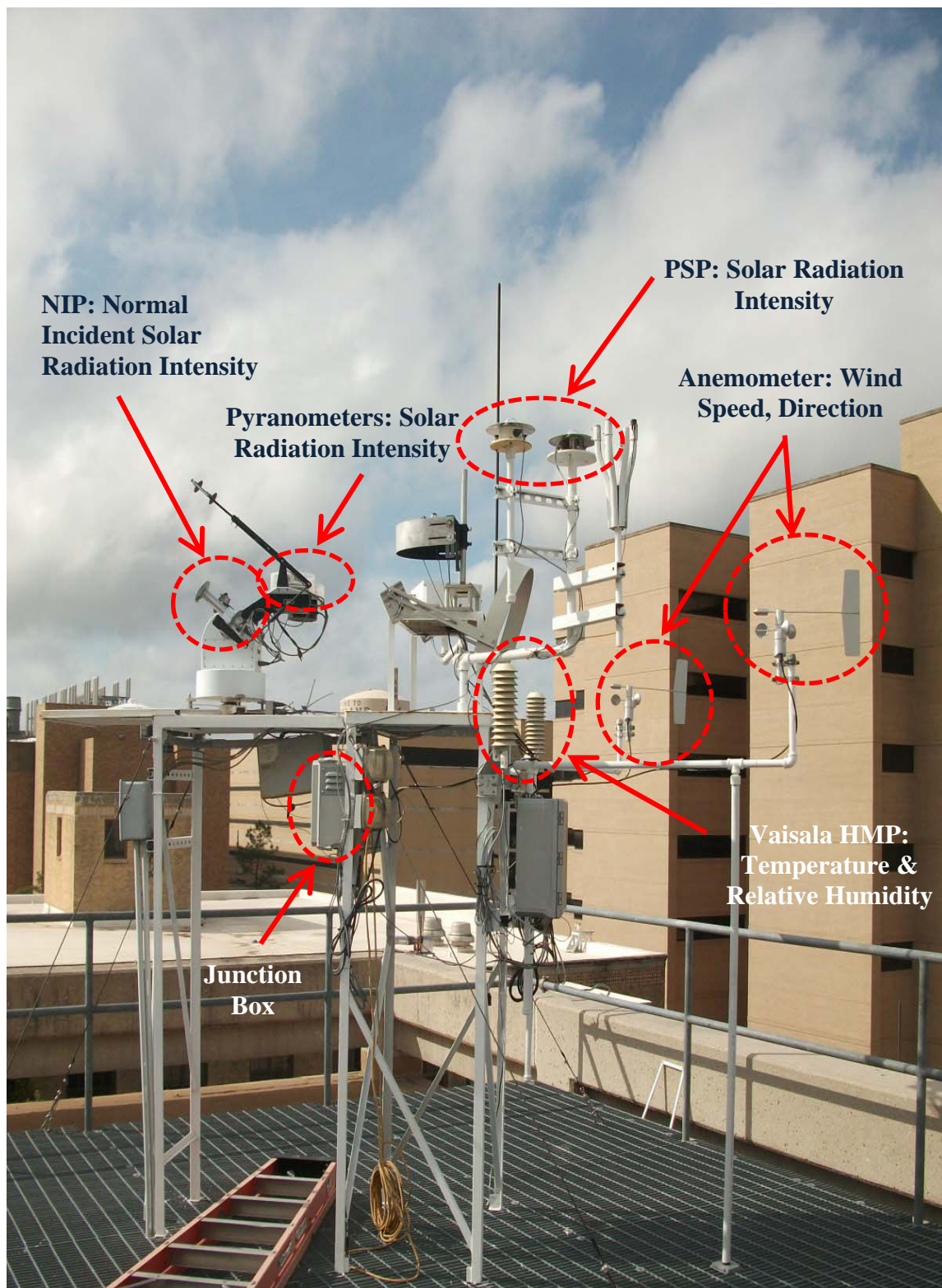


Figure 41. Location of Sensors and Junction Box for the Solar Test Bench

7.4.4 Phase IV Summary

Phase IV data collection was most comprehensive and time consuming in terms of collecting and analyzing the data. The measured indoor environmental data were obtained and adopted from a previous study. Since the sensors were already installed by ESL, obtaining adequate level of knowledge about the actual sensors, location of these sensors and their functions were important to identify prior to visiting the site. The measurement output of these sensors had to be analyzed as well. Information about the sensors were accomplished by reviewing the sensor manual that was put together by the researchers at ESL and by setting up a visit with researcher that assisted with installing the sensors and that maintained the measurement output data. The measured data was first thoroughly analyzed for a one week period to check for reasonableness. Then the data that was necessary to calibrate the whole building energy simulation was extracted..

Phase IV data collection process also included gathering measured weather data from a near-by weather station. The raw information was collected over a one year period, consolidated and verified against with weather database accumulated by the national government prior to being assembled into a usable format. Usable format indicates being modified so the simulation program can read the file to calculate the predicted energy consumption for the building. Hence, during this phase, the information provided the most accurate information about the building space, equipment and the actual condition the building was operating in. Accordingly, all of the information collected from Phase IV was used to improve the whole-building simulation model. Table 25 shows the updated data collection protocol for Phase IV.

Table 25. Data Collection Protocol - Phase IV

| CHARACTERISTIC | Phase IV: Detailed Measured Data | SOURCES |
|---|--|---|
| Building | | |
| Building type | Office | Phase I, II, Assisted Site Visits |
| Gross area (sq-ft) | 124,000 | Phase II, Assisted Site Visits, Drawings |
| Dimension (ft. x ft.), Aspect Ratio | T-shape | Phase II, Drawings |
| Number of floors | 7 | Phase II, Assisted Site Visits, Drawings |
| Floor to floor height (ft.) | 13 | Phase I, II, Assisted Site Visits, Drawings |
| Orientation | West | Phase II, Assisted Site Visits, Drawings |
| Construction | | |
| Wall Construction | Masonry | Phase I, Drawings |
| Roof Construction | Sprayed Urethane | Phase I, Drawings |
| Foundation Construction | | |
| Wall absorptance | 0.7 | Phase I |
| Wall insulation R-value (hr.-sq.ft-F/Btu) | 9.52 | Phase I, Drawings |
| Roof absorptance | 0.7 | Phase I |
| Roof insulation R-value (hr.-sq.ft-F/Btu) | 29.03 | Phase I, Drawings |
| Ground reflectance | 0.2 | Phase I |
| U-factor of glazing (Btu/hr.-sq.ft-F) | 0.48-0.50 | Phase II, Drawings |
| Solar Heat Gain Coefficient (SHGC) | 0.34 | Phase II, Drawings |
| Window-to-wall ratio (%) | 40 | Phase II, Drawings |

Table 25. Continued

| CHARACTERISTIC | Phase IV: Detailed Measured Data | SOURCES |
|--|--|---|
| Space | | |
| Area per person (ft ² /person) | 275 (325 occupants) | Phase I |
| Occupancy schedule | 6am-5pm (Mon - Sat) | Phase I, Assisted Site Visit |
| Space Heating Set Point | 72F Heating / 74F Cooling | Phase I, Assisted Site Visit |
| Space Cooling Set Point | 72F Heating / 74F Cooling | Phase I, Assisted Site Visit |
| Lighting Power Density (W/ft ²) | 1.9 | Phase I, Measured Indoor Environmental Data ⁵² |
| Lighting schedule | JBC Diversity Factor | Phase I, Measured Energy Data |
| Equipment Power Density (W/ft ²) | 0.75 | Phase I |
| Equipment schedule | JBC Diversity Factor | Phase I, Assisted Site Visit, Measured Energy Data |
| HVAC Systems | | |
| HVAC system type | VAV with terminal reheat | Phase I, Assisted Site Visit, Drawings |
| Number of HVAC units | 19 | Phase I, Assisted Site Visit, Drawings |
| Supply motor efficiency (%) | 90 | Phase I, Drawings |
| Supply fan efficiency (%) | 61 | Phase I, Drawings |
| Supply fan total pressure (W.G) | 2.5 | Phase I, Drawings |
| Plant Equipment | | |
| Chiller type | 2 Centrifugal (280 ton cooling) | Phase I, II, Assisted Site Visit, Drawings |
| Chiller COP | 5.55 (For 280 ton chiller) | Phase I |
| Boiler type | Hot water boiler | Phase I, Assisted Site Visit, Drawings |
| Boiler fuel type | Natural gas | Phase I, Assisted Site Visit, Drawings |
| Boiler thermal efficiency (%) | 80 | Phase I, Drawings |
| DHW fuel type | Natural gas | Phase I, Assisted Site Visit, Drawings |
| DHW heater thermal efficiency (%) | 85 | Phase I, Assisted Site Visit |

⁵² Table 5.4.4, Cho, S. 2009. "Methodology to Develop and Test an Easy-To-Use Procedure for the Preliminary Selection of High-Performance Systems for Office Buildings in Hot and Humid Climates" Doctoral Dissertation, Department of Architecture, August 2009.

7.5 Summary of Data Collection Process

This study developed a four phased data collection protocol that provided a systematic way of collecting the necessary data to calibrate an as-built whole building simulation model. Each phase increased in the level of effort, time and expertise required to gather the data. As seen in Figure 42, the circles in each cell indicated that the specific category of information was obtained for this study. The colors of the circles represent the level of effort and the accuracy of the data. Darker shades indicated the increasing level of effort, time, expertise, and also the accuracy of the information.

The study found that as more information is collected, there is a need to understand where the data originates from and that some information may be particularly useful for the purpose of calibrating the as-built whole building simulation model. For example, it is expected that in the future there will be more sophisticated sensors to measure the performance of many individual equipment used throughout the building. For the purpose of calibrating the as built whole building energy simulation model it was most useful to document the daily whole building electricity use and daily chiller use. As such, with the use of smart meters, building owners and building energy auditors may have access to valuable information at their fingertips to quickly develop an as-built calibrated whole building energy simulation models.

| INFORMATION SOURCE | INFORMATION SOURCE | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
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| | Owner | Municipality / Utility | | CBECs | | | ASHRAE Standard 90.1 - Relevant Version | | | Huang & Franconi, 1999 | | | Abushakra et al., 2001 | | | Pre-existing Building Photographs | | | New Building Photograph - Google Street View | | | Visual Inspection - Building Exterior | | | Visual Inspection - Building Interior | | | Visual Inspection with Bldg. Proctor | | | Visual Inspection with Plant Manager | | | Meet with Design Engineer | | | Rough Floor Plans (Egress Plans) | | | Original Construction Documents | | | Current As-built Construction Documents | | | Lighting Logger | | | Temperature Logger | | | Humidity Logger | | | Energy Logger WBE (Heating/Cooling) | | | Measured/Consistent Weather Data | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| ACTIVITY CATEGORY | Direct Contact | Reference (Code Compliant) | | | | | Building Image | | Un-assisted Site Visit | | Assisted Site Visit | | Drawings | | | | Measured Indoor Environmental Data | | | Measured Energy Data | | | Weather Data | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| PHASE | Phase I: Code Compliant | | | | | | Phase II: Simple Investigation | | | | | | Phase III: Assisted Visits & Drawings | | | | | | Phase IV: Detailed Measured Data | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Building | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

Figure 42. Use of the Data Collection Protocol in this Study

8. RESULTS: CALIBRATED AS-BUILT WHOLE BUILDING ENERGY SIMULATION MODEL

8.1 Calibration Method

The whole-building energy simulation program selected for this study is the DOE-2.1e simulation program, which produced the hour-by hour simulation of the case-study building. The simulation input file was created by using the Building Description Language (BDL) in a text editor. The DOE-2.1e is composed of four major sub-programs. These include LOADS, SYSTEM, PLANT, and ECONOMICS sub-program. For the case-study building the hourly energy use was simulated using only LOADS, SYSTEM and PLANT simulations. The LOADS sub-program calculated the peak loads on each zone, including the effect of internal heat gains, the occupants, and infiltration loads and heat conduction and radiation through the building envelope.

The energy use was then simulated for the HVAC systems in the SYSTEM sub-program using the hourly thermal loads calculated by the LOADS sub-program. The SYSTEM sub-program calculates the SYSTEM loads based on varying temperature conditions for each individual space served by the system. Finally, the PLANT sub-program calculated the electricity and fossil fuel energy consumption of the building's chillers and boilers. The DOE-2 simulation program has built-in engineering algorithms that calculate the hourly energy simulation using default coefficients or custom-entered coefficients. Thus, as described in Chapter 7, information was collected in sequential order to refine the model and to create a calibrated simulation, which was then used to

determine the potential energy savings. This chapter, Chapter 8 further explains the information, process and decision thresholds used to calibrate the model.

The simulated model used both measured data to calibrate the model as described in Chapter 7. Regarding the measured data, a combination of 2009 sub-hourly data measured from the John B. Connally (JBC) thermal plant sensors, 2009 utility bills, and measured meteorological data from the ESL's solar test bench (STB) were used. Fifteen different sensors inside the JBC thermal plant measured the sub-hourly (15 minute) electricity and cooling energy use for the JBC building. The study extracted the sub-hourly data, converted the data into hourly whole-building electricity (WBE) use, office building electricity (OBE) use, and whole-building cooling energy use (CHW). In addition, monthly natural gas (NG) use from the 2009 utility bills was used to check the data measured by the hourly data logger and the simulation model.

The WBE measured data agreed well against monthly utility electricity bills. The monthly difference between the simulated and billed electricity charges ranged from -11.1% to 6% with an average of -0.02%. Total annual difference between the simulated and billed electricity charges were -0.2%. The billed demand ranged from 0.9% to 32.7% above the simulated demand charges. From June of 2009 to October of 2009, demand charges were 7% to 32.7% above the prediction. During those periods, both chillers were operating causing higher demand charges than what the simulation predicted. Demand charges for other months (January through May and November through December) were within 10% of the simulated demand values. Thus, it was

assumed that when the building operated under normal conditions, the simulated demand values would be reasonable.

To calibrate the simulation model, the WBE use data were first used to create time-series plots to identify any abnormality. The unusual peaks found in the time-series plots are described further in Chapter 7. Next, to further calibrate the model, the WBE time series plots were converted into a usable format where the hourly data was converted into daily electricity consumption and plotted against the average ambient temperature for each day. Then, using the hourly office building electric consumption data, weekday and weekend profiles for the non-weather dependent electricity use (i.e., the lighting and equipment loads) were created to provide the necessary inputs to the DOE-2.1e program. This is because the hourly simulation program requires realistic inputs of the representative hourly values of the electrical consumption of the lights and plug loads since people come in and out of the building and lights can also be on and off throughout the day in a schedule that must be determined before the simulation is run. In order to model this variability in the operation of the office equipment and people, the simulation needs diversity factor. Such diversity factors are composed of the hourly (0 to 1) values that are derived from the measured data. These factors are then multiplied times the peak consumption to determine the 24-hour electricity use profile. Thus, during the weekdays in the office, the peak use (i.e., number closest to 1) tends to be between 9 am and 4 pm when people are most actively working. In this way, the monitored electricity use is disaggregated into end-use electricity use using 24 hour load shapes for lighting and equipment loads for use by the DOE-2 program using the overall

procedure outlined by Bronson et al. (1992). Figure 43 shows the 24-hour weekday profiles for the JBC building that were created using a specialized toolkit that was produced as part of the ASRHAE RP-1093 research project. The ASHRAE RP-1093 project also developed a standard library of schedules and diversity factors based on measured electricity consumption of 32 office buildings across the US for both weekdays and weekends. As part of this effort, the project also developed a toolkit that calculates the 0-to-1 diversity profiles from measured data that are needed by the DOE-2 program. The toolkit uses a percentile analysis and recommends using the 50th percentile for the 24-hour diversity factor when calculating the energy use and 90th percentile when calculating the peak usage. Figure 43 shows the weekday profile and Figure 44 shows the weekend profile derived from using the ASHRAE's toolkit. As seen in both Figures, the JBC building consumed approximately 40% of the peak non-weather dependent energy use during the unoccupied hours.

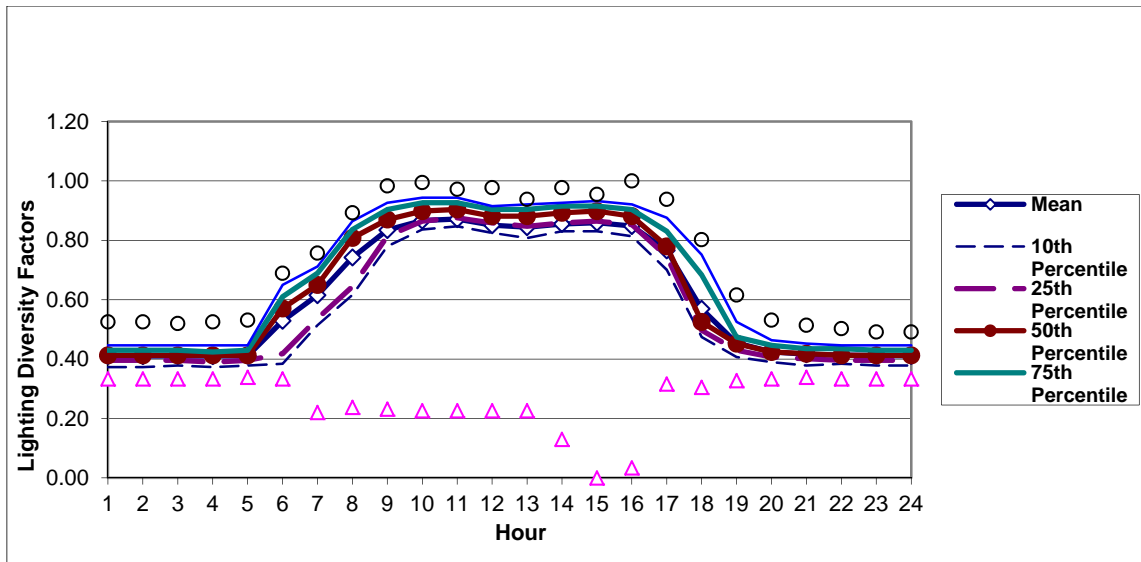


Figure 43. Weekday Profiles Developed Using the ASHRAE RP-1093 Toolkit

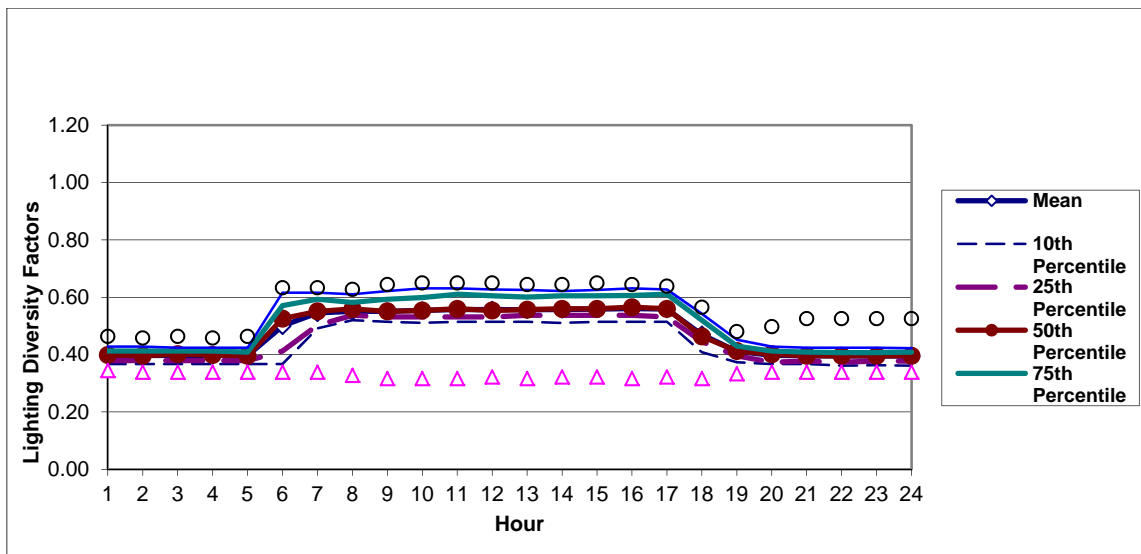


Figure 44. Weekend Profiles Developed Using the ASHRAE RP-1093 Toolkit

Measured climatic data was used to calibrate the model based on findings from Haberl et al. (1995). The use of measured weather data can improve the accuracy of the hourly energy simulation results with the calibrated model. Using actual hourly weather

data requires an intermediate data formatting process to convert the weather data from a raw format to a format that can be used in the DOE-2 simulation program environment. The process of creating this coincident weather data is called “packing” the weather file. This process was explained in detail in the previous chapter. The Energy Systems Lab (ESL) maintains yearly packed weather files for the College Station, Texas location which helped this study significantly. The ESL’s 2009 packed weather file was used to calibrate the model in this study.

To assess how well the model fits the measured data, both graphical and statistical methods were used to analyze the goodness-of-fit. Graphical methods included using graphs for comparative displays, which include scattered plots and time-series plots. The accuracy of the hourly data calibration was also verified using statistical indices such as the Mean Bias Error (MBE) and Coefficient of Variation of the Root Mean Square Error (CV(RMSE)) as recommended by various authors (Haberl and Thamilseran 1996; Pan et al. 2007; Yoon et al. 2003). The MBE is calculated as:

$$MBE = \frac{\frac{\sum_{i=1}^n (y_{pred,i} - y_{data,i})}{n - p}}{\bar{y}_{data}} \times 100 \quad (1)$$

$$CV(RMSE) = \frac{\sqrt{\frac{\sum_{i=1}^n (y_{pred,i} - y_{data,i})^2}{n - p}}}{\bar{y}_{data}} \times 100 \quad (2)$$

From (Haberl and Bou-Saada 1998) where:

$y_{data,i}$ = measured data for independent variable
 $y_{pred,i}$ = simulated data for independent variable
 \bar{y}_{data} = mean value of dependent variable of the data set
 n = number of data points in the data set
 p = total no. of regression parameters in the model (arbitrarily assigned 1)

The MBE represents the non-dimensional bias measure (Haberl and Bou-Saada 1998). The measure of bias of the model describes the slope of the error in the simulation when compared to the measured data. The drawback of the MBE is that large positive errors and negative errors can compensate for each other resulting in small difference or error if observed in aggregation. To avoid this weakness a secondary measure usually accompanies the MBE calculation which is the CV(RMSE). The CV(RMSE) can be calculated by first determining the Root Mean Square Error (RMSE). A RMSE is the square root of a Mean Squared Error (MSE). The MSE is the sum of the squares errors for each paired data (measured and simulated), added for each month for the total periods and then divided by the number of data points.

8.2 Calibration Results

Regarding the whole-building electricity (WBE) calibration, this study used both graphical and statistical methods to analyze the goodness-of-fit. As seen in Figure 45, the daily WBE use was summed from the hourly WBE and plotted versus the outdoor ambient temperature for 2009. Figure 45 shows a close match between the measured and simulated WBE use. As seen in Figure 45, the measured and simulated values had two distinctive lines parallel to each other. The upper line represented the weekday WBE use and the lower line represented the weekend WBE use. There was

approximately 1-2 MW of variation between weekday and weekend electricity use. More specifically, Figure 45 revealed that there is a fixed electricity use of approximately 4-6 MWh/day. The measured data displayed a flat consumption value up to 45°F. From 45 °F to 75°F, WBE use and outdoor ambient temperature displayed a linear relationship indicating the weather sensitivity. The linear relationship decreased when the outdoor ambient temperature reached above 75°F. The simulation slightly over-predicted the WBE consumption when the ambient temperature was below 45°F and also when the ambient temperature was over 75°F. The simulation showed good prediction between 45 to 75°F. This study used one schedule for the weekdays and another for the weekends and holidays. Use of additional schedules to reflect university breaks (i.e., spring break and winter break) could have further improved and reduced the slight over-prediction observed in this study.

The sum of the total measured WBE for year 2009 was 2,612 MWh while the sum of the simulated total WBE use was 2,533 MWh (97% of the measured value). Thus, the MBE for the year 2009 was 3.04%, which is considered acceptable for this study. The hourly Mean Bias Error (MBE) and hourly Coefficient of Variation of the Root Mean Square Error (CV(RMSE)) for each month was also calculated following the guidelines by Haberl and Thamilsaran (1996) and Haberl and Bou-Saada (1998). Allowable tolerance levels published by ASHRAE (ASHRAE 2002), IPMVP (IPMVP 2009) and FEMP (FEMP 2008) were used to determine the tolerance level and develop the final calibrated as-built whole-building energy simulation model. Using the hourly data, a tolerance level for the calculated MBE of 10 percent (plus or minus) and 30

percent for the CV (RMSE) was used. Table 26 shows the detailed statistical results of the WBE use, including monthly and total measured MWh/month, measured hourly mean MWh, total simulated MWh/month, and simulated hourly mean MWh. These values were used to quantify and compare the monthly and total difference in percentage between the measured and simulated data set (e.g., hourly MBE %). To calculate the hourly CV(RMSE), first the hourly RMSE was calculated. Once the RMSE was calculated the CV(RMSE) was derived using the equations that are provided above.

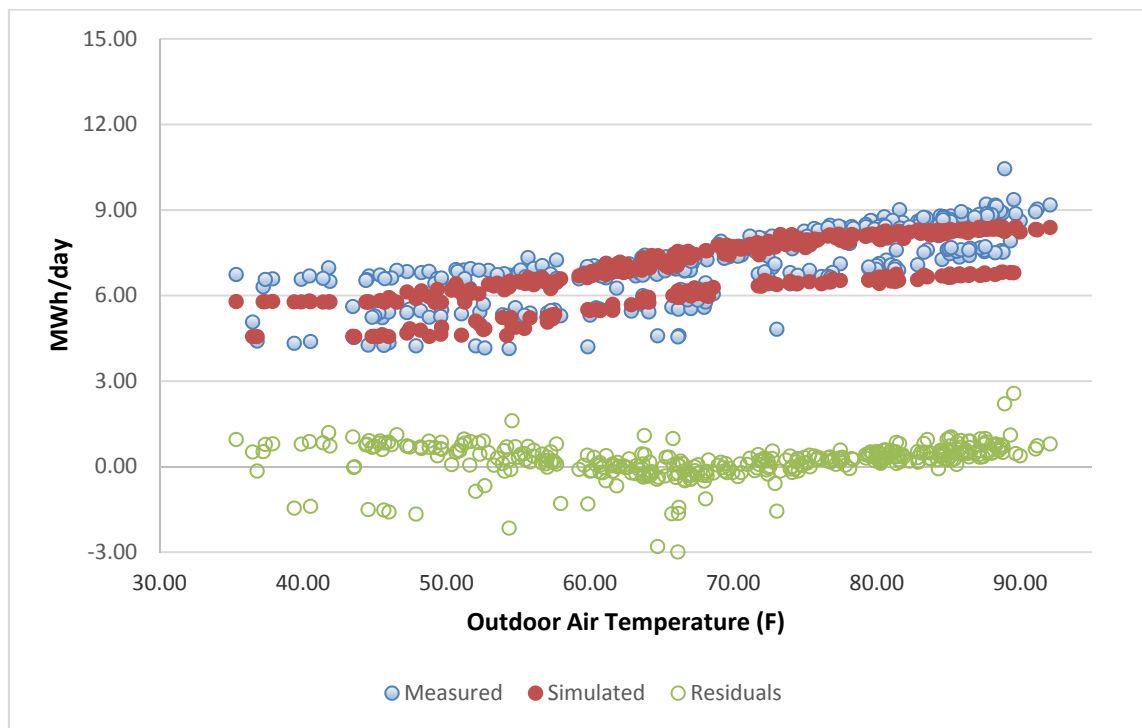


Figure 45. Simulated Use and Measured Whole-Building Electricity (WBE) Use Versus Temperature

Table 26. Statistical Summary for the WBE use

| Mon. | Total Measured (MWh) | Mean (MWh) | Total Simulated (MWh) | Mean (MWh) | Total Diff. % | Hourly MBE % | Hourly RMSE (MWh) | Hourly CV (RMSE) % |
|-------------|----------------------|------------|-----------------------|------------|---------------|--------------|-------------------|--------------------|
| <i>Jan</i> | 191.8 | 6.2 | 185.3 | 6.0 | -3.3% | 3.3% | 0.9 | 13.7% |
| <i>Feb</i> | 188.0 | 6.7 | 179.5 | 6.4 | -4.5% | -4.4% | 0.5 | 7.7% |
| <i>Mar</i> | 205.0 | 6.6 | 203.0 | 6.5 | -1.0% | -1.0% | 0.7 | 10.1% |
| <i>Apr</i> | 213.0 | 7.1 | 210.5 | 7.0 | -1.2% | -1.2% | 0.4 | 5.0% |
| <i>May</i> | 237.9 | 7.7 | 230.1 | 7.4 | -3.3% | -3.3% | 0.3 | 4.3% |
| <i>June</i> | 251.4 | 8.4 | 234.3 | 7.8 | -6.8% | -6.8% | 0.8 | 9.5% |
| <i>July</i> | 261.4 | 8.4 | 242.8 | 7.8 | -7.1% | -7.1% | 0.6 | 7.6% |
| <i>Aug</i> | 257.1 | 8.3 | 239.6 | 7.7 | -6.8% | -6.8% | 0.6 | 7.3% |
| <i>Sept</i> | 230.9 | 7.7 | 226.7 | 7.6 | -1.8% | -1.8% | 0.3 | 3.4% |
| <i>Oct</i> | 215.8 | 7.0 | 215.3 | 7.0 | -0.3% | -0.3% | 0.3 | 4.7% |
| <i>Nov</i> | 184.8 | 6.2 | 192.7 | 6.4 | 4.3% | 4.3% | 0.7 | 10.7% |
| <i>Dec</i> | 175.6 | 5.7 | 173.1 | 5.6 | -1.4% | -1.4% | 1.0 | 17.9% |

Regarding the cooling energy use (CHW) produced by the two chillers, the building mechanical engineer was able to verify that in 2009 this case-study building had simultaneous heating and cooling with frequent manual overrides due to various reasons. In addition, while reviewing the quality of the data it was found that the chiller sensor for one of the chillers in the thermal plant failed to collect accurate and usable data. Nevertheless, the study chose to graphically compare the model by observing the scatter plot of the daily cooling energy use (MMBtu/day) versus the ambient temperature for only part of year in 2009⁵³ as a secondary method to checking the calibration. Future studies can consider calibrating the simulation model to a full set of hourly cooling energy use data. As seen in Figure 46, the measured cooling energy use showed 0 to 15

⁵³ The study used months of April and May of 2009 to further verify that the model was calibrated. Both months were served exclusively with one of the chillers that had a properly functioning sensor and could be used to calculate the daily cooling energy use.

MMBtu/day use when the outside temperature was below 55°F. However, the simulation showed no cooling energy use below 55°F. The measured cooling energy displayed a linear relationship above 55°F. The simulation slightly under-predicted between 55° to 70°F and then slightly over-predicted when the outside temperature was above 70°F. The reason for the increase in CHW use when the outside temperature was above 70°F is unknown.

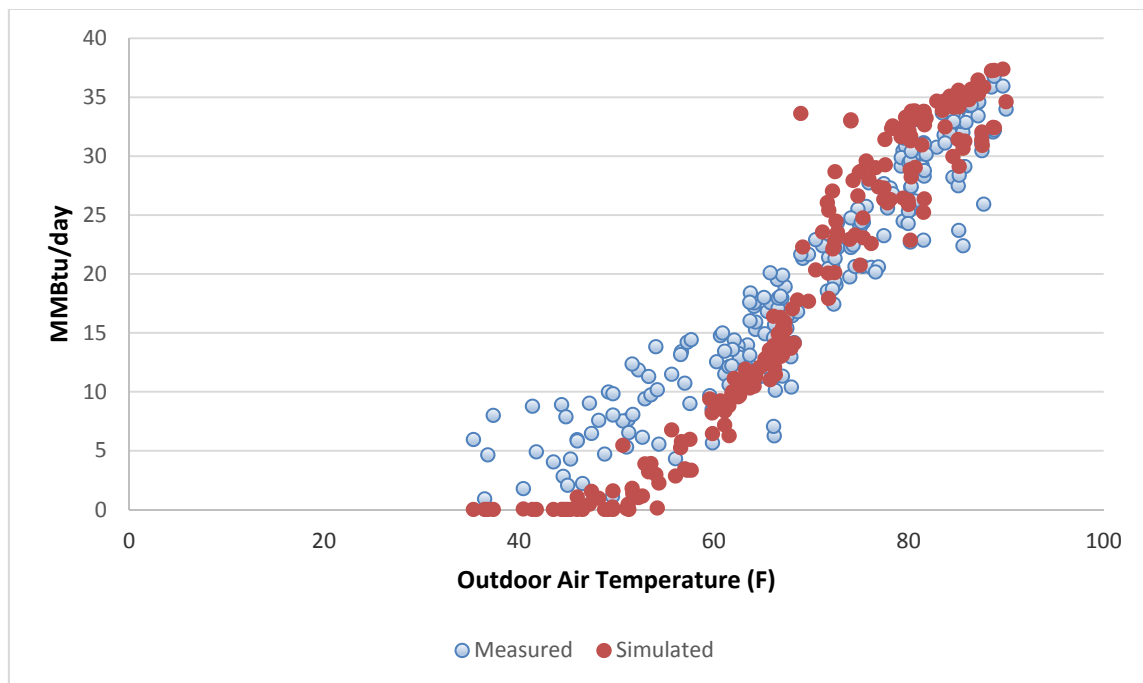


Figure 46. Simulated CHW Use and Measured CHW versus Average Daily Ambient Temperature

8.3 Calibration Summary

The process to construct and calibrate the simulation started with identifying the relevant codes, conducting simple investigation about the building envelope, system, plant and collected measured data as described in Chapter 7. Measured data in its raw form needed to be converted into comparable metrics to determine whether the model is calibrated for its intended use, which is to quantify the ECM savings. Sub-metered office building electricity use was used to generate diversity factors for lighting and office equipment schedule. Sub-hourly WBE electricity use was converted and summed to daily WBE use for the entire year of 2009 which was plotted against average outdoor ambient temperature also extracted from the measured climatic data. This research used both graphical methods and statistical methods to determine whether the model was calibrated. The statistical indices included MBE and CV (RMSE). The more stringent and conservative threshold published by ASHRAE (ASHRAE 2002), IPMVP (IPMVP 2009) and FEMP (FEMP 2008) were used to calibrate the model. In addition to checking the calibration of the model to the whole-building hourly electrical use for a full year which was considered adequate for this study, this study also checked the simulation model against short-term hourly cooling energy use.

9. RESULTS: ENERGY PERFORMANCE EVALUATION

The two energy conservation measures (ECMs) analyzed in this study are lighting and lighting control retrofits. The first measure consisted of replacing linear fluorescent lamps from 40 Watts to 34 Watts with more efficient lamps and ballasts (e.g., ECM 1) and the second measure included installing occupancy sensors (e.g., ECM 2) in addition to replacing the linear fluorescent lamps on floors four through seven of the case-study building⁵⁴. Within ECM 1, two approaches were tested. The first approach used all stipulated values as provided by the various Technical reference manuals (TRMs) selected for this study. The second approach included testing the ECM 1 with the same stipulated values as in the first approach for all parameters specified in the TRMs except for a change in hours of occupancy parameter. Since previous studies have shown that occupancy schedule is important in calibrating the building energy simulation model, the second approach used measured hours of occupancy, which were derived from measured hourly whole building electricity use.⁵⁵ For ECM 2, all of the prescribed stipulated values were used in quantifying energy savings.

⁵⁴ Testing the ECMs on floors 1, 2 and 3 of the case-study building were excluded from this study because the layout of the floor plans and usage type varied widely.

⁵⁵ More information about deriving measured hours of use from WBE can be found in Chapter 8. The motivation for testing this approach was based on the perception that future buildings will be equipped with Smart Meters that can track WBE at the minimum hourly or sub-hourly intervals. Hourly WBE could then be used to develop occupancy profiles.

Hence, there were three major groups of comparisons made in this study. These were:

- The first ECM 1 approach which included all prescribed stipulated values for the six different TRMs versus an as-built calibrated whole-building energy simulation model
- The second ECM 1 approach included a combination of stipulated values and measured occupancy parameter for the six different TRMs versus an as-built calibrated whole-building energy simulation model
- The ECM 2 approach included all stipulated values for the four different TRMs versus an as-built calibrated whole-building energy simulation model

Comparisons of the results were made for the total energy savings. The total energy savings included energy savings and demand savings. The energy savings included electricity savings and adjustments to the cooling and heating energy savings/penalties from the lighting retrofit. The demand energy savings in this study was quantified as the peak energy consumption for the individual months for the same baseline year.

9.1 Lighting Energy Audit for the Case-study Building

To perform the current industry method of quantifying the energy savings from lighting and lighting control retrofits, this study referred to the information gathered from the literature review, interview data, and the TRMs to mimic the process. Table 27 shows a list of activities and outcomes that were performed in order to quantify the ECM1 and ECM2 savings. For example, by conducting a visual inspection of counting the fixtures and the number of lamps on the 4th floor (i.e., activity), it was possible to develop a lighting fixture inventory (i.e., activity results). In general, the activities started by collecting and conducting desk audits of the construction documents and then

verifying the information on-site. Assuming that the construction documents were available for the energy audit analysis, the goal was to confirm that the existing construction documents were reasonably accurate and representative of the real conditions of the building to quantify ECM1 and ECM2. This reduced the time and effort necessary to document existing conditions.

Table 27. Summary of Lighting Energy Audit Activities and Results

| Activity Description | Activity Results |
|--|---|
| Obtain Construction Documents related to lighting system in the building | Reviewed floor plan, lighting schedule, reflected ceiling plan, and lighting specification |
| Select typical floor to conduct an in-depth, on-site lighting survey | Selected 4 th floor of the case-study building |
| Conduct space inventory | Figure 47. Fourth Floor Space Usage Plan for the JBC Building |
| Count fixtures and number of lamps for a typical space or floor | Figure 48. Fourth Floor Lighting Plan for the JBC Building Table 29. Lighting Fixture Inventory for 4th Floor of JBC Building |
| Compare existing reflected ceiling plan and lighting schedule to existing lighting schedule (Table 29) | Verified over 95% of the space and minimal discrepancies found. Determined the existing reflected ceiling plan and lighting schedule to be accurate to quantify energy savings. |
| Determine whether current lighting level is adequate | Assumed current lighting level is adequate based on previous study (Kim 2012) |
| Determine measured lighting fixture wattage | Photographed fixtures with a cellular phone to determine whether the fixture had electronic or magnetic ballast. Light fixtures in the case-study building were verified as magnetic ballast. Also conducted experimental tests with a wattmeter to determine if the standard lighting tables used by the current industry was reasonable. Based on the readings, standard lighting tables |

The reflected ceiling plan and lighting schedule for the JBC building was obtained from the Office of Facilities Planning and Construction. A partial lighting schedule is shown in Table 28. The reflected ceiling plan showed the location of the fixtures and the general description of the fixture such as whether it was a 2'X4' recessed fluorescent or a 2'X2' fixture. Based on the lighting schedule a separate effort was made to obtain the manufacturer's specification or lighting catalogue. The manufacture's specification was used as a method to check the reasonableness of the values presented in the lighting schedule.

As seen in Table 28, the lighting schedule showed various fixture types used throughout the building and provides detailed description of fixtures including fixture configuration, lamp specifications, number of lamps for each fixture type and ballast information. Most of the fixtures were recessed with a few hanging from chain and even wall mounted 2' X 4' or 2' X 2' florescent lights. Linear fluorescents were predominantly used throughout the building and occasionally down lights were used in hallways or lounge spaces.

Table 28. Partial Lighting Schedule of the JBC Building

| I D | Mfg. and Catalog no. | Detailed Descript. | Mount | Lamps | Ballast | Diffuser | Remarks |
|--------|--|--------------------------------------|-----------------|----------------|---------|--------------------------|--|
| 1 | Metalux HR 2P3GAX 3 40 S 36H 277 ⁵⁶ | 2'X4' Layin return air troffer | Recessed | 3F40W /CW | 277V | 18 cell parabolic | With energy saving mark III ballast |
| 2 | Metalux HR 2P3GAX 2 40 S 36H 277 | 2'X4' Layin return air troffer | Recessed | 2F40W /CW | 277V | 18 cell parabolic | With energy saving mark III ballast |
| 3 | Metalux HR 2P3GAX 2 U6 S33H 277 ⁵⁷ | 2'X2' Layin return air troffer | Recessed | 2F40U/ W/CW | 277V | 9 cell parabolic | With energy saving mark III ballast |
| 4 | Metalux SS 2 40 277 WG/SS-4FT. | 4FT. Strip light: | Chain Hung | 2F40W /CW | 277V | .125" acrylic | With wire guard and energy saving mark III ballast |
| 5 | Halo H801-277-801C | Fluorescent down light | Recessed | 2-28W DTT | 277V | .125" acrylic | Specular clear alzak reflector |
| 6 | Lithonia WC 240A 277 | Stair lighting | Surface wall | 2F40W /CW | 277V | White opal acrylic | With energy saving mark III ballast |
| 7 | Metalux SL 2 40 277 ⁵⁸ | Rest room cove lighting | | | 277V | .125" acrylic | |

A follow up, on-site audit was performed to verify the accuracy of these drawings and specifications. For the case-study building, floors four through seven were nearly identical to each other in terms of the total square footage, space layout, space usage and lighting plan. So, based on existing drawings and specifications, the fourth floor was selected as a representative space to be studied in more detail. To accomplish

⁵⁶ 2'X4' recessed fluorescent return air troffer: *Heat Removal, 2', Paralux, Grid lay-in, A(x)ir-Supply Floating Louver, 3 lamps, 40 Watt, Silver, 36 cell configuration (2 rows of 6,12 cell) n, H (lover finish), 277 volt*

⁵⁷ 2'X2' recessed fluorescent return air troffer: *Heat Removal, 2', Paralux, Grid lay-in, Air Supply Floating Louver, 2 lamps, U, 6 in?, Silver, 33 cell configuration (3,9), lover finish, 277 volt*

⁵⁸ Spring loaded lamp holders, 2 lamp, 40 watt, 277 volt

this, an effort was made to plan a lighting survey with the building proctor and the office departmental staff in advance to the actual auditing commencing at the site. The lighting audit was scheduled to minimize any disturbance of the occupants. In addition, color-coded light symbols were used to quickly document which fixtures had been observed while performing the audit. Photographs also assisted with what was observed on-site. Immediately after returning to the office, effort was made to document what was visually inspected. Any inaccessible rooms and spaces were addressed during a second visit. The second visit allowed verifying a few additional office spaces and one of the two mechanical rooms on the 4th floor. In total, were 95% of the lighting fixtures on the 4th floor were visually inspected and the information used to cross check what was documented in the original construction document. Figure 47 and Figure 48 shows the verified space usage plan and lighting plan for the fourth floor of the JBC building.

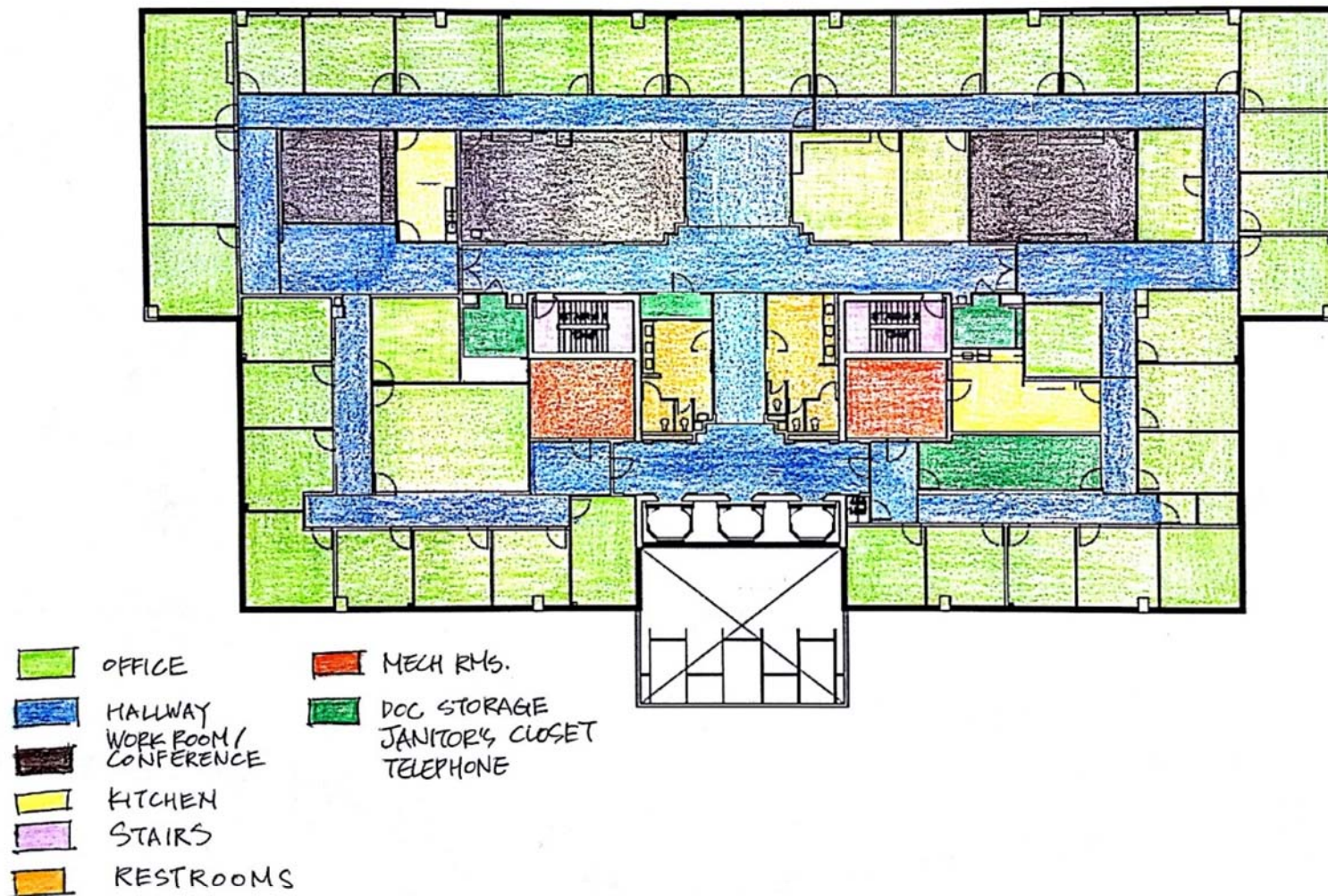


Figure 47. Fourth Floor Space Usage Plan for the JBC Building

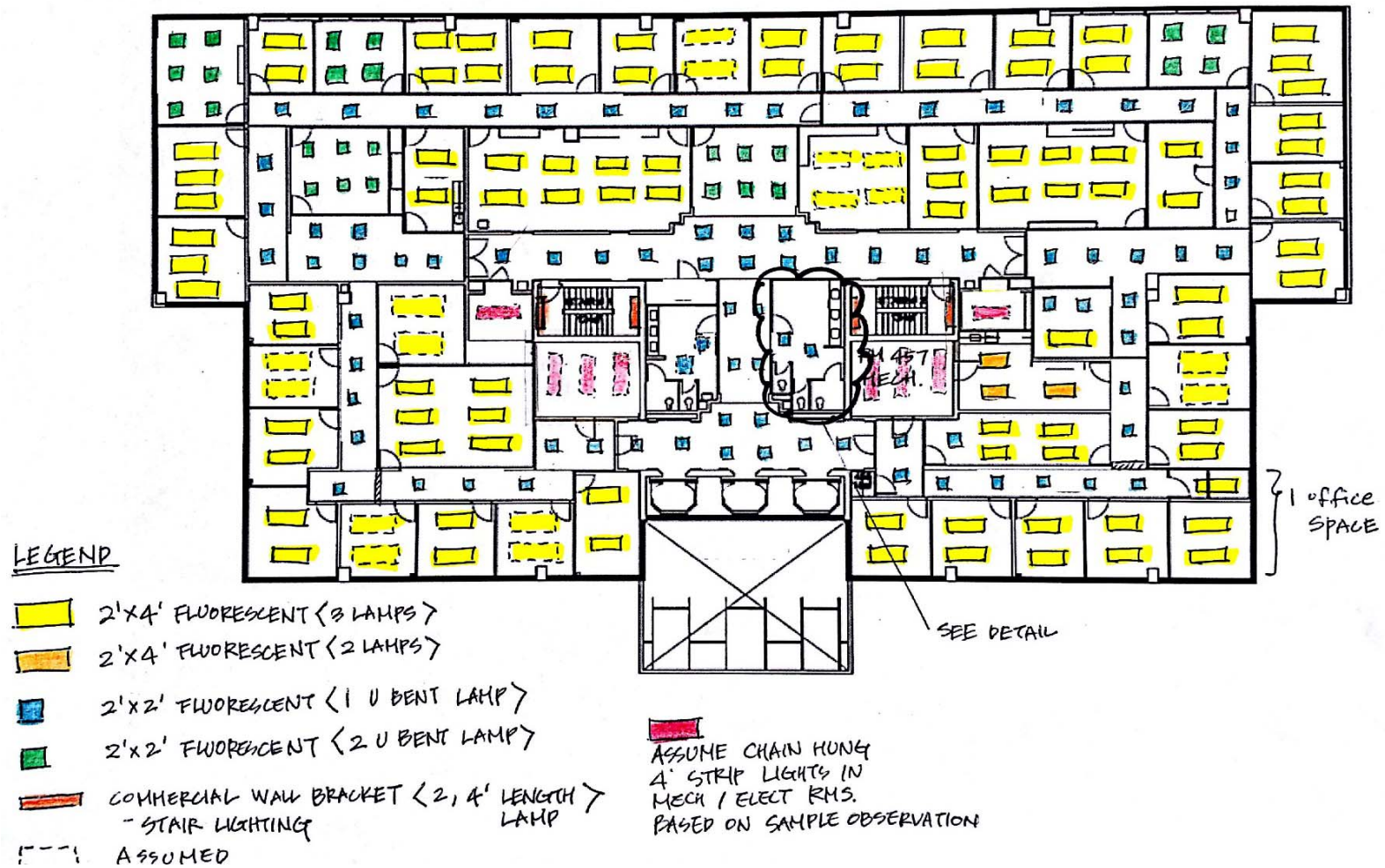


Figure 48. Fourth Floor Lighting Plan for the JBC Building

As seen in Figure 47 and Figure 48, by conducting a space inventory, it was found that the private offices occupied the outer portion of the building floor plan. All of the office spaces had a window with blinds or shades to allow the occupants to control the amount of daylighting that entered into their private office spaces. More common spaces such as meeting rooms, the kitchen, and hallways were located towards the center of the building providing access to the core which included restrooms, exit stairs, mechanical, and electrical rooms. Almost all of the private offices had 2’X4’ recessed fluorescent fixtures with three linear fluorescent lamps. Hallways were mostly 2’X2’ recessed fluorescent fixtures with two U-bent fluorescent lamps.

Table 29. Lighting Fixture Inventory for 4th Floor of JBC Building

| Flr. | Type of lighting fixture | Lamp type | Number of lamps | Energy use/Watt per lamp (W) | Number of fixtures |
|------|--|--------------------------|-----------------|------------------------------|--------------------|
| 4 | Metalux HR 2P3GAX 3 40 S 36H 277 | 3F40W/CW (cool white) | 3 | 40 ⁵⁹ | 108 |
| 4 | Metalux HR 2P3GAX 2 40 S 36H 277 | 2F40W/CW | 2 | 40 | 3 |
| 4 | Metalux HR 2P3GAX 2 U6 S33H 277 | 2F40U/W/CW | 2 | 40 | 26 |
| 4 | Metalux HR 2P3GAX 1 U6 S 44H 277 | 1F40U/W/CW | 1 | 40 | 86 |
| 4 | Metalux SS 2 40 277 WG/SS-4FT. | 2F40W/CW | 2 | 40 | 8 |
| 4 | Metalux SL 2 40 277 | 2F40W/CW | 2 | 40 | 12 |
| 4 | Lithonia WC 240A 277 | 2F40W/CW | 2 | 40 | 4 |

⁵⁹ Assumed this was accurate based on 2009 measured office electricity use. On-site lamp inventory study conducted in 2013 showed that the building has started to use 34 W T12 lamps as opposed to the 40W T12 lamps.

In addition to visually inspecting the fixtures, to confirm that the existing ballast in the case-study building was magnetic without a ballast tester, a photograph was taken with a cell phone camera directly underneath one of the fixtures on the fourth floor to determine if dark bands or strips were noticeable.⁶⁰ In Figure 49, a photograph of a similar fixture in a newly built facility with an electronic ballast was taken to compare the differences in the photograph. As seen in Figure 49, the fixture on the right, taken from the case-study building, showed dark bands due to 60 Hertz frequency of the magnetic ballast while the fixture on the left, taken from the newly built facility, did not show any bands due to the higher frequency of the electronic ballast.



Figure 49. Fixture Ballast Verification Using a Cell Phone Camera

Next, to confirm the standard lighting table wattage listing that was used by various TRM agencies and organizations, a Watt meter was used to measure the fixture.

⁶⁰ New Light Energy Design (2012). "How can I tell whether I have a magnetic ballast or an electronic ballast?", <<http://www.newlighted.com/how-can-i-tell-whether-i-have-an-old-fashioned-magnetic-ballast-or-the-newer-electronic-ballast/>>. (February, 10, 2014).

Wattage of one of the available fixture type in the standard lighting table. The experiment included measuring two, 32 Watt, T8 lamps with a 120 VAC electronic ballast. The Watt meter indicated 54 to 55 Watts. Two of the publically available standard lighting tables⁶¹ were used to verify that these values were reasonable. Without any prior knowledge about the specific details of the electronic ballast, it was possible to limit the types of probable ballast types to rapid start ballast with Regular Light Output (RLO) from the Oncor's 2009 Standard Lighting Table and New York State Energy and Research Development's Table of Standard Wattages (54 Watts). However, it was also observed that without measuring the fixture Wattage, the auditor can select from several types of ballast (i.e., rapid start ballast with four different levels of light outputs, instant start ballast with four different levels of output, etc.) with a wide range of total fixture Wattage (i.e., 53 Watts to 85 Watts) for a fluorescent or two 48", 32 Watt T-8 lamps with an electronic ballast. This experiment indicated the importance of measuring the fixture Wattage on-site to obtain the most accurate information. Thus, as the experts indicated during the interviews, it was found that measuring the fixture Wattage is a good practice when conducting an energy audit for a lighting retrofit project to verify the existing fixture types.

61 The two references compared were Oncor's Standard Files for Lighting Retrofits (<https://www.oncoreepm.com/commprogram.aspx>) and New York State Energy Research & Development Authorities' Standard Lighting Table (www.nyserda.ny.gov/Commercial.../EFP_Lighting_Form.ashx)

9.2 Quantifying ECM1

9.2.1 Current Industry Methods: TRMs

Based on the previous effort of reviewing drawings, a specification, conducting an on-site audit and spot measurements, the current industry methods to quantify the savings for an energy conservation measure for replacing commercial linear fluorescent (LF) lamps includes estimating the values for various parameters in the algorithm.

These parameters are defined and described in Table 30.

Table 30. Description of Parameters Specified in the TRMs to Quantify the Lighting Retrofit Energy Saving

| Parameter | Description | Reference |
|------------------------------|--|---|
| Fixture wattage | Total wattage required by ballast and lamp | Uniform Methods Project |
| Fixture quantity | Total number of fixture | Uniform Methods Project |
| Usage group | Examples of different usage groups are: office, conference, kitchen, bathroom, hallway and lobby. Typically individual usage groups have unique hours of use | Uniform Methods Project |
| Hours of use | Annual hours of use | Uniform Methods Project |
| Interactive factor - Cooling | Ratio of cooling energy saving per unit of lighting energy saving due to reduction in lighting waste heat removed by the HVAC system | Uniform Methods Project |
| Interactive factor - Heating | Ratio of heating energy increase per unit of lighting energy saving due to reduction in lighting waste heat that must be supplied by the HVAC system during the heating season | Uniform Methods Project |
| Coincident demand | Fraction of connected load expected to occur at the same time as a particular system peak period | UI/CL&P C&LM Program Savings Documentation – 2008 |
| Coincidence factor | Demand of a measure that occurs at the same time as some other peak. A measure of demand savings that is coincident with electric system peak demand. | UI/CL&P C&LM Program Savings Documentation - 2008 ⁶² |

⁶² Connecticut Light & Power Company, and The United Illuminating Company (2007). CL&P and UI Program Savings Documentation for 2008 Program Year

The prevailing method for quantifying total energy saving was:

$$(baseline\ energy\ use) - (post - retrofit\ energy\ use) \pm adjustments \quad (3)$$

Where:

*baseline energy use = baseline fixture Wattage * hours of operation*

*post – retrofit energy use = post – retrofit fixture Wattage * hours of operation*

adjustments = interactive factors for cooling and heating

The methods to quantify the demand savings were less consistent with varying terminology. Nevertheless, there were fundamentally two parameters that were used in quantifying the demand savings. These included a coincident factor (e.g., demand diversity factor) and a coincidence factor. This study used the previous studies ((Stern 2013) (Jacobs et al. 1992)) to distinguish what these two parameters accounted for. In summary, the demand diversity factor considered how much of the actually installed energy efficiency technology may operate at any given time. For example, if nine of the ten newly installed fixtures were used for any given time, then the diversity factor was 9/10 or 90 percent. In addition to accounting for new energy efficient technology not being utilized at full capacity, the building's peak demand and utility system peak can vary. If at the time of utility's peak demand only three of those nine installed fixtures are on, then the coincidence factor became 3/9 or 30 percent. The prevailing method for quantifying demand savings was:

$$connected\ lighting\ load\ reduction * diversity\ factor * coincidence\ factor \quad (4)$$

Where:

connected lighting load reduction = pre lighting demand – post lighting demand

Six of the seven TRMs provided stipulated values for the parameters used in the algorithm. These values are presented in Table 31.

Table 31. Stipulated Values Provided by Technical reference manuals (TRMs)

| TRM ID | Fixture Wattage Reference Document | Hours of Use (yr.) by Usage Group | Interactive Factor (% or as noted) | | Diversity Factor (%) | Coincident Demand (%) |
|--------|--|--|------------------------------------|------------------------------|----------------------|-----------------------|
| | | | Cooling | Heat | | |
| 1 | CenterPoint Central Wattage Table | Office: 3737 | +5 | | 77 | 10 |
| 2 | Entergy Table of Standard Fixture Wattages | Office: 3760 | +5 | | 80 | 10 |
| 3 | DEER Table of Standard Fixture Wattages & Sample Lighting Table | Office: 2641 Conf: 2250 Hall: 2523 Bath: 2641 | +17 | | 71 | 25 |
| 4 | CO TRM, Deemed Fixture Table | Office: 3435 | +11 | | 78 | 33 |
| 5 | MassSave (2010). <i>C&I New Construction Lighting Baseline Wattage Tables.</i> | Office: 3610 (3845) ⁶³ | +1-4 (5.4) | -1277 Btu/kWh (-691 Btu/kWh) | 88 (63.88) | 1-4 |
| 7 | 2009 Oncor Electric Delivery Lighting Table | Office: 2500 Conf: 1500 Hall: 8760 Bath: 8760 | 2500 Btu/kWh | -250 Btu/kWh | Not Used | Not Used |

The stipulated parameters shown in Table 31 were developed using various resources. In this study, the references for these values were traced back to determine

⁶³ Values in parenthesis are updated values found in a recent impact evaluation study: KEMA, Inc. Impact Evaluation of 2010 Prescriptive Lighting Installations – FINAL REPORT, June 21, 2013.

the origin and the method used to develop these values⁶⁴. It was also recommended that hours of use be developed by interviewing the building manager. Use of measured operating hours was obtainable if the building was equipped with an Energy Management System (EMS) or by using temporary data loggers. Change of state, on/off data loggers were most commonly used as opposed to data loggers that continuously monitored the light levels (Gowans 2013). As seen in Table 31, two of the six TRMs provided different stipulated hours based on space usage type. Technical reference manual 3 had been updating the hours based on impact studies and TRM 7 developed the stipulated hours based on interviews with building managers and building occupants. The stipulated hours varied as much as one hundred fifty percent (2,500 hours versus 3,845 hours).

The interactive factors for the cooling energy saving and heating penalty were dependent upon the HVAC types and efficiency. The preferred method was to develop a computer simulation because heating and cooling interactions were difficult to accurately quantify (Gowans 2013). If the computer simulation was cost-prohibitive, interactive factors were estimated from other TRMs with interactive values from a similar climate zone or existing studies (Rundquist et al. 1993) that provided algorithms to quantify the interactive factors based on equipment schedule and inventory. As seen in Table 31, only two of the six TRMs considered separate interactive cooling factors and a heating penalty factor. For TRM 5, the cooling interactive savings were calculated

⁶⁴ For the stipulated hours, the values typically originated from other Technical reference manuals or recent impact evaluation reports or measurement and verification reports.

as a percentage of the electricity savings. The heating penalty was -691 Btus for every kWh of electricity saved as a direct result of implementing the ECM1. For TRM 7, the cooling interactive savings were an additional 2,500 Btus of cooling energy savings for every kWh of electricity saved as a direct result of implementing the ECM1 and the heating penalty was -250 Btus that had to be additionally supplied during the heating season as a direct result of implementing ECM1. The heating penalty between TRM 5 and TRM 7 was more than two hundred and fifty percent different. However, given that TRM 5 originated from a cold climatic region and TRM 7 was conducted in a hot and humid climate zone, it was not surprising to see that more heating was necessary during the heating season for TRM 5 than in TRM7. The other TRMs provided a single, aggregated savings factor that varied more than 200 percent between TRMs (between 5-17%).

One of the reasons why demand diversity factors and coincidence demand factors varied across TRMs was the fact that because these factors were contingent upon summer and winter peak demand hours as designated by the utility company. Summer months were anywhere between June to September and winter months were anywhere between December to February. Peak hours varied considerably depending on the program. For example, for TRM1, winter peak hours were 4 hours during the day and 4 hours in the evening. For TRM 5, winter peak hours were only 2 hours in the evening. In summary, the industry method of deriving savings from the installation of efficient light fixtures included a combination of energy and demand savings. Therefore,

multiple parameters need to be estimated or measured to quantify the total savings and varied greatly depending on the geographical location.

9.2.2 Simulation Method: As-Built Calibrated Whole-Building Simulation Model

To simulate the effect of replacing a fixture with more efficient linear fluorescent lamps (e.g., ECM1) in the DOE-2 model, the input file was modified to reflect the reduced Watts/square foot from 1.7 Watts/square foot⁶⁵ to 1.4 Watts/square foot⁶⁶ for floors four through seven. The hourly simulation results were extracted using AWK and specially prepared spreadsheets that allowed isolating the WBE, CHW, NG use into individual columns. In addition, the specially prepared spreadsheet was used to transform the hourly data into both average daily use and total daily use. This post-processing procedure allowed separating quantification of the electricity savings, interactive savings/penalties, and demand savings for individual months using a spreadsheet.

Savings included electricity savings, cooling interactive savings, heating interactive penalty and demand savings. For comparative purposes, savings were quantified in terms of U.S. dollars as a common unit. The unit cost for each commodity was obtained from the Texas A&M University Utilities and Energy Management Department as \$0.071/kWh for electricity, \$10.40/kW for electricity demand, and \$0.555/CCF for natural gas.

⁶⁵ The watts/square foot was derived by taking the sum of the lighting power (24,035 watts) on each floor divided by the total square footage for each floor of the case-study building (14,400 square feet). Since floors four through seven were identical, the lighting power density for floors four through seven were all the same.

⁶⁶ Reduction in lighting power density was due to reduction in watts/lamp.

Electricity Savings

Regarding the electricity savings, the monthly electricity savings were relatively consistent month to month as seen in Table 32. The average savings was about 3.82 percent (8.03 MWh/month) and the total savings for the annual period equaled 96.4 MWh. By replacing with more energy efficient fluorescent lighting fixtures from floors four to seven, the building could save approximately \$6,800 a year. Table 32 provides a summary of pre-retrofit (baseline) electricity use, the post-retrofit (ECM1) electricity use and total monthly and annual electricity savings in consumption and cost. By replacing the florescent lamps that were 40Watts to 34 Watts from the fourth floor to seventh floor the building could save approximately \$6800 a year.

Table 32. Summary of Electricity Savings from Implementing ECM1

| | | | | Electricity Savings |
|----------------|----------------------|------------------|--------------|---------------------|
| Mon | Baseline Total (MWh) | ECM1 Total (MWh) | Change (MWh) | Change (\$) |
| Jan | 185.3 | 177.9 | 7.4 | \$ 527 |
| Feb | 179.5 | 172.6 | 6.9 | \$ 493 |
| Mar | 203.0 | 195.1 | 7.9 | \$ 560 |
| Apr | 210.5 | 202.7 | 7.8 | \$ 556 |
| May | 230.1 | 221.6 | 8.5 | \$ 603 |
| June | 234.3 | 225.4 | 8.9 | \$ 633 |
| July | 242.8 | 233.6 | 9.2 | \$ 650 |
| Aug | 239.6 | 230.8 | 8.9 | \$ 630 |
| Sept | 226.7 | 218.4 | 8.3 | \$ 589 |
| Oct | 215.3 | 207.3 | 7.9 | \$ 564 |
| Nov | 192.7 | 185.4 | 7.3 | \$ 515 |
| Dec | 173.2 | 165.8 | 7.3 | \$ 522 |
| Total (Annual) | 2533.0 | 2436.6 | 96.4 | \$ 6,842 |

Adjustments to Energy Savings

One of the benefits of more efficient light fixtures was that the lamps produced less heat in the summer and thus reduced the need for additional cooling. However, this also created the need to provide more heat in the winter to replace the heat loss from the more efficient lamps to maintain the existing indoor temperature during the winter. According to the building proctor, this building was set to 74 degrees both in the winter and summer with no night-time setbacks. By simulating the model with these operating conditions, there was a minor gain in the summer period but a larger penalty in the winter period. The average cooling interactive savings was 1.3 percent (0.7 percent minimum to 1.7 percent maximum). Savings were greater (than the average) during the cooling season (May-September). Regarding the heating penalty, the penalty was a total of 12.8 percent. The building required an average of 17.6 MMBtu/month that needed to be supplied back to the space in order to maintain the indoor thermostat setting of 74 (°F) throughout the year. Greater penalties (above average) occurred during the heating season (October to April). Table 33 provides a summary of pre-retrofit (baseline) cooling and heating energy use versus the post-retrofit (ECM1) cooling and heating energy use. The column labeled change is a saving or a penalty.

Table 33. Summary of Interactive Cooling and Heating Penalty from Implementing ECM1

| Mo. | Cooling | | | | Heating | | | |
|------|----------------------|------------------|--------------|-------------|------------------------|--------------------|----------------|--------------|
| | Baseline Total (kWh) | ECM1 Total (kWh) | Change (kWh) | Saving (\$) | Baseline Total (MMBtu) | ECM1 Total (MMBtu) | Change (MMBtu) | Penalty (\$) |
| Jan | 13,096 | 12,999 | 97 | \$7 | 314.1 | 341.5 | -27.4 | -\$152 |
| Feb | 20,677 | 20,474 | 203 | \$14 | 209.1 | 230.3 | -21.2 | -\$118 |
| Mar | 25,713 | 25,405 | 308 | \$22 | 217.6 | 239.5 | -21.9 | -\$122 |
| Apr | 35,223 | 34,829 | 394 | \$28 | 126.1 | 145.3 | -19.2 | -\$107 |
| May | 50,275 | 49,551 | 724 | \$51 | 48.2 | 60.9 | -12.7 | -\$71 |
| June | 55,117 | 54,180 | 937 | \$67 | 10.6 | 15.1 | -4.5 | -\$25 |
| July | 58,278 | 57,310 | 968 | \$69 | 4.7 | 9.6 | -4.9 | -\$27 |
| Aug | 57,055 | 56,161 | 894 | \$64 | 7.8 | 15.7 | -7.9 | -\$44 |
| Sept | 49,525 | 48,810 | 715 | \$51 | 39.9 | 55.3 | -15.4 | -\$86 |
| Oct | 36,016 | 35,597 | 419 | \$30 | 122.7 | 144.5 | -21.8 | -\$121 |
| Nov | 23,625 | 23,434 | 191 | \$14 | 185.1 | 209.5 | -24.4 | -\$136 |
| Dec | 3,518 | 3,474 | 44 | \$3 | 370.7 | 400.7 | -30 | -\$167 |
| Tot. | 428,118 | 422,224 | 5,894 | \$419 | 1656.6 | 1867.9 | -211.3 | -\$1,174 |

Demand Savings

For the purpose of this study, the demand savings was defined as the difference in the peak demand for the electricity for the year 2009 using the same site-specific coincident weather data. This resulted in a demand usage pattern that was similar to the baseline simulation. Month to month savings were relatively consistent. The average saving was 4.5% (20.4 kW/month) and the total savings which equaled 244.5 kW for the year 2009 as seen in Table 34.

Table 34. Summary of Electricity Savings and Demand Savings from Implementing ECM1

| | | | | Demand Savings |
|--------------|---------------------|-----------------|-------------|-----------------------|
| Month | Baseline Total (kW) | ECM1 Total (kW) | Change (kW) | Change (\$) |
| Jan | 436.0 | 417.0 | 19.0 | \$ 198 |
| Feb | 444.6 | 425.4 | 19.2 | \$ 200 |
| Mar | 452.1 | 431.4 | 20.7 | \$ 215 |
| Apr | 453.4 | 432.4 | 21.0 | \$ 218 |
| May | 476.3 | 456.2 | 20.1 | \$ 209 |
| June | 481.6 | 460.0 | 21.6 | \$ 224 |
| July | 477.0 | 457.0 | 20.0 | \$ 208 |
| Aug | 478.4 | 458.3 | 20.1 | \$ 209 |
| Sept | 487.4 | 463.7 | 23.7 | \$ 247 |
| Oct | 473.0 | 453.0 | 20.0 | \$ 208 |
| Nov | 443.0 | 423.8 | 19.2 | \$ 199 |
| Dec | 437.1 | 417.1 | 20.0 | \$ 208 |
| Total | 5539.9 | 5295.4 | 244.5 | \$ 2,543 |

Total Energy Savings

The total energy savings was calculated by taking the sum of energy savings and demand savings. Energy savings was further broken down into electricity savings, an adjustment for cooling, and an adjustment for heating. In this case, the adjustment for cooling was a positive gain of additional electricity savings while the adjustment for heating was a negative penalty.

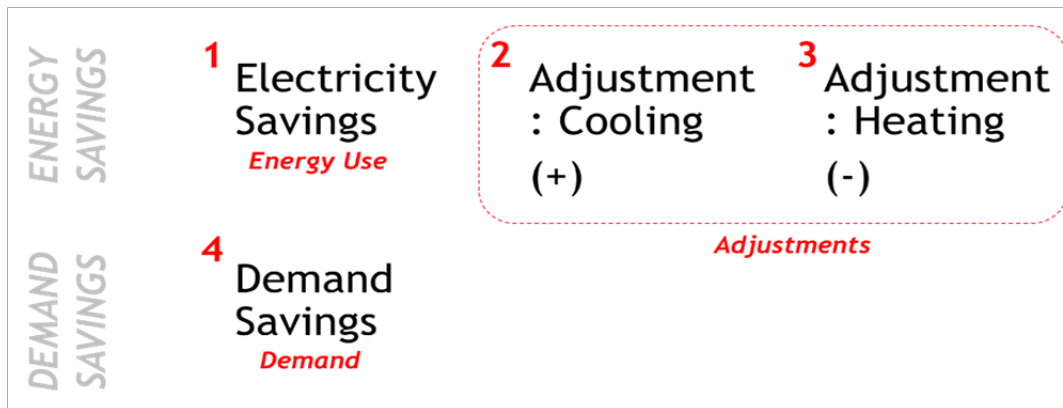


Figure 50. Quantifying total energy savings

As seen in Table 35, the energy savings was about 74 percent of the total energy savings and the demand savings was 26 percent of the total energy savings indicating that the demand savings is a significant portion and a major contributor to the total energy savings.

Table 35. Summary of Total Cost Savings for ECM1

| | Energy | | | Demand |
|-----------------------------|---------------------|-----------------|-----------------|----------------|
| Current Method (Simulation) | Electricity Savings | Cooling Savings | Heating Penalty | Demand Savings |
| Savings | 96,370 kWh | 5,894 kWh | -2,113 CCF | 245 kW |
| Unit Cost | \$0.071 /kWh | \$0.071 /kWh | \$0.56 /CCF | \$10.40 /kW |
| Cost Savings | \$ 6,843 | \$419 | -\$1,174 | \$2,543 |
| | \$6,090 | | | |
| Total Savings | \$8,633 | | | |

9.2.3 Comparisons Between the Industry Methods and Current Simulation Method:

First Approach

Based on the information that was collected and assessed, comparisons of savings were made between results calculated from the six TRMs using the specified stipulated values and the calibrated building simulation model. Electricity savings (kWh), demand savings (kW), and interactive savings/penalties (kWh, CCF) were analyzed separately and then the unit cost for each commodity was calculated based on local utility provider for the year 2013 for a comparison of the total energy savings.

Electricity Savings

Regarding the electricity savings, the industry methods (i.e., TRM methods) were consistently lower than the predicted value as compared to the calibrated simulation model. As seen in Table 36, the differences in kWh savings ranged from 17 percent to as much as 41 percent below the predicted savings that was projected by the calibrated simulation model.

Table 36. Comparisons of Electricity Savings for the First Approach

| Method | Electricity Saved (Wh) | Electricity Saved (kWh) | Difference (%) | kWh Save (\$0.071/kWh) |
|-----------------------|------------------------|-------------------------|----------------|------------------------|
| TRM 1 | 62,004,304 | 62,004 | -36% | \$4,402 |
| TRM 2 | 62,385,920 | 62,386 | -35% | \$4,430 |
| TRM 3 | 57,130,704 | 57,131 | -41% | \$4,056 |
| TRM 4 | 72,760,170 | 72,760 | -25% | \$5,166 |
| TRM 5 | 79,997,600 | 79,998 | -17% | \$5,679 |
| TRM 7 | 61,107,280 | 61,107 | -37% | \$4,339 |
| Calibrated Simulation | 96,373,358 | 96,373 | | \$6,843 |

Adjustments to Energy Savings

Six of the TRMs included in the analysis proposed a method to quantify interactive cooling energy savings. In general, the cooling energy savings were inconsistent across the various TRMs. As seen in Table 37, TRMs 1, 2 and 5 were approximately 45 - 47 % below the predicted value while the others were above the predicted value. TRMs 1 and 2 originated from utility companies. Whereas TRM5 was a reference manual that was developed for the Northeastern part of the U.S perhaps indicating that the utilities and states in the cooler parts of the U.S. were more conservative in quantifying cooling energy savings. Most notably, TRM 7 indicated over five times the saving as compared to the predicted value. TRM 7 was a typical utility assessment report conducted in a hot and humid climate. For this particular TRM, the excessive amount of savings was contributed to night-time setback and lower temperature setting in the heating season and higher temperature setting in the cooling season, which was not the case for the case-study building used in the current study. In addition, TRM 7 assumed that approximately 73% of the heat from lighting would impact the cooling load. However, this value was derived from two assumptions: First, replacing existing fixtures with efficient fixtures; Second, installation of occupancy sensors which explains why cooling energy savings were extremely large⁶⁷.

⁶⁷ TRM 7 did not isolate the cooling energy savings for the two different measures (lighting and lighting control ECM). Thus, without a clear explanation of the breakdown of cooling energy savings, the entire value was used to calculate the total energy savings for ECM1.

Table 37. Comparisons of Adjustments for the First Approach

| Method | Cooling Savings (kWh) | Heating Penalty (CCF) | Savings (\$0.07/kWh) | Penalty (\$0.56/CCF) | Total (\$) |
|-----------------------|-----------------------|-----------------------|----------------------|----------------------|------------|
| TRM 1 | 3100 | - | \$220 | | \$220 |
| TRM 2 | 3119 | - | \$221 | | \$221 |
| TRM 3 | 9712 | - | \$690 | | \$690 |
| TRM 4 | 8004 | 646 | \$568 | \$359 | \$210 |
| TRM 5 | 3200 | - | \$227 | | \$227 |
| TRM 7 | 31365 | 107 | \$2,227 | \$59 | \$2,167 |
| Calibrated Simulation | 5894 | 2113 | \$418 | \$1,174 | -\$755 |

Regarding the heating penalty, only two of the TRMs addressed the heating penalty. Both methods under-predicted by 69 percent (Method 4) and by 93 percent (Method 7). TRM1, 2, 3, and 7 originated from regions that are hot and humid or mild in terms of temperatures, which may explain why no heating penalty was included or was low compared to the predicted value. Even when the heating penalty was quantified for TRM 4, the predicted value was under-predicted indicating that perhaps heating and cooling interactions should be determined based on building specific characteristics such as equipment performance, indoor temperature settings and ambient temperature.

Demand Savings

As seen in Table 38, demand savings in general were all extremely conservative as compared to the value provided by the calibrated simulation model. This aligned with the findings from the expert interviews where the expert said that quantifying the demand charges was complex and uncertain as it depended on operations and occupant behavior and could easily vary depending on the region and utility provider.

Table 38.Comparisons of Demand Savings for the First Approach

| Method | Demand Savings (kW) | Difference (%) | kW Saved (\$10.40/kW) |
|-----------------------|---------------------|----------------|-----------------------|
| TRM 1 | 1 | -99% | \$13 |
| TRM 2 | 1 | -99% | \$14 |
| TRM 3 | 4 | -98% | \$41 |
| TRM 4 | 5 | -98% | \$57 |
| TRM 5 | 22 | -91% | \$230 |
| TRM 7 | 17 | -93% | \$173 |
| Calibrated Simulation | 245 | - | \$2543 |

Total Energy Savings

In summary, the comparison between industry methods and the calibrated simulation model is presented in Table 39. The unit cost for the electricity and demand charge (per kW) was obtained from City of College Station, website (<http://www.cstx.gov/index.aspx?page=3852>). The current electricity rate and demand charge for the large commercial category was used. This study did not incorporate monthly service charges, taxes or transmission delivery charges. Natural gas rate for commercial property was obtained from the Atmos Energy website (<http://www.atmosenergy.com/about/tariffs.html?st=mtx&pass=1>). Natural gas rate used in this study is the published November 2013 rate for the same geographical location as the case-study building. In general, the total predicted energy cost savings using the industry method was under-estimated as compared to the current method by 23 to 43 percent.

Table 39. Summary of Total Energy Savings for ECM1 Using Various Methods for the First Approach

| | Energy Savings | | | Demand Savings | Total Energy Savings | |
|-----------------------|------------------------|------------------------------|------------------------------|-----------------------|---------------------------|----------------|
| Method | kWh Saved (\$0.07/kWh) | Cooling Savings (\$0.07/kWh) | Heating Penalty (\$0.56/CCF) | kW Saved (\$10.40/kW) | Total Energy Savings (\$) | Difference (%) |
| TRM 1 | \$4,402 | \$220 | - | \$13 | \$4,636 | -46% |
| TRM 2 | \$4,429 | \$221 | - | \$14 | \$4,665 | -46% |
| TRM 3 | \$4,056 | \$690 | - | \$41 | \$4,787 | -45% |
| TRM 4 | \$5,166 | \$568 | \$359 | \$57 | \$5,432 | -37% |
| TRM 5 | \$5,680 | \$227 | - | \$230 | \$6,137 | -29% |
| TRM 7 | \$4,339 | \$2,227 | \$59 | \$173 | \$6,679 | -23% |
| Calibrated Simulation | \$6,843 | \$418 | \$1,174 | \$2543 | \$8,630 | - |

As seen in Table 39, the total energy savings for all of the current industry method was 23 to 46 percent below the current simulated value. TRM 7, which was a typical utility assessment report developed by a large ESCO, was the closest to the simulated value. TRM 1 and 2, which provided generic guidance from the utility providers' perspective, was the most conservative in quantifying the total energy savings. Finally, state supported TRMs, developed by energy consultants, which were geographic specific ranked in between the ESCOs and utility providers in terms of how close the aggregated total energy savings was to the prediction made by the calibrated simulation model. Notably, the breakdown of energy saving and demand saving was distinctively different between the current industry methods to the calibrated simulation method. Of the total energy savings, the calibrated simulation predicted that the energy savings would be about 74 percent and the remaining 26 percent coming from the demand savings. All of the current industry methods predicted 96 to 99 percent from the

energy savings and a much smaller fraction from one to from four percent from demand savings.

9.2.4 Comparisons Between the Industry Methods and Simulation Method: Second Approach

In addition to the analysis the stipulated values, this study also investigated the effect of measured occupancy on the calculated savings. The rationalization for testing the effect of occupancy was based on the idea that future buildings will most likely be equipped with smart meters. Therefore, with the availability of WBE interval data, obtaining an occupancy parameter may be a useful improvement to predicting savings. The hypothesis was that by using measured occupancy data, the current industry methods could improve in terms of their ability to predict the total energy savings. In this analysis, all other stipulated values remained identical as in the first approach to testing ECM1. Measured occupancy hours were derived from one year of sub-hourly, sub-metered electricity data for the case-study building collected by the ESL.

Electricity Savings

As seen in Table 40, in general, all of the current industry methods improved in terms of how close the prediction was to the calibrated simulation method. The range of prediction was the same but the error was smaller as compared to the calibrated simulation method. Predicted electricity savings were within plus or minus 12 to 18 percent (with a range of 40 percent) as opposed to 17 to 41 percent (with a range of 41 percent) below the predicted values. However, applying the measured occupancy hours not only increased the accuracy but also over-estimated the savings for TRMs 3, 4 and 5.

All three of these methods were developed by various States in conjunction with their recent measurement and verification studies.

Table 40. Comparisons of Electricity Savings for the Second Approach

| Methods | Electricity Saved (Wh) | Electricity Saved (kWh) | Difference (%) | kWh Save (\$0.071/kWh) |
|-----------------------|------------------------|-------------------------|----------------|------------------------|
| TRM 1 | 85,199,920 | 85,200 | -12% | \$6,049 |
| TRM 2 | 85,199,920 | 85,200 | -12% | \$6,049 |
| TRM 3 | 113,791,600 | 113,792 | 18% | \$8,079 |
| TRM 4 | 108,769,570 | 108,770 | 13% | \$7,722 |
| TRM 5 | 113,791,600 | 113,792 | 18% | \$8,079 |
| TRM 7 | 85,199,920 | 85,200 | -12% | \$6,049 |
| Calibrated Simulation | 96,373,358 | 96,373 | - | \$6,843 |

Adjustments to Energy Savings

As seen in Table 41, the interactive cooling savings was affected both positively and negatively by the measured occupancy hours. TRMs 1, 2 and 5, which under-predicted (e.g., half the simulated prediction using stipulated occupancy hours) improved resulting in predictions that were 70 to 80 percent of the predicted cooling energy saving using the calibrated simulation methods. However, TRMs 3, 4 and 7 increasingly over-estimated the cooling energy savings. This was expected since TRMs 1, 2 and 5 assumed four to five percent of interactive heating and cooling savings while TRMs 3 and 4 assumed 11 and 17 percent respectively of interactive heating and cooling savings. By using the measured occupancy hours, not only did the electricity savings increase, but the cooling energy savings increased proportionally as well. Concurrently, with the measured occupancy hours, the heating penalty also improved slightly. Nevertheless,

the improvements (i.e., how close the values were to the calibrated simulation's predicted values) were still less than half of the simulated penalty value and therefore, the consequences remained relatively low.

Table 41. Comparisons of Adjustments for the Second Approach

| Method | Cooling Savings (kWh) | Heating Penalty (CCF) | Savings (\$0.07/kWh) | Penalty (\$0.56/CCF) | Total (\$) |
|-----------------------|-----------------------|-----------------------|----------------------|----------------------|------------|
| TRM 1 | 4260 | | \$302 | | \$302 |
| TRM 2 | 4260 | | \$302 | | \$302 |
| TRM 3 | 19345 | | \$1,373 | | \$1,373 |
| TRM 4 | 11965 | 965 | \$849 | \$536 | \$313 |
| TRM 5 | 4552 | | \$323 | | \$323 |
| TRM 7 | 43731 | 149 | \$3,105 | \$83 | \$3,022 |
| Calibrated Simulation | 5894 | 2113 | \$418 | \$1,174 | -\$755 |

Demand Savings

Regarding the demand savings, there was no significant difference in the demand savings as compared to the first approach where all stipulated values were used. This was due to the fact that in quantifying total energy savings, the pre-retrofit hours of occupancy and post-retrofit hours of occupancy remained the same. Therefore, the peak consumption would still constitute the same proportion of savings leading to no change as seen in Table 42.

Table 42. Comparisons of Demand Savings for the Second Approach

| Method | Demand Savings (kW) | Difference (%) | kW Saved (\$10.40/kW) |
|-----------------------|---------------------|----------------|-----------------------|
| TRM 1 | 1 | -99% | \$13 |
| TRM 2 | 1 | -99% | \$14 |
| TRM 3 | 4 | -98% | \$41 |
| TRM 4 | 5 | -98% | \$57 |
| TRM 5 | 22 | -91% | \$230 |
| TRM 7 | 17 | -93% | \$173 |
| Calibrated Simulation | 245 | | \$2,543 |

Total Energy Savings

When comparing the total energy savings, using the current industry methods using measured hours of occupancy improved the prediction of the total energy savings as calculated by the calibrated simulation. As seen in Table 43, TRMs 3, 4, 5 and 7 were all within $\pm 10\%$ of the predicted (i.e., simulated) value with the measured hours of occupancy. TRMs 1 and 2 still under-predicted the total energy savings by 26 percent as compared to the simulated value but showed a 20 percent improvement as compared to using all stipulated values (i.e., the first approach to quantifying ECM1). TRMs 3, 4, 5 and 7 were all developed by state agencies using consultants and existing TRMs from other states. Although the aggregated total energy savings were fairly close to the simulated value, the proportion of energy savings and demand savings did not coincide with the simulated values. For TRMs 3, 4, 5 and 7 the energy savings were over-predicted and demand savings were under-predicted.

Table 43. Summary of Total Energy Savings for ECM1 Using Various Methods for the Second Approach

| | Energy Savings | | | Demand Savings | Total Energy Savings | |
|-----------------------|------------------------|------------------------------|------------------------------|-----------------------|----------------------|------------------------|
| Method | kWh Saved (\$0.07/kWh) | Cooling Savings (\$0.07/kWh) | Heating Penalty (\$0.56/CCF) | kW Saved (\$10.40/kW) | | kWh Saved (\$0.07/kWh) |
| TRM 1 | \$6,049 | \$302 | - | \$13 | \$6,365 | -26% |
| TRM 2 | \$6,049 | \$302 | - | \$14 | \$6,365 | -26% |
| TRM 3 | \$8,079 | \$1,373 | - | \$41 | \$9,494 | 10% |
| TRM 4 | \$7,723 | \$849 | \$536 | \$57 | \$8,093 | -6% |
| TRM 5 | \$8,079 | \$323 | - | \$230 | \$8,633 | 0% |
| TRM 7 | \$6,049 | \$3,105 | \$83 | \$173 | \$9,244 | 7% |
| Calibrated Simulation | \$6,843 | \$418 | \$1,174 | \$2,543 | \$8,630 | - |

TRMs 1 and 2, which were developed by the utility companies, were conservative in quantifying the demand savings. Although the aggregated total energy savings for both these TRMs were only about three quarters of what was predicted as compared to the calibrated simulation model, when comparing the energy savings only and not the demand savings, the energy savings for TRMs 1 and 2 showed a smaller difference of four percent as compared to the simulated value. Even so, the breakdown of electricity savings, cooling energy savings and heating penalty still did not correspond with the calibrated simulation method.

9.2.5 Summary of Quantifying ECM1

In summary, quantifying lighting savings from ECM1, total energy savings required calculating energy savings and demand savings. Energy savings included electricity savings, adjustments for cooling energy saving and adjustments for heating penalty. Two approaches were used to compare the current industry methods (TRMs) to

the calibrated simulation method. The first approach, which included using all of the prescribed values, lead to under-predicting the total energy savings as much as half of the simulated value. By using measured occupancy in the second approach, the current industry methods improved in quantifying the total energy savings as compared to the calibrated simulated methods. However, in both cases, the breakdown of savings was not similar as compared to the simulation method. In particular, the adjustment for the cooling energy and the heating penalty as well as demand savings revealed a large difference. The current industry methods also claimed only minimal demand savings perhaps indicating the difficulty of quantifying the savings due to its volatility.

According to the experts that participated in the interviews, demand savings can be easily diminished based on operational modifications and exterior weather conditions. This coupled with the utility companies unique and complex pricing structure makes it challenging to accurately quantify demand savings. This trend was confirmed in this study.

Hence, this study found that the current industry has developed reasonably sound methods to quantify the lighting retrofits in existing commercial buildings without necessarily having to create an as-built calibrated whole-build energy simulation model. The primary method for accomplishing this has been the collection of measurement and verification data from historical projects. Nevertheless, relying solely on stipulated parameters for the current industry methods leaves savings money on the table because it only provides a ballpark estimate of the total aggregated savings and does not accommodate the unique operational characteristics such as the hours of occupancy to

determine electricity savings and indoor temperature settings for adjustments for energy savings. Assuming that future buildings will be equipped with smart meters, a second approach was developed that used all of the prescribed values except for the hours of occupancy. By substituting this new parameter, the total aggregated energy savings improved yet the breakdown of energy savings and demand savings still remained inconsistent as compared to the saving predicted by the calibrated simulation method. In conclusion, the use of measured occupancy as opposed to stipulated occupancy improved the accuracy of all the current industry methods in quantifying the total energy savings yet it was less successful in determining the breakdown of the total energy savings. The calibrated simulation model was able to take into consideration the unique indoor temperature settings for different zones in the building and was able to quantify the demand savings based on peak energy consumption for individual months.

9.3 Quantifying ECM2

The second conservation measure, ECM2 consisted of adding occupancy variable in addition to ECM1. Four of the seven industry methods were compared against the current method.⁶⁸

9.3.1 Current Industry Methods: TRMs

The prevailing method to quantify the savings for installing occupancy sensors was:

⁶⁸ Four TRMs included one from the utility company, two from state agency, and one from a typical utility assessment report.

$$= (\text{controlled fixture Wattage}) \times (\text{Hours}_{\text{pre-retrofit}} - \text{Hours}_{\text{post-retrofit}}) \quad (5)$$

Where:

controlled fixture Wattage = total sum of the Wattages for the affected fixtures

Hours_{pre-retrofit} = total annual hours of the controlled fixtures before ECM

Hours_{post-retrofit} = total annual hours of the controlled fixtures after ECM

Controlled fixture wattage referred to the total sum of the Wattages for the affected (i.e., controlled) fixtures. The pre-retrofit hours were the total annual hours that these controlled fixtures were in operation prior to installing the occupancy sensors. The post-retrofit hours were equivalent total annual hours that these controlled fixtures would operate following the installation of the occupancy sensors. Frequently, the current industry methods would express the difference between the pre-retrofit hours and post-retrofit hours as a multiplier. These multipliers were referred to as power adjustment factors, realization rates, and or hours of effect. As previously mentioned the varying terminology and stipulated values that were used to quantify the savings for ECM2 are summarized in Table 44. Three of the four TRMs included adjustments to energy savings.

Table 44. Power Adjustment Factors and Adjustments for Quantifying ECM2

| TRM ID | Multiplier | Values for installing Occupancy Sensors | Includes Adjustments to kWh calculation? |
|--------|---|--|---|
| TRM 1 | Power adjustment factors (PAF) | PAF = 0.7 | Yes Interactive energy factor: 5% |
| TRM 3 | Hours of effect = (Hours X power adjustment factor) | Hours in effect is 1050 (Stipulated pre-retrofit hours for office is 2641) Energy savings factor (ESF) = 0.397 Power adjustment factor (PAF) = 0.603 | Yes Interactive energy factor: 17% |
| TRM 5 | Realization rate | RR = 0.76 | No |
| TRM 7 | Hours of effect = (Hours X power adjustment factor) | Office PAF = 0.7 Hallway, bath, closet, break room CSF = 0.6 Lounge CSF = 0.975 | Yes Interactive heating: -250 Btu/kWh Interactive cooling: 2500 Btu/kWh |

9.3.2 Simulation Method: As-Built Calibrated Whole-Building Simulation Model

To simulate the effect of ECM2 in the DOE-2 model, the input file was modified to reflect the reduced hours for floors four through seven in the case-study building. The original, pre-retrofit lighting power density was 1.4 Watts/sq-ft. as determined from the calibrated simulation of ECM1. The pre-retrofit lighting profiles were created from the ASHRAE RP-1093 toolkit which used hourly measured data for 2009 for the case-study building.

Then a modified lighting profile for simulating the occupancy was created following the study conducted by Cho (2010). The modified lighting schedule combined the pre-retrofit lighting profile and standard lighting profile for commercial buildings with occupancy profiles developed by ASHRAE Standard 90.1-1989. In addition, to accommodate for emergency lighting, a minimum value for the modified lighting

schedule was determined to be at least five percent of the maximum lighting power as opposed to being zero percent as developed by the ASHRAE Standard 90.1-1989 for any given hour of the day. Hence, the assumption for ECM2 was that when occupants left the building, the lights would automatically turn off.

As seen in Table 45, a separate weekday (WD) and weekend and holiday schedules (WEH) were created for the calibrated simulation. Pre-retrofit lighting profile represented the lighting profile prior to implementing ECM2. ASHRAE 90.1-1989 occupancy profile represented the optimum lighting profile when occupancy sensors were installed in the building. The modified post-retrofit lighting profile combined the pre-retrofit lighting profile and the ASHRAE 90.1-1989 occupancy profile. If the pre-retrofit lighting profile indicated a smaller value than the optimized ASHRAE 90.1-1989, the smaller value was used to represent the actual building and rather than assuming no lighting use during the unoccupied hours, the simulation assumed five percent of the maximum lighting energy use to represent emergency lighting.

Table 45. Comparison of Pre-Retrofit Lighting Profile and Modified Post-Retrofit Lighting Profile

| Hour of Day | Pre-Retrofit Lighting Profile | | ASHRAE 90.1-1989 Occupancy Profile | | Modified Post-Retrofit Lighting Profile | |
|-------------|-------------------------------|------|------------------------------------|-----|---|------|
| | WD | WEH | WD | WEH | WD | WEH |
| 1 | 0.41 | 0.4 | 0 | 0 | 0.05 | 0.05 |
| 2 | 0.41 | 0.4 | 0 | 0 | 0.05 | 0.05 |
| 3 | 0.41 | 0.4 | 0 | 0 | 0.05 | 0.05 |
| 4 | 0.41 | 0.4 | 0 | 0 | 0.05 | 0.05 |
| 5 | 0.41 | 0.4 | 0 | 0 | 0.05 | 0.05 |
| 6 | 0.57 | 0.53 | 0 | 0 | 0.05 | 0.05 |
| 7 | 0.65 | 0.55 | 0.1 | 0.1 | 0.1 | 0.1 |
| 8 | 0.81 | 0.56 | 0.2 | 0.1 | 0.2 | 0.1 |
| 9 | 0.87 | 0.55 | 0.9 | 0.3 | 0.87 | 0.3 |
| 10 | 0.9 | 0.55 | 0.9 | 0.3 | 0.9 | 0.3 |
| 11 | 0.9 | 0.56 | 0.45 | 0.3 | 0.45 | 0.3 |
| 12 | 0.89 | 0.55 | 0.45 | 0.3 | 0.45 | 0.3 |
| 13 | 0.88 | 0.56 | 0.9 | 0.1 | 0.88 | 0.1 |
| 14 | 0.89 | 0.56 | 0.9 | 0.1 | 0.89 | 0.1 |
| 15 | 0.9 | 0.56 | 0.9 | 0.1 | 0.9 | 0.1 |
| 16 | 0.88 | 0.56 | 0.9 | 0.1 | 0.88 | 0.1 |
| 17 | 0.78 | 0.56 | 0.9 | 0.1 | 0.78 | 0.1 |
| 18 | 0.53 | 0.46 | 0.3 | 0 | 0.3 | 0.05 |
| 19 | 0.45 | 0.41 | 0.1 | 0 | 0.1 | 0.05 |
| 20 | 0.42 | 0.4 | 0.1 | 0 | 0.1 | 0.05 |
| 21 | 0.42 | 0.4 | 0.1 | 0 | 0.1 | 0.05 |
| 22 | 0.41 | 0.4 | 0 | 0 | 0.05 | 0.05 |
| 23 | 0.41 | 0.4 | 0 | 0 | 0.05 | 0.05 |
| 24 | 0.41 | 0.4 | 0 | 0 | 0.05 | 0.05 |

Figure 51 and Figure 52 represents pre-retrofit lighting profile and modified post-retrofit lighting profile superimposed in a single graph for the weekday and weekend/holiday respectively. The shaded area between the pre-retrofit and post-retrofit profile represents the hypothetical savings. As seen in both Figures, the pre-retrofit lighting profile showed 40 percent of the maximum lighting energy used even during the heavily unoccupied hours. By installing the occupancy sensors, the assumption was that

these lights would automatically shut off during those periods leading to significant amount of savings.

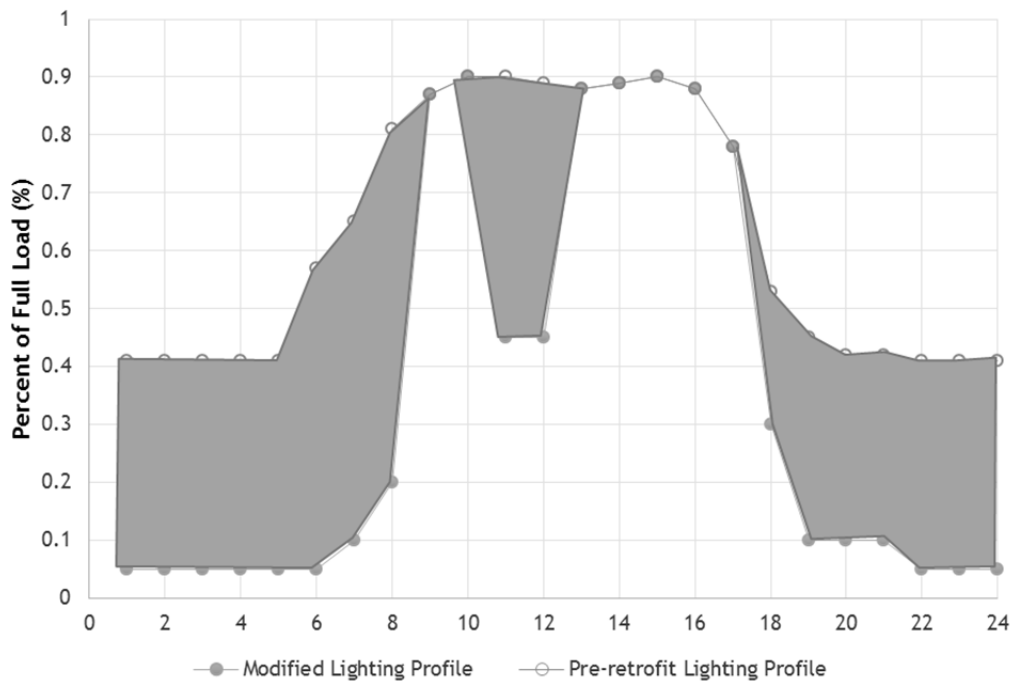


Figure 51. The Weekday Pre-Retrofit and Modified Lighting Profile for the JBC Building

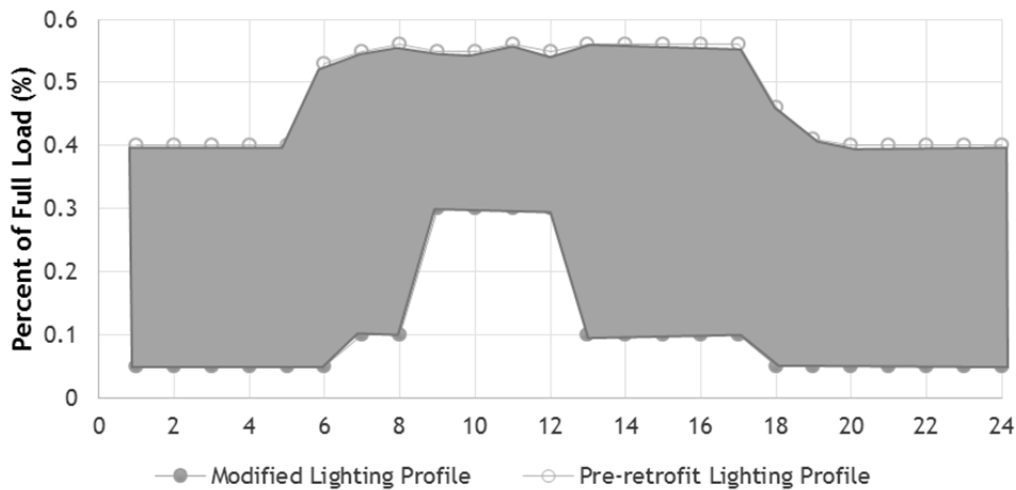


Figure 52. The Weekend Pre-Retrofit and Modified Lighting Profile for the JBC Building

Similar to analyzing the ECM1, for the ECM2, the hourly simulation results were extracted using a data processing program that allowed the WBE, CHW, NG use to be extracted in an individual columnar format. Then a special toolkit was used to transform the hourly data into both average and total daily use. These hourly and daily data were then used to quantify the electricity savings, interactive savings/penalties, and demand savings using a spreadsheet.

Electricity Savings

Regarding the electricity savings, the monthly electricity savings were relatively consistent month to month. The average savings was about 9.1 percent (18.3 MWh/month) and the total annual savings equaled 219.8 MWh. The total electricity savings was greater than ECM1. The findings were determined to be rational given the fact that by implementing the occupancy sensors, it was possible to reduce the hours of operation to approximately 56 percent of the original schedule which reduced the

lighting load. In addition, since the simulation used a single schedule throughout the year, it was expected that the electricity savings be consistent throughout the year.

Table 46. Summary of Electricity Savings From Implementing ECM2

| | | | | Electricity Savings |
|----------------|------------------|------------------|--------------|---------------------|
| Mon | ECM1 Total (MWh) | ECM2 Total (MWh) | Change (MWh) | Change (\$) |
| Jan | 178 | 160 | 18 | \$1,294 |
| Feb | 172 | 156 | 16 | \$1,174 |
| Mar | 195 | 177 | 18 | \$1,292 |
| Apr | 203 | 185 | 18 | \$1,242 |
| May | 222 | 202 | 20 | \$1,362 |
| June | 225 | 206 | 19 | \$1,358 |
| July | 234 | 214 | 20 | \$1,406 |
| Aug | 231 | 211 | 20 | \$1,381 |
| Sept | 218 | 201 | 17 | \$1,263 |
| Oct | 207 | 189 | 18 | \$1,294 |
| Nov | 185 | 168 | 17 | \$1,259 |
| Dec | 166 | 148 | 18 | \$1,279 |
| Total (Annual) | 2437 | 2217 | 220 | \$15,604 |

Adjustments to Energy Savings

The cooling interactive savings was 7,665 kWh. Savings were greater (than the average) during the cooling season (June-August) and in December. Regarding the heating penalty, the building required an average of 68 MMBtu/month of additional heating to be supplied back into the building in order to maintain the indoor thermostat setting of 74 (°F) throughout the year. Greater penalties (above average) occurred during the heating season (September to April) as seen in Table 43. Table 43 provides a summary of pre-retrofit (ECM1) cooling energy use versus the post-retrofit (ECM2)

cooling energy use. The change is the savings that would occur from implementing the ECM2. The same information is summarized for the heating energy use. The difference is a penalty. By installing the occupancy sensors, there was a small gain in the cooling energy saving but a relatively large heating penalty to make up for all the lost heat during the unoccupied hours when all the lights and equipment were shut down.

Table 47. Summary of Interactive Cooling and Heating Penalty from Implementing ECM2

| Mo. | Cooling | | | | Heating | | | |
|------|------------------------|------------------------|-----------------|----------------|--------------------------|--------------------------|-------------------|-----------------|
| | ECM1 Total (kWh) | ECM2 Total (kWh) | Change (kWh) | Saving (\$) | ECM1 Total (MMBtu) | ECM2 Total (MMBtu) | Change (MMBtu) | Penalty (\$) |
| Jan | 12,999 | 12,938 | 61 | \$4 | 342 | 417 | -75 | -\$420 |
| Feb | 20,474 | 20,319 | 155 | \$11 | 230 | 297 | -67 | -\$374 |
| Mar | 25,405 | 25,147 | 258 | \$18 | 240 | 313 | -73 | -\$407 |
| Apr | 34,829 | 34,455 | 374 | \$27 | 145 | 217 | -72 | -\$399 |
| May | 49,551 | 48,689 | 862 | \$61 | 61 | 129 | -68 | -\$379 |
| June | 54,180 | 52,896 | 1,284 | \$91 | 15 | 62 | -47 | -\$257 |
| July | 57,310 | 55,994 | 1,316 | \$93 | 10 | 60 | -50 | -\$277 |
| Aug | 56,161 | 55,060 | 1,101 | \$78 | 16 | 76 | -60 | -\$333 |
| Sept | 48,810 | 48,075 | 735 | \$52 | 55 | 125 | -70 | -\$389 |
| Oct | 35,597 | 35,240 | 357 | \$25 | 145 | 223 | -78 | -\$438 |
| Nov | 23,434 | 23,295 | 139 | \$10 | 210 | 287 | -77 | -\$432 |
| Dec | 3,474 | 2,451 | 1,023 | \$73 | 401 | 474 | -73 | -\$407 |
| Tot. | 422,224 | 414,559 | 7,665 | \$544 | 1868 | 2681 | -813 | -\$4,512 |

Demand Savings

On the other hand, demand savings were small as compared to implementing ECM1. The average saving was 0.5% (2.3 kW/month) and the total demand savings equaled 27 kW for the year 2009 as seen in Table 48. This was rational given the facts that by implementing ECM2, most of the hours were reduced from the evenings and un-

occupied periods. Since the demand savings were the peak consumption for the particular month, this did not have a large effect on the demand savings.

Table 48. Summary of Electricity Savings and Demand Savings from Implementing ECM2

| | | | | Demand Savings |
|--------------|-----------------|-----------------|-------------|-----------------------|
| Month | ECM1 Total (kW) | ECM2 Total (kW) | Change (kW) | Change (\$) |
| Jan | 417 | 416 | 1.4 | \$15 |
| Feb | 425 | 424 | 1.5 | \$16 |
| Mar | 431 | 430 | 1.6 | \$17 |
| Apr | 432 | 429 | 3.4 | \$35 |
| May | 456 | 454 | 2.0 | \$21 |
| June | 460 | 458 | 2.2 | \$23 |
| July | 457 | 453 | 3.8 | \$40 |
| Aug | 458 | 456 | 2.0 | \$21 |
| Sept | 464 | 460 | 4.2 | \$43 |
| Oct | 453 | 451 | 1.9 | \$20 |
| Nov | 424 | 422 | 1.5 | \$15 |
| Dec | 417 | 415 | 1.7 | \$18 |
| Total | 5295 | 5268 | 27 | \$284 |

Total Energy Savings

Finally, looking across the breakdown for total energy cost savings, the electricity savings was the largest contributor of the total energy savings. The demand savings was relatively small as compared to the total energy cost savings. A large heating penalty cost, which was almost a quarter of the electricity savings, was lost due to the heating penalty as seen in Table 49.

Table 49. Summary of Total Cost Savings for ECM1

| | Energy | | | Demand |
|-----------------------------|---------------------|-----------------|-----------------|----------------|
| Current Method (Simulation) | Electricity Savings | Cooling Savings | Heating Penalty | Demand Savings |
| Savings | 219,780 kWh | 7,665kWh | -8,129 CCF | 27 kW |
| Unit Cost | \$0.071 /kWh | \$0.071 /kWh | \$0.56 /CCF | \$10.40 /kW |
| Cost Savings | \$15,604 | \$544 | -\$4,512 | \$284 |
| | \$11,636 | | | |
| Total Savings | \$11,920 | | | |

9.3.3 Comparison Between the Industry Methods and Simulation Method

Based on the information that was collected and assessed, the comparison of savings for ECM2 were made between four TRMs using the specified stipulated values and the simulation method. Electricity savings (kWh), demand savings (kW), and interactive savings/penalties (kWh, CCF) were analyzed separately and then the unit cost for each commodity was estimated based on local utility provider for the year 2013 for a comparison of the total energy savings.

Electricity Savings

Similar to ECM1, for the electricity savings, the industry method was consistently lower than the predicted value as compared to the simulation method. As seen in Table 50, the differences in kWh ranged from 54 percent to as much as 70 percent below the predicted savings as quantified by the calibrated simulation model.

Table 50. Comparisons of Electricity Savings for ECM2

| Method | Electricity Save (Wh) | Electricity Save (kWh) | Difference (%) | kWh Save (\$0.071/kWh) |
|-----------------------|-----------------------|------------------------|----------------|------------------------|
| TRM 1 | 8,939,203 | 89,392 | -59% | \$6,347 |
| TRM 3 | 7,909,440 | 79,094 | -64% | \$5,616 |
| TRM 5 | 6,526,418 | 65,264 | -70% | \$4,634 |
| TRM 7 | 10,199,844 | 101,998 | -54% | \$7,242 |
| Calibrated Simulation | 21,978,110 | 219,781 | | \$15,604 |

Adjustments to Energy Savings

All of the current industry methods included a method to quantify the cooling interactive energy savings. Unfortunately, the cooling energy savings were inconsistent between the various TRMs. As seen in Table 51, according to the calibrated simulation model, the heating penalty outweighed the benefits of the cooling energy savings. This heating penalty was only addressed by one current industry method which was significantly lower than the current values.

Table 51. Comparisons of Adjustments for ECM2

| Method | Cooling Savings (kWh) | Heating Penalty (CCF) | Savings (\$0.07/kWh) | Penalty (\$0.56/CCF) | Total (\$) |
|-----------------------|-----------------------|-----------------------|----------------------|----------------------|------------|
| TRM 1 | 4470 | | \$317 | | \$317 |
| TRM 3 | 13446 | | \$955 | | \$955 |
| TRM 5 | 2611 | | \$185 | | \$185 |
| TRM 7 | 22437 | 76 | \$1,593 | -\$43 | \$1,550 |
| Calibrated Simulation | 7673 | 8129 | \$545 | -\$4,516 | -\$3,971 |

Demand Savings

The demand savings were lower as well, ranging from 78 to 98 percent lower than the predicted demand saving from the calibrated simulation method. The variation was caused by a combination of the values in the standard lighting table, difference in power adjustment factors, and interactive factors. Thus, lower power adjustment factors (e.g., larger savings factor) did not necessarily lead to larger demand savings. Table 52 summarizes the electricity savings and demand savings for the ECM2 following the four different TRMs and the simulated method.

Table 52. Comparisons of Demand Savings for ECM2

| Method | Demand Savings (kW) | Difference (%) | kW Saved (\$10.40/kW) |
|-----------------------|---------------------|----------------|-----------------------|
| TRM 1 | 2 | -93% | \$19 |
| TRM 3 | 1 | -95% | \$14 |
| TRM 5 | 1 | -98% | \$6 |
| TRM 7 | 6 | -78% | \$61 |
| Calibrated Simulation | 27 | | \$281 |

Total Energy Savings

In summary, the comparison between the total energy cost savings is presented in Table 53. The cost information was obtained from the same source used to calculate the ECM1 savings. In general, the total predicted energy cost savings using the industry methods were under-estimated as compared to the calibrated simulation method by 26 to 60 percent.

Table 53. Summary of Total energy savings for ECM1 using various methods for ECM2

| | Energy Savings | | | Demand Savings | Total Energy Savings | |
|-----------------------|------------------------|------------------------------|------------------------------|-----------------------|----------------------|------------------------|
| Method | kWh Saved (\$0.07/kWh) | Cooling Savings (\$0.07/kWh) | Heating Penalty (\$0.56/CCF) | kW Saved (\$10.40/kW) | Method | kWh Saved (\$0.07/kWh) |
| TRM 1 | \$6,347 | \$317 | | \$19 | \$6,683 | -44% |
| TRM 3 | \$5,616 | \$955 | | \$14 | \$6,585 | -45% |
| TRM 5 | \$4,634 | \$185 | | \$6 | \$4,825 | -60% |
| TRM 7 | \$7,242 | \$1,593 | -\$43 | \$61 | \$8,853 | -26% |
| Calibrated Simulation | \$15,604 | \$545 | -\$4,516 | \$282 | \$11,915 | |

A review of the breakdown of electricity saving, adjustments to savings, and heating penalty the analysis showed a difference in the pattern. As seen in Table 53, according to the current industry methods, most of the savings were a result of the electricity savings, and adjustments to savings were minimal. Demand savings across the TRMs were relatively small compared to the electricity savings as well. However, the calibrated simulation showed almost twice as much electricity savings. Almost of third of that savings was lost due to the simulated heating penalty.

9.4 Summary of Energy Performance Evaluations

This study performed a comparative analysis between two different energy conservation measures. These were:

- ECM 1: Replacement of linear fluorescent (LF) fixtures
- ECM 2: Installation occupancy sensors

A total of three different analyses were conducted between industry methods (i.e., Technical reference manuals (TRMs)) and the as-built calibrated whole-building energy simulation model. These included:

- ECM 1 - first approach included all prescribed stipulated values for six different TRMs versus an as-built calibrated whole-building energy simulation model
- ECM 1 - second approach included a combination of stipulated values and measured occupancy parameter for six different TRMs versus an as-built calibrated whole-building energy simulation model
- ECM 2 included all stipulated values for four different TRMs versus an as-built calibrated whole-building energy simulation model

In order to quantify ECM 1 using the industry TRMs, the prevailing methods required stipulating, estimating, measuring or simulating four key parameters. These parameters were:

- Hours of use: This parameter estimates the annual hours of use for the baseline condition and after the energy efficiency measure has been implemented
- Interactive factor for cooling: This parameter represents the ratio of cooling energy reduction per unit of lighting energy reduction that results from the reduction in lighting waste heat during the cooling season.
- Interactive factor for heating: This parameter represents the increase per unit of lighting energy that results from reduction in lighting waste heat during the heating season.
- Diversity factor: This parameter accounts for how much of the actually installed energy efficiency technology may operate at any given time.
- Coincident factor: This parameter accounts for the ratio of building's peak demand to the utility system peak demand.

The stipulated values for these parameters varied widely depending on the origin or reference document, location and developer. All of the TRMs quantified energy savings and demand savings to determine the total energy savings from ECM 1. The energy savings included electricity savings, cooling interactive saving, and heating

interactive penalty. The demand savings were calculated as the difference in the peak electricity consumption for the particular month using the same baseline year. EMC 1 was analyzed first using published stipulated values in the TRMs (ECM 1 - first approach) and then analyzed using published stipulated values and measured occupancy hours (ECM 1- second approach). Relying entirely on the published stipulated values lead to a larger error in calculating the total energy savings. In general, the industry methods were conservative in quantifying the savings. Using the occupancy hours increased the accuracy. The net effect was a large improvement on the overall total cost savings prediction indicating that a good practice is to measure the occupancy hours when quantifying lighting ECMs with TRMs. However, when individual categories of savings and penalties were examined, the results showed that large savings can compensate for the greater penalty value or vice versa. Hence, the proportion of the electricity, interactive savings/penalties and demand savings varied widely between the TRMs and the current method. This was due to the fact that individual TRMs had distinctive site-specific characteristics such as general climatic conditions, indoor heating and cooling temperature settings and system equipment.

In order to quantify ECM 2 using the industry TRMs, the prevailing methods required stipulating, estimating, measuring or simulating five key parameters. These parameters were, hours of use, interactive factor, diversity factor, coincident factor, and impact factor. The industry method to quantify ECM 2 was similar to ECM 1. The main difference was the impact factor which was a coefficient/multiplier that determined the reduced hours of use based on the conservation measure. Using the stipulated

parameters, the study found that the industry method was conservative as compared to the current method. The proportion of sub-categories of savings also widely varied depending on the TRMs. The simulation showed a greater electricity savings and heating penalty. Thus, for lighting control ECMs, a superior method would be to obtain the pre-retrofit hours of use and post-retrofit hours of use to find site and space specific impact factors and building specific indoor heating and cooling temperature settings.

The results of this study indicated that the current method can be improved by measuring only selected parameters. To more accurately quantify the savings by major categories (electricity, heating penalty and demand saving), it is necessary to measure the occupancy, measure the indoor heating and cooling temperature and to know the performance factors of the building's heating and cooling equipment.

10. SUMMARY AND CONCLUSIONS

The objective of this study was to determine how the current industry quantified energy service projects using a comparative analysis between the current industry methods and an as-built calibrated whole-building energy simulation model. Through this study, the goal was to identify and develop procedures that could lead to improving the current industry methods of quantifying energy service projects.

Expert interviews, a desk audit of an existing typical energy service company's utility assessment report, and publically available Technical reference manuals (TRMs) were used to assess the current industry practices. An as-built hourly calibrated building simulation model was created using an existing whole-building energy simulation program. To demonstrate the research, a well-instrumented case-study building from Texas A&M University campus was selected to measure the effect of lighting and lighting control efficiency measures. This Chapter provides the conclusions and future research.

10.1 Conclusions

The results of this study have the following implications for stakeholders:

- (1) *Thoroughly evaluate the applicability of the selected Technical reference manual (TRM) for individual projects:* For lighting and lighting control efficiency measures, the study showed that the majority of current industry methods used algorithms. Although most agreed that total energy savings was quantified as the sum of energy savings and electricity demand savings, the use of specific terminology and values, mainly coefficients, varied

drastically depending on the agencies. For example, states in warmer climate regions claimed more cooling interactive savings while states in colder climate regions did not. It was also observed that individual states have tailored their TRMs and were continuously updating their TRMs based on impact evaluation studies. The main differences for the values in the TRMs were perceived to be location specific and weather driven in addition a lack of any agreement as to how to quantify the demand savings.

In recent years, the US government has taken the role of producing national guidelines on quantifying energy service projects. Unfortunately, although the U.S. guideline provides effort to unify the language and approach to quantify savings for the energy community it did not provide specific values for many of the coefficients in the protocols. Hence, each project had to be individually evaluated to determine if the selected methods and values correspond to the project of interest.

(2) *Carefully evaluate the breakdown of savings and conduct follow-up*

measurements: Assessment of the current industry practices indicated that energy savings for lighting and lighting control included direct electricity savings, interactive cooling electricity savings, and interactive heating penalty. Demand savings were primarily determined based on the percentage of how much of the new installation would be on simultaneously at any given time and how much of that usage would coincide with the utility's peak consumption. All of the current industry methods claimed energy savings

and demand savings. However, in all situations that were tested, the current industry methods were consistently conservative in quantifying the total energy savings for lighting and lighting control measures. In particular, demand savings were only seven to thirteen percent of the demand savings the calibrated simulation predicted for lighting measures. Hence, rather than relying on pre-determined savings, stakeholders should measure and verify savings after implementing the ECMs, including, demand savings.

(3) *Use measured occupancy of the building whenever possible:* The study showed that using measured occupancy significantly reduces the error in quantifying the total energy savings in current methods as compared to the as-built calibrated whole-building energy simulation model. At a minimum, stakeholders can interview the building engineer to obtain an occupancy schedule. Installing lighting loggers with on and off capability may be another option to obtain more detailed occupancy schedules. Assuming that future buildings will be equipped with smart meters, stakeholders should use the measured electricity data to develop 24-hour occupancy profile of the building.

(4) *Measure the indoor temperature settings:* The study showed that the heating interactive penalty and cooling interactive savings varied significantly depending on the climate zone but also on the indoor temperature settings. Prior to any retrofits being considered, stakeholders should measure the current indoor thermal conditions of the building and discuss with the

building engineer what the optimal indoor temperature setting would be for the occupants. Many times, the building engineers override the temperature setting controls based on occupant feedback, which lends to complaints that can create a discrepancy in the predicted versus measured savings.

Considerations for retrofit selections and quantifications should incorporate occupants' thermal comfort.

The study found that lighting and lighting control efficiency projects can be better predicted using a calibrated as-built whole-building simulation model. In particular, the simulation was able to accurately show the breakdown of energy savings based on building thermal performance, occupancy, equipment performance, indoor temperature setting, and outside climatic conditions. It was also possible to quickly calculate the demand savings by reviewing the hourly energy consumption reports. However, given the limited resources and a short time to develop the utility assessment reports, experts indicated during the interviews that their algorithms were a better alternative when the retrofits only include lighting and or lighting control efficiency measures. Findings indicated that when using the current industry methods, a significant improvement to the current methods for quantifying lighting and lighting control measure can be achieved by obtaining the occupancy of the building, indoor temperatures, and measuring and verifying the savings after the ECMs are implemented.

10.2 Limitations and Further Research

First, this study was conducted using a representative sample of the current industry methods as compared to a calibrated whole-building energy simulation model for a single case-study building. The possibility of extending this study for multiple buildings should be explored in future research using the procedures outlined in this study. Second, the ECMs tested in this study included only lighting and lighting control measures. Since more projects are implementing comprehensive upgrades that include HVAC efficiency measures, further research could improve this study by expanding its coverage to include HVAC measures. Finally, the unit price used to quantify the total energy cost savings excluded price variations over time. A future study could extend his work by studying the effect of time-varying energy price.

Despite these limitations, this study made several contributions. This study suggests that measuring and verifying the ECM savings should be an integral part of the energy service performance contract. This study also agrees with previous research that measured occupancy and indoor temperature can lead to better prediction of the energy use in buildings.

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APPENDIX A

INTERVIEW TRANSCRIPTION: SME #1

Doctor of Philosophy Dissertation

Developing a procedure for improving the uncertainty in energy service projects

Interview Respondent: SME#1

Interview Date: May 15, 2013

Interview Time: 8:00 am – 8:40 am CST

Interview Contact Number: -

Interview Location: Wisenbaker Engineering Research Center Rm 214-A

Interview Questions

Thanked the SME for participating in the interview. Reiterated the purpose of the study and asked if the SME had any questions before starting the interview.

Part I: Retrofit Selection Process for Energy Service Performance Contracts (ESPCs)

1) How do you identify and approach potential customers?

This firm provided consulting services to the ESCOs. ESCOs hired this company to conduct audits, select retrofits, quantify retrofits and conduct M&V for both before and after implementation of ECMs.

In general, ESCOs typically work with State Utilities that run energy service programs. So there is already an established relationship with the client. Most of the work is around public clients. Typically, government entities have a 10 year payback period as opposed to public clients who have a shorter payback period (typically 5 years). Industrial plants have even a shorter pay back requirement which may be about 2-3 years. Industrial plants see a lot of good opportunities that never get implemented.

Asked why such a short payback for industrial plants.

The SME said that this is because many times the plants are owned by stock holders. Since these plants can go on sale the payback requirement is short and they are very conscience about their quarterly earnings. Long paybacks are not acceptable. So, a lot of good opportunities do not get implemented.

2) What is the basic process once a potential customer is identified?

Identify Need → Scope Visit → Develop General Contract → Full Audit

Once the client is identified, the next step in the process is to meet with the government building owners to see if they have a need. Understanding their needs (capital retrofits) i.e. “what they want to do” is a good place to investigate first and perhaps most beneficial. Need to confirm that the owner is interested.

Some of the large office building owners may propose “window” upgrades. Windows facing northeast with old/single glazing, leaky frames and poor heat transfer characteristics are inefficient but this is not a good option for ESCOs in most cases. This is problematic for ESCO’s because the building owners do not have the upfront cost to pay for this retrofit. Typically in this case the ESCOs will bundle with lower cost ECMs to get the pay back.

Retrofits that pay include:

- Controls
- Mechanical upgrades
- Lighting (Visible to everyone and typically the first thing that gets identified)
- Ventilations
- VFD for fans/pumps

Scope visit allows identifying major projects in facility. This provides a quick estimate. Typically, perform an ASHRAE Level II audit. Do perform measurements. For office building, look at energy management system trends.

A general contract is in place before a full blown audit.

What information do you collect before the site visit vs. during the site visit?

Before the site visit:

- Utility bills
- Identify energy cost
- Identify rate of return required for the customer

During the site visit:

There is a typically a checklist but rely on experienced auditors to identify ECMs. Best ECMs are unique to the building and one cannot just rely on a checklist.

Part II: Identifying and Quantifying Retrofits

3) How do you identify retrofits?

Available spreadsheets and experienced people

Start with the problems in the building. These may be the best opportunities for improving the energy efficiency in the facility.

For central plants:

Investigate the efficiency

See how the controls are set up (there are often issues with this)

Consider staging if there are multiple units

Understanding how the systems works, why it is set up the way it is set up.

4) How do you calculate the savings from the retrofits?

Spreadsheets: refined based on experience

Based on previous performance data and actual measurement

Calculations based on experience

Quantify the variables involved

For lighting and lighting control measures:

Typically use spreadsheets and calculations.

Do take measurements before and after. Some data required to quantify lighting and lighting control measures are:

- Energy use if existing lights: obtain specifications for lamps and ballast
- Measure spark reading of electric circuits for instantaneous power
- Measure run time with light loggers, 3 weeks measurement with battery operated light logger
- Measure on/off, 3 weeks measurement for operating schedule
- For dimming capabilities, measure power (check in the field) and look at the specification sheet

Do you use simulations? If so, when do you use simulations?

Simulations are used when complex ECMs are involved or especially when replacing the whole mechanical plants.

Use eQUEST program.

Need to collect all of the information related to building the simulation model. These include:

- Full set of blue print
- Energy bills (match the monthly energy bills)
- Investigate peak demand every month for the building
- Calibrate the model using operating schedule (energy management system can help identify this)

5) Do you perform actual measurement?

Yes, see answer to question #4.

This also depends on how the contract is signed.

The options are:

- Multiyear measurement
- Some do not perform measurement (stipulated savings in this case)
- Measure the 1st year and maintain throughout the contract period

Final Comments

6) Do you have anything else that you would like to share that may be pertinent for this study which is to improve the current method of selecting and quantifying energy service projects?

May contact SME in the future for further information or clarification.

Most ESCO's emphasize keeping the design cost down. They tend to focus on large projects rather than smaller pieces of retrofit projects to keep the cost in line.

Lighting is typically the first ECM that gets identified. Believes that there are still opportunities with the technology changing so fast. Do start to see state transportation agencies using LED lights. Expects that eventually that everything will be LED in the future.

<Shared transcription: 5/29/13>

APPENDIX B

INTERVIEW TRANSCRIPTION: SME #2

Doctor of Philosophy Dissertation

Developing a procedure for improving the uncertainty in energy service projects

Interview Respondent: SME#2

Interview Date: May 17, 2013

Interview Time: 8:00 am – 8:59 am CST

Interview Contact Number: -

Interview Location: Wisenbaker Engineering Research Center Rm 214-A

Interview Questions

Thanked the SME for participating in the interview. Reiterated the purpose of the study and asked if the SME had any questions before starting the interview.

Part I: Retrofit Selection Process for Energy Service Performance Contracts (ESPCs)

1) How do you identify and approach potential customers?

Industry has evolved. Vast majority of opportunities exist in the public sector with some private (non-profit) sector. This business sector can be largely divided into federal government and the MUSH market. The federal government and specific agencies (such as NAVY, GAS) may have their own program rules.

The way to identify and approach customer is to build networks one at the time. This way the company can gather intelligence on facilities. All of the agencies or organizations have requirements and some form of competition.

Although before it was possible to submit unsolicited proposals this option is no longer available. All federal and MUSH projects go through a competitive process. Customers send out an RFP (typically prepared in conjunction with 3rd party involvement). Some states actually have an established program.

Performance Contracts fill a niche by providing opportunities for saving energy when customers do not have the upfront capital to resolve issues such as deferred maintenance. Traditional funding can takes years and may not always be available for that purpose. The advantage of ESCOs is that they make this happen much faster.

For the private sector this may not always be the case. The private sector has a more sophisticated financial management system and also more flexibility. They have other sources that are less expensive.

Would private sector clients require shorter payback? May not always be the case.

When do projects become a project? As soon as the opportunity is identified the project gets a project number. There is still a significant amount of effort on putting together a bid package. Experience and network (understanding the constraints and needs) are keys to successful project. Start to see new type of contracting methods. See State of Massachusetts's Division of Capital Asset Management and Maintenance (DCAMM) has a design build type of contract which does not require any long term measurement and savings guarantee. The department has determined that the retrofits justify themselves based on past performance.

2) What is the basic process once a potential customer is identified?

Prospecting → Benchmarking → Walk-through Audit → Submit and Select Proposal → Make Presentation → Make a decision → Conduct Investment Grade Audit

Prospecting: Included Accounting Executives to evaluate if the customer has interest and potential. Considers the following items:

- Age of the building
- Condition of building
- Financial situation / identify any potential obstacles
- KW density, energy density (not utility bills yet during this stage)

Benchmarking: CBECS and compare to historical database, start to identify potential opportunities

Walk-through Audit: Look at utility bills, identify specific ECMs, just enough to put together a rough scope and pricing (+/- 20% at proposal stage)
For lighting retrofits, these would include doing spot checks and not line by line at this point.

Some customers do their “homework” and include a site data package which includes information such as:

- utility bills
- sq. footage
- usage
- equipment list

The auditor will verify the site data package.

Submit and Select Proposal: The customer selects 3-5 proposals and invites selected ESCOs for interviews. ESCOs present and the customer identify the winning proposal and ESCO.

Conduct Investment Grade Audit: For lighting retrofits, checking 95%+ or more of the existing fixtures in the building. Will pop ceilings to verify lamp type and ballast type. Key is to identify what exists and also obtain the operating hours. Baseline is established by spot measurement of lighting fixture power. Conduct short term monitoring and determine lighting fixture run time and occupancy of the space.

Part II: Identifying and Quantifying Retrofits

3) How do you identify retrofits?

Some facility owners have a predetermined list of ECMs they would like for the ESCOs to investigate. In some cases, the ESCOs are limited to investigating the predetermined list of ECMs. These are broken down by technology categories. Federal government for example has 17-18 technology categories. The advantages of having predetermined list are:

- Allows customer to evaluate using common scope of work
- Constrains their effort

Also look at:

- Existing systems
- Discuss with the building operators

Existing conditions can help identify ECMs and determine what will be applicable.

How do you identify lighting/lighting control retrofits?

Existing fixtures each have a code type. Depending on the code type there is a set of available ECMs. These however do not drive the cost down. Lighting retrofit paybacks are becoming longer as lighting technology evolves. Nevertheless, lighting ECMs are frequently implemented because lighting ECMs can boost the total project cost by bundling into the entire upgrade package.

Do see more and more opportunities in water conservation technology. Especially in prison type facilities by looking at controls and flush valves in toilets.

4) How do you calculate the savings from the retrofits?

Use engineering calculation. A reality check is done during QC process. Past performance is compared to determine how much of the utility bill can be saved. Each ECM has a specific M&V protocol. This informs what the process should be.

Do you use simulations? If so, when do you use simulations?

It depends. Simulations are typically used for large buildings with complex air handling system or more sophisticated HVAC systems. Large buildings mean that they are typically over 100,000 sq. ft.

Use eQUEST program. DOE-2 has worked well so use eQUEST. Switching to EnergyPlus takes too much of a learning curve. Need to collect all of the information

related to building the simulation model. This process starts with developing a data collection method.

Major or key information include things like collecting name plate data but also some measured data. May install temporary data logger (2 weeks) for measuring power. The real challenge with monitoring measurement is the time constraint on submitting the report to the client. Measuring data takes time. After the report is submitted there may be a period to re-evaluate the scope which requires negotiation and additional time to go through the buildings. Since time is a physical constraint, there have been cases where the occupancy data loggers may be installed as the preliminary walk-through audits are being performed.

5) Do you perform actual measurement?

Do perform measurement when aspects tend to be unique and uncommon at other locations.

For lighting ECMs, do measure sample power and baseline occupancy schedule. Once it is installed do obtain a sample on new fixture (just power). Assume that the baseline occupancy and operating schedule is the same. Recommend 1 year M&V rather than multiple years for lighting.

Final Comments

6) Do you have anything else that you would like to share that may be pertinent for this study which is to improve the current method of selecting and quantifying energy service projects?

<Transcription shared: 5/29/2013>

APPENDIX C

INTERVIEW TRANSCRIPTION: SME #3

Doctor of Philosophy Dissertation

Developing a procedure for improving the uncertainty in energy service projects

Interview Respondent: SME#3

Interview Date: May 20, 2013

Interview Time: 9:00 am – 9:59 am CST

Interview Contact Number: -

Interview Location: Wisenbaker Engineering Research Center Rm 214-A

Interview Questions

Thanked the SME for participating in the interview. Reiterated the purpose of the study and asked if the SME had any questions before starting the interview.

Part I: Retrofit Selection Process for Energy Service Performance Contracts (ESPCs)

1) How do you identify and approach potential customers?

This can (metaphorically) be a silo, vertical market structure. Within the company, each team works with or investigates a group of potential clients. For example, some groups work with municipal, some K-12 and some higher educational facilities.

Try to contact the customers that have previously worked with the group or are currently working with the group. Building trust and relationship is important. Clients with aging facilities are a good target.

In some cases the client approaches the ESCOs. This is because of the good reputation with past performance on previous projects.

2) What is the basic process once a potential customer is identified?

Initial Meeting → Preliminary Energy Audit → Post-audit Meeting → Submit RFQ → Submit “Letter of Intent” → Conduct Investment Grade Audit

Initial Meeting:

Considers the following items:

- Size of the facility, square foot
- Owner’s initiatives (what will the client do within the next 5 years, what will the client do to take care of deferred maintenance, were there any other retrofits done within 3-5 years)
- Consumption: water / gas

- Discuss performance contracting with client. Will adapt or tailor to fit the client's need.

Are clients aware of performance contracting? What is their take on performance contracting?

Some are aware of it. Some potential customers have had a negative idea of performance contracting from some past projects completed in the market. However, for customers that tend to be highly involved with the projects seem to monitor the project more closely which in turn prevents problems from getting out of hand.

Preliminary Energy Audit: Try to obtain the site plan and possible floor plan before conducting the preliminary energy audit. This requires a quick turn-around period. If the building has control systems, try to identify any controls issues (look at graphics, any problem spots, and pull screen shots before the preliminary energy audit). No intensive data collection period though since limited in time and budget. Recommendation is to have an efficient data collection plan before setting foot in the building. Typically do not send in new engineers out in the field to do this. More experienced engineers with 10+ years and with several performance contracting experience are sent to do this work. Do tell the engineers that if the project goes forward, this document becomes the foundation for future work.

Do a walk through and do spot checks. If this is a portfolio of projects, look at typical facilities. Consider the following items:

- Utility bill
- Data: drawings, capital asset plans

No hard savings. These figures are very high number budgets. For example, will tell clients they will save 20% of the current energy use. Do not have equipment data at this point. Did not specify any specific guideline but determination of what may be effective for this specific project.

Post-audit Meeting/Submit RFQ: This phase includes meeting with and discussing with other potential stakeholders. Is there anyone else involved in making decisions or need "buy-in" from? Generally, the client has a committee that will form and generate a RFQ. ESCOs interested in the project would then respond to the RFQ.

Submit "Letter of Intent": Provide a "Walk away number" based on required payback period and maximum amount of money the client is willing to spend. If the detailed audit is within the requirements specified by the owner, and the owner decides not to proceed with the project, the owner will owe an ESCO certain amount of money. If the owner decides to move ahead with the project, the cost of audit is rolled into the project. In essence, the savings will pay for the audit.

Conduct Detailed Audit: A lot of time and resources are spent on the detailed audit. For a campus that is 3-10 million sq. ft. the audit may take 4-6 months to develop. For an office building about 125,000 sq. ft. and 10 stories high, the audit will likely take about 1 ½ to 2 months to generate because it will require looking at every light (count lighting) and equipment in the building to understand what's going to be optimal. Also investigate rebates that may be feasible from Utility providers, etc.

Part II: Identifying and Quantifying Retrofits

3) How do you identify retrofits?

Problem area → Lighting → Water use → Automations (building and plant side) → Automations (HVAC water side)

(1) Understand customer needs. Focus on problems first. This can in many times point to the right direction for possible ECMs.

(2) Lighting is a big component with huge paybacks. Do consider occupancy sensors, changing out the light fixtures, changing out the ballasts etc.

(3) Look at water consumption (flushing toilets)

(4) Automations are good candidate projects – Can you tie in Automation controls to VAV boxes, and execute advanced scheduling techniques.

(5) Can you provide operational savings by replacement of equipment?

(6) Look at cooling towers. Do they need to be replaced? Chiller Plant.

Asked if lighting/lighting control and HVAC were indeed popular retrofits? How about windows and insulation?

Was involved in projects that implemented other types of retrofits such as solar films and foam roofing. The reasons these do not get selected is because most projects require a less than 10 year payback period. Projects and ECMs need to be justified and these have a longer pay back period. Solar panels for example require a payback period longer than the useful life which makes it difficult to implement with ESPC.

4) How do you calculate the savings from the retrofits?

Look at Energy Coalition, SECO Guideline or Texas LoanSTAR for projects in Texas as an example. Project financing is less strenuous. The operational savings can be used to justify the cost of the project.

Do you use simulations? If so, when do you use simulations?

Do not have the background knowledge to discuss this particular question.

Use DOE-2 program.

Will follow guidelines such as ASHRAE's to build the model.

Simulations are used as needed (case by case).

5) Do you perform actual measurement?

For lighting:

Loggers are used to determine on/off and occupancy (typically 1 week)

Light level are measured during the audit as well and consider daylight harvesting options as well. Do perform pre and post measurement

Final Comments

6) Do you have anything else that you would like to share that may be pertinent for this study which is to improve the current method of selecting and quantifying energy service projects?

For ESPC's it is important to understand that the payback required is short and that both the client and company should realize quick savings to be successful.

It is also important to note that you cannot qualify a project by just looking at sq. ft. and utility spending but that each building is unique and that it varies.

<Transcription shared: 5/29/2013>

<Transcription reviewed by SME: 6/3/2013>

APPENDIX D

INTERVIEW TRANSCRIPTION: SME #4

Doctor of Philosophy Dissertation

Developing a procedure for improving the uncertainty in energy service projects

Interview Respondent: SME#4

Interview Date: May 23, 2013

Interview Time: 8:45 am – 9:50 am CST

Interview Contact Number: -

Interview Location: -

Interview Questions

Thanked the SME for participating in the interview. Reiterated the purpose of the study and asked if the SME had any questions before starting the interview.

Part I: Retrofit Selection Process for Energy Service Performance Contracts (ESPCs)

1) How do you identify and approach potential customers?

Need to understand the difference between an ESCO and regular firms.

ESCO's go into the facility (typically a set of buildings), go through them, and tell the client what the problem is. They bring in the financing, the savings, measurement and prediction of savings. They typically provide the guarantee.

ESCOs are moving from stipulated savings to measurement based savings calculations. The savings are used to purchase equipment for the facility. Facility personnel need to select ESCOs who provide measurement based savings and it's also recommended that a third party either provide the measurement and verification or at least review the measurement and verification provided by the ESCO.

2) What is the basic process once a potential customer is identified?

Respond to RFQ → Quick walk-through audit → Detailed audit

Government projects typically require responding to the RFQ before a detailed audit. A Quick walk-through audit will consist of a day or two with a sales engineer to determine if this building has potentials and look for general opportunities.

A detailed audit will also require conducting the audit with their technical people (typically their own) to calculate the predicted savings from identified ECM.

Part II: Identifying and Quantifying Retrofits

3) How do you identify retrofits?

Retrofits are identified during the detailed energy audit process. The technical people assess how the building is operating as efficiently as they can. They look at:

- The quality of operation
- Which equipment needs to be replaced?
- Ask how much savings will this produce?

They put together a bid for the client afterwards.

4) How do you calculate the savings from the retrofits?

There are multiple ways to calculate the predicted savings.

- Stipulated
- Holistic method of calculation
- Customized Spreadsheet
- Energy Calculation using energy simulation (most likely DOE-2, eQUEST, EnergyPlus): With skilled engineers the ESCOs will probably do a good job of predicting savings

In any case, measurement should be part of the contract.

5) Do you perform actual measurement?

Measurement and Verification (M&V) is a complex and difficult process to reliably calculate the actual savings from a building or facility. Several issues exist, including:

a) Stipulated savings: Although the use of measurement based M&V is increasing, instances still occur where the savings are stipulated. When the savings are stipulated, the savings have been contractually pre-agreed to for the life of the contract. Stipulated savings are not recommended since this method pre-establishes the level of savings before the improvements are started.

b) Baseline adjustment: When measurements are used, this involves changes that the building personnel make to the operation of the building that change the energy use. It is generally recommended to hire a third independent party which has skills and experience in M&V to perform these tasks.

Final Comments

6) Do you have anything else that you would like to share that may be pertinent for this study which is to improve the current method of selecting and quantifying energy service projects?

- It is important to note that ESCO's objectives and the client's objectives can be contradictory which creates challenges in balancing what level or risk the two groups share.
- Consider the uncertainties in savings. Think of a 10-15% total error with savings of the same magnitude. How should this be reported? Rather than promising the pre-determined level of savings based on stipulation, try to do the best in quantifying and measure and report how much saving is being realized.
- One common error in predicting energy saving is that some do not consider the breakdown of total energy consumption for a facility. For example, both parties should understand the % of cooling vs. heating vs. lighting etc. for the total energy consumption. If cooling only consists of 25% of the total energy consumption, does it make sense when the analysis shows up to 30% of energy savings for implementing a retrofit that could potentially reduce cooling energy consumption?

<Transcription shared: 5/29/2013>

<Transcription reviewed by SME: 5/30, 5/31/2013>

APPENDIX E

INTERVIEW TRANSCRIPTION: SME #5

Doctor of Philosophy Dissertation

Developing a procedure for improving the uncertainty in energy service projects

Interview Respondent: SME#5

Interview Date: May 30, 2013

Interview Time: 3:10 pm – 3:58 pm CST

Interview Contact Number: -

Interview Location: -

Interview Questions

Thanked the SME for participating in the interview. Reiterated the purpose of the study and asked if the SME had any questions before starting the interview.

Part I: Retrofit Selection Process for Energy Service Performance Contracts (ESPCs)

1) How do you identify and approach potential customers?

SME is not in the business of installing retrofits. SME has worked on contracts to evaluate savings from ESCOs. Typically clients approach the SME. They are typically building owners, government or industrial organizations that write protocols and guidelines for savings.

As far as ESCOs, the SME indicated that ESCOs reply to proposals (e.g. respond to proposals that are typically announced by utility companies, state/federal government)

2) What is the basic process once a potential customer is identified?

For example, the SME was responsible for an on-going energy management for a federal facility.

This work involved conducting an independent work to verify whether:

(1) Is the savings reasonable?

(2) Do savings actually occur?

This work involved very little interaction with ESCOs with desk studies and work that was primarily accomplished with metered data.

This analysis would be presented to the manager. Sometime ESCO's participated in those meetings. To some extent this was beneficial since ESCO's could point to why certain results were found during the analysis.

Fifty to 75% of buildings the SME was involved with did not have data and looked at calculated savings. SME believed that having an independent party evaluate the savings improved the quality of the on-going energy management.

Part II: Identifying and Quantifying Retrofits

3) How do you identify retrofits?

The SME indicated that ESCOs will most likely be interested in the following issues when identifying retrofits:

- Payment arrangement: When do ESCOs get paid?
- Data collection: How much data needs to be gathered?

Identifying good candidates is important. Equally important is understanding that time is money.

Payment arrangement: Understanding when ESCO's get paid can have an impact on the type of retrofits that can be identified. Will the payment occur during specific time period with specific reports or be paid through savings? For Time and Material (T&M) base, the ESCO will typically take a gross look at the building. This includes identifying the following items:

- Total energy use and demand
- Investigate interior environmental conditions (temperature, lighting level)

The intent is to identify if there is a problem with the building. The specific retrofits are not identified at this point. Retrofits may be identifiable as the ESCO progress and get more familiar with the building and into the building. Common retrofits identified early in the process may include:

- Controls
- Inefficient windows
- Better sensors

The general practice is to identify these types of retrofits long before replacing equipment. The idea is to use existing equipment but this may also be challenging since there is always something broken found during the audit process.

Data collection: Having computerized data can lead to identifying new retrofits.

The best building to work on is a big, brand new, complex building with advanced computer systems. The worst building to work on is a building that has no control, no data and no maintenance done for the last 20-30 years.

In summary, for ESCOs it is important to quantify the retrofit savings as quickly as possible with as less resources.

4) How do you calculate the savings from the retrofits?

The word "savings" has a very loose definition. In some cases, the salary savings of an operator can be claimed as "savings" when an automatic control is installed.

There should be care taken in measuring existing conditions as well. In summary, there is need for firm definition of savings in the contract.

Regarding lighting retrofits:

Lighting retrofits are very predictable but can be easily manipulated. Qualified ESCOs will not manipulate the schedule or the foot-candle.

Quantifying the lighting retrofits will require installing a lighting logger and look at fixtures and lamps to identify the hours being used and the level of lighting. The amount of data that needs to be collected from a lighting logger will depend on the facility use. Although the optimum is to collect 1 years' worth of data this is in many times not practice. At the minimum, the logger should collect 1 weeks' worth of data that has both the weekday and weekend use. This would be applicable for an office type building. For schools, this may differ. For schools the ESCO's need to identify the different schedules for in-session period, break period and so forth.

For large buildings the following items should be considered:

- Verify the nameplate data of the equipment
- Take a few days to conduct walk-through audits
- Have a knowledgeable person conduct the audits
- Make sure individuals have access to the equipment

Depending on when the auditor visits the building, certain retrofits may not be identifiable because it is in the wrong season. Again, this is why a years' worth of data collection period is necessary to identify all potential retrofits. However, the industry has forced ESCOs to develop quick analysis and reports of possible retrofits making this impossible. In turn, many ESCOs have involuntarily resorted to non-weather dependent retrofits.

Savings can be calculated with measured data (which includes monthly or irregular monthly data). Average daily monthly consumption vs. coincident weather data are used to derive the parameters. ASHRAE Guideline 14 also provides a method to determine savings using regression (with pre-retrofit and post-retrofit data). This requires (1) coincident weather data, (2) 12 months minimum consumption data for equal coverage over the independent variable (IV), and (3) reporting the uncertainties in savings.

Most time try to do this without simulations. In case where this is not possible then the simulation will be used. Simulations can take weeks or even months to develop. Need to collect all of the data for the components. It can get expensive to build an accurate model. If sensors are used to collect data for calibration then need to understand who put the sensors and who calibrated the model as well. Typically perform a whole building energy simulation when it is required. Hence, it is recommended but difficult to do.

Suspect that many ESPCs will adopt a prototypical building simulation which are uncalibrated to the actual building. If they try to pin this to the building, these might be a pretty good tool to use.

Regarding demand savings, there is no consensus on calculating this value. This can be difficult and perhaps hard to reproduce. Most ESPCs do include demand savings. For lighting, can conduct blink test to determine the demand saving. Can use the top down approach of calculating the demand savings by using a 3 phase meter that can be clamped on to collect real field measurement. However, this still takes time and money to do all this.

5) Do you perform actual measurement?

Yes. For buildings, start at the building meter. Try to sub-meter if possible. Collect 9-12 months of hourly data on large piece of equipment. Start this effort in the plant, transformer and lighting.

For an office it would still cost about \$25,000 - \$50,000 for installing permanent metering devices. This includes measuring hourly whole building electric (WBE), gas, chilled water and hot water. For 3 phase system need at least a double and triple sensors.

Weather station will cost about \$10,000 for installation and more to collect and analyze data.

For lighting retrofits, running a blink test will probably be the cheapest. Need light loggers and name plate the lights, and collect samples of lighting measurement. How often you do perform the M&V is still hotly debated. The answer is probably somewhere in between measuring once to continuously monitoring this.

Final Comments

6) Do you have anything else that you would like to share that may be pertinent for this study which is to improve the current method of selecting and quantifying energy service projects?

- Be aware of what the Environmental Defense Fund is doing with City of NY to upgrade 100 million SF of space
- State of California has significant requirements on M&V procedures
- What is ASHRAE doing with M&V protocols. MTG BPM meets every 6 months and is still evaluating and improving the M&V protocol
- Investigate NAESCO and AEE. There is also a certification process for people
- EnergyPlus is becoming yet more complicated to use

<Transcription shared: 6/6/2013> <Transcription reviewed by SME: 6/13/2013>

APPENDIX F

INTERVIEW TRANSCRIPTION: SME #6

Doctor of Philosophy Dissertation

Developing a procedure for improving the uncertainty in energy service projects

Interview Respondent: SME #6

Interview Date: June 4, 2013

Interview Time: 11:30 am – 12:20 am CST

Interview Contact Number: -

Interview Location: Wisenbaker Engineering Research Center Rm 214-A

Interview Questions

Thanked the SME for participating in the interview. Reiterated the purpose of the study and asked if the SME had any questions before starting the interview.

Part I: Retrofit Selection Process for Energy Service Performance Contracts (ESPCs)

1) How do you identify and approach potential customers?

SME is not an ESCO but do provided services in the following areas:

1. Turn-key retrofit services - typically perform smaller scale project than an ESCO, most work focus on HVAC and Lighting. Project size range from \$100-500 thousand dollars.
2. Retro commissioning services
3. Energy audits
4. M&V consulting services to demonstrate energy savings

Potential customers are utility providers and 3rd party (energy-efficiency implementation) programs. These include:

1. Hospital
2. Retail
3. High Tech
4. Hospitality

Within sector they all have differing operating characteristics. Need to understand the constraints, requirements and how they operate to be successful. The company can tailor the offer based on these varying characteristics.

ESCOs typically focus on a much more comprehensive project. Large ESCOs typically work on projects that are over 10 million dollars. Their main customers are large owners in the MUSH market.

2) What is the basic process once a potential customer is identified?

Conduct site walk-through to identify potential retrofits – Send senior level engineer to do this.

More specifically, request utility bill, arrange a quick tour of the facility, and arrange a meeting. This may be different from an ESCO since the work is pre-arranged by the supporting efficiency program. ESCOs typically approach the owner and engage the owner to do a performance contract. This requires a longer cycle for sales and marketing period. In many instances, the process would involve a large scale presentation followed by a detailed audit for the construction work to proceed. Detail audits can range from \$20-100 thousand. Will consider utility incentives.

What kind of data is collected at which point of the process.

Regarding data, do have a toolbox that assist the project manager identify promising retrofits. The toolbox includes (in general) collecting information regarding the following items:

- Comprehensive control data (may be separate for lighting)
- Type of central system (air cooled vs. water cooled)
- Building vintage (newer technology may be more efficient)
- Operating characteristics of the building
- Level of documentation
- Monthly utility bills
- Short time interval data

The company has an internally developed tools for collecting and formulating weather data. The key point during this process is to have an experienced person identify potential saving opportunities that exist even in smaller buildings.

Part II: Identifying and Quantifying Retrofits

3) How do you identify retrofits?

After the agreement is signed, start with the commissioning efforts.

Need to start with collecting data to identify retrofits. The company has capabilities to analyze control system trends and install data loggers to conduct functional tests. Data analysis includes investigating the following components:

- Temperature set points
- AHU Air flows
- Chilled or hot water system water flows
- Equipment status (on/off)
- Chiller loading
- Cooling tower cycling

Typical process is as follows:

Familiarize with the project in the office → Spend a day at the site (install loggers, collect site data such as condition of the facility and operational characteristics of the building, cross check drawings to the actual condition) → Set up trends (typically 2 weeks or more) → Collect the data loggers and document the analysis

One thing to note is that it is important to engage the operational engineer and owner before conducting a full blown audit.

How is the payment arranged?

Payment is mostly time and material (T&M) based. For some of the 3rd party programs, they could be performance based. Work with a payment schedule where some of the cost is paid in advance but eventually paid through savings. Before the work has been approximately 50/50 between T&M based and performance based. However, do see a little more T&M these days.

4) How do you calculate the savings from the retrofits?

For lighting retrofits, these can easily be quantified using the stipulated savings methodology. Lighting controls can be more difficult. Lighting control retrofit refers to installing occupancy sensors (OS), daylight harvesting and installing dimming controls. For lighting control retrofits, need to make assumptions. In addition, need to collect pre and post measurements that are long enough to go through a season.

In case multiple lighting/lighting control retrofits are implemented, it will be easier to set up a schedule to look at individual components separately. For example, collecting data regarding OC only, then daylight harvesting only and then dimming only makes it easier to track the data.

Again some of the issues with M&V is that the project has to be large enough to warrant all of the M&V. Utilities have come up with a lighting tables for that reason. However, there is nothing equivalent for lighting control strategies. One of the energy efficiency technology demonstration project this firm is performing is related to this topic.

Do you use simulations to calculate the savings from retrofits?

Simulations are not typically used. Calibrating the model is difficult and can be too costly. This is probably the last resort.

Have used simulation parametrically. Used prototypical building simulations augmented with site audit work.

5) Do you perform actual measurement?

Use data to develop the savings. Then take the same data to justify the savings. Typically look at it from the whole building perspective. Do use sub-meter data if it exists.

Occupancy can be harder to track. There are logger packages that can track occupancy but would need to install one wherever there is an OS.

Do perform measurement for before and after implementation but do not engage in long term contracts. The company advises on how to operate the system and how to maintain the system.

Final Comments

6) Do you have anything else that you would like to share that may be pertinent for this study which is to improve the current method of selecting and quantifying energy service projects?

There are advancements in this industry that should be carefully considered. Wireless control and wireless monitoring is an example. Calculating the savings before and after the retrofit implementation is a cumbersome process but nevertheless mandated by regulatory agencies. However, this process is not sustained by people that are actually managing the buildings. Better alignment need to exist between the governing agencies and building operators. This can be achieved by advancement in smart buildings to streamline the process of conserving the building and long term M&V approaches.

<Shared transcription: 6/11/13>

<Transcription reviewed by SME: 6/12/13>

APPENDIX G

ANALYSIS OF INTERVIEW QUESTION #1

The first interview question asked how the experts identify and approach potential customers. The first step to analyzing this question involved extracting segments of the finalized transcription text that identified certain sectors as their target client. Next, any reasons or justifications for targeting these sectors were extracted and further investigated.

Table 54 summarizes what was found and bracketed in the transcription. Important key words were then bolded in the table for further reduction.

Table 54. Insert Bracket in Transcription

| | |
|-------|---|
| Q # 1 | <p>How do you identify and approach potential customers?</p> <ul style="list-style-type: none"> • Different sectors or organizations • Reasons why these groups/ organizations are targeted |
| SME 1 | <ul style="list-style-type: none"> • State Utilities that run energy service programs with an already established relationship (public clients) • Government entities have a 10 year payback period as opposed to public clients who have a shorter payback period (typically 5 years) |
| SME 2 | <ul style="list-style-type: none"> • Public sector with some private (non-profit) sector, federal government and the municipal and state governments, universities and colleges, K-12 schools, and hospitals (MUSH market) • Build networks one at the time, experience and network important to gather intelligence on facilities • All federal and MUSH projects go through a competitive process • Private sector has a more sophisticated financial management system and also more flexibility • Significant amount of effort on putting together a bid package |
| SME 3 | <ul style="list-style-type: none"> • Group of potential clients (i.e., municipal, some K-12 and some higher educational facilities) • Previously worked with the group or are currently working with the group, Building trust and relationship is important. • Clients with aging facilities are a good target • In some cases the client approaches the ESCOs |
| SME 4 | <ul style="list-style-type: none"> • ESCO's go into the facility (typically a set of buildings), go through them, and tell the client what the problem is |
| SME 5 | <ul style="list-style-type: none"> • Clients approach the SME, building owners, government or industrial organizations that write protocols and guidelines for savings • ESCOs apply to proposals (e.g. respond to proposals that are typically announced by utility companies, state/federal government) |
| SME 6 | <ul style="list-style-type: none"> • Utility providers and 3rd party (energy-efficiency implementation) programs. |

| | |
|-------|--|
| Q # 1 | How do you identify and approach potential customers? <ul style="list-style-type: none"> • Different sectors or organizations • Reasons why these groups/ organizations are targeted |
| | <ul style="list-style-type: none"> • ESCOs typically focus on a much more comprehensive project. Large ESCOs typically work on projects that are over 10 million dollars. Their main customers are large owners in the MUSH market. |

The benefit of extracting key words and descriptive codes into a single table was that this allowed the researcher to quickly identify patterns and visually identify reoccurring texts. Table 55 represents only the key words that were bolded and extracted from Table 54.

Table 55. Extract Keywords from the Transcription

| | |
|-------|---|
| Q # 1 | How do you identify and approach potential customers? |
| SME 1 | <ul style="list-style-type: none"> • State Utilities • Established relationship (public clients) • 10 year payback period |
| SME 2 | <ul style="list-style-type: none"> • Public, non-profit, federal government, MUSH market • Build networks, experience, network, gather intelligence • Competitive process • Private sector = sophisticated financial management system, flexibility • Effort |
| SME 3 | <ul style="list-style-type: none"> • Group, municipal, K-12, higher educational • Previously worked, currently working • Building trust and relationship • Aging facilities • Client approaches |
| SME 4 | <ul style="list-style-type: none"> • ESCO's initiate the effort |
| SME 5 | <ul style="list-style-type: none"> • Clients approach • owners, government or industrial organizations • ESCOs apply • utility companies, state/federal government |
| SME 6 | <ul style="list-style-type: none"> • Utility providers and 3rd party programs. • Over 10 million dollars • MUSH market. |

Once the keywords were identified, these words were sub-divided into themes. The themes for the interview Question 1 included potential clients, approaches, reasons, and process.

The keywords were then regrouped and organized into the appropriate category of columns based on these four available themes. Themes were chosen by the researcher and evolved during the winning process. Table 56 shows the themes and keywords organized into the appropriate theme in the columns.

Table 56. Identify Themes

| Q # 1 | Potential Clients (Code: C) | Approaches (Code: A) | Reasons (Code: R) | Process (Code: P) |
|--------------|--|--|--|------------------------------------|
| SME 1 | State utilities Public clients | Established relationship | 10 year payback period | |
| SME 2 | Public Private: non-profit Federal government MUSH market | Build networks Experience Network Gather intelligence | Private sector = sophisticated financial management system, flexibility | Competitive process |
| SME 3 | Municipal K-12 Higher educational Aging facilities | Previously worked, currently working Building trust and relationship | | Client approaches |
| SME 4 | | | | ESCO's initiate the effort |
| SME 5 | Owners Industrial org. Utility companies State/Federal Gov. | | | Clients approach ESCOs apply |
| SME 6 | Utility providers 3 rd party programs MUSH market | | Over 10 million dollars | |

Based on what was identified from this table, a list of codes were developed to further simplify the visual representation and to allow the researcher to scan the data. The codes used for the first question were mostly substantive codes which were related to and pertained to the interview content itself (Harrell 2009). Table 57 shows the codes that were generated to identify and to tag the keywords from the transcription. This code tree was developed to assist with cataloguing the information and to transition from descriptive coding to interpretative coding. Progressing from descriptive coding to interpretive coding allowed for encapsulating similar motifs into a common theme for this particular interview question. For example, building

relationship, having previous experience working with the group, building a network of clients and gathering intelligence on buildings were all categorized as building a positive relationship (code A1). Once the codes were generated, each cell in Table 56 was transformed by tagging the text with the appropriate code. The results in a matrix format is shown in Table 58.

Table 57. Code Tree for Interview Question #1

| Code Type | Code Description | |
|-----------|-------------------|---|
| C | Potential Clients | C1. Public and institutional sector C1.1 K-12 schools C1.2 State/local government C1.3 Federal government C1.4 Universities/colleges C1.5 Health/hospitals C2. Private sector (non-profit sector) |
| A | Approaches | A1. Build positive relationships – build trust, previous experience, network, gather intelligence |
| R | Reasons | R1. Length of payback period – 10 years R2. Availability of financing - not available R3. Size of the project – 10 Million or greater R4. Age of facility – Aging infrastructure |
| P | Process | P1. Competitive process – initiate, effort P2. Clients approach |

Table 58. Converting the Code Table into a Matrix Table

| S M E | C | | | | | | A | R | | | | P | |
|-------------|-----|-----|-----|-----|-----|----|----|----|----|----|----|----|----|
| | C1 | | | | | C2 | A1 | R1 | R2 | R3 | R4 | P1 | P2 |
| | 1.1 | 1.2 | 1.3 | 1.4 | 1.5 | | | | | | | | |
| 1 | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | | | | | |
| 2 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | | | ✓ | |
| 3 | ✓ | ✓ | | ✓ | | | ✓ | | | | ✓ | | ✓ |
| 4 | | | | | | | | | | | | ✓ | |
| 5 | | ✓ | ✓ | | | | | | | | | ✓ | ✓ |
| 6 | ✓ | ✓ | | ✓ | ✓ | | | | | ✓ | | | |

APPENDIX H

ANALYSIS OF INTERVIEW QUESTION #2

Extract highlighted text from each of the transcriptions for question #2

| | |
|-------|--|
| Q # 2 | <p>What is the basic process once a potential customer is identified?</p> <ul style="list-style-type: none"> • List of activities • List of information sought at each step of the process • Activities not considered during this process |
| SME 1 | <p>Identify Need → Scope Visit → Develop General Contract → Full Audit</p> <ul style="list-style-type: none"> • Understanding their needs (capital retrofits) i.e. “what they want to do” is a good place to investigate first and perhaps most beneficial • Retrofits that pay include: Controls, mechanical upgrades, lighting (Visible to everyone and typically the first thing that gets identified), ventilations, VFD for fans/pumps • ASHRAE Level II audit • Before the site visit: Utility bills, identify energy cost, identify rate of return required for the customer • During the site visit: checklist but rely on experienced auditors to identify ECMs. Best ECMs are unique to the building and one cannot just rely on a checklist. |
| SME 2 | <p>Prospecting → Benchmarking → Walk-through Audit → Submit and Select Proposal → Make Presentation → Make a decision → Conduct Investment Grade Audit</p> <ul style="list-style-type: none"> • Prospecting: Age of the building, condition of building, financial situation / identify any potential obstacles, KW density, energy density (not utility bills yet during this stage) • Benchmarking: CBECS and compare to historical database • Walk-through audit: rough scope and pricing (+/- 20% at proposal stage, for lighting retrofits, these would include doing spot checks • Conduct Investment Grade Audit: For lighting retrofits, checking 95%+ or more of the existing fixtures in the building. Will pop ceilings to verify lamp type and ballast type. Key is to identify what exists and also obtain the operating hours. Baseline is established by spot measurement of lighting fixture power. Conduct short term monitoring and determine lighting fixture run time and occupancy of the space. |
| SME 3 | <p>Initial Meeting → Preliminary Energy Audit → Post-audit Meeting → Submit RFQ → Submit “Letter of Intent” → Conduct Investment Grade Audit</p> <ul style="list-style-type: none"> • Initial Meeting: Size of the facility, square foot, Owner’s initiatives, consumption: water / gas, discuss performance contracting with client. Will adapt or tailor to fit the client’s need • Preliminary Energy Audit: Try to obtain the site plan and possible floor |

| | |
|-------|---|
| | <p>plan before conducting the preliminary energy audit. This requires a quick turn-around period. If the building has control systems, try to identify any controls issues (look at graphics, any problem spots, and pull screen shots before the preliminary energy audit). No intensive data collection period though since limited in time and budget. Recommendation is to have an efficient data collection plan before setting foot in the building. Typically do not send in new engineers out in the field to do this. More experienced engineers with 10+ years and with several performance contracting experience are sent to do this work.</p> <ul style="list-style-type: none"> • Do a walk through and do spot checks. If this is a portfolio of projects, look at typical facilities. Consider the following items: Utility bill, Data: drawings, capital asset plans (No hard savings. These figures are very high number budgets. For example, will tell clients they will save 20% of the current energy use. Do not have equipment data at this point. Did not specify any specific guideline but determination of what may be effective for this specific project.) • Conduct Detailed Audit: A lot of time and resources are spent on the detailed audit. For a campus that is 3-10 million sq. ft. the audit may take 4-6 months to develop. For an office building about 125,000 sq. ft. and 10 stories high, the audit will likely take about 1 ½ to 2 months to generate because it will require looking at every light (count lighting) and equipment in the building to understand what's going to be optimal. Also investigate rebates that may be feasible from Utility providers, etc. |
| SME 4 | <p>Respond to RFQ → Quick walk-through audit → Detailed audit</p> <ul style="list-style-type: none"> • A Quick walk-through audit will consist of a day or two with a sales engineer to determine if this building has potentials and look for general opportunities. • A detailed audit will also require conducting the audit with their technical people (typically their own) to calculate the predicted savings from identified ECM. |
| SME 5 | <p>SME was responsible for an on-going energy management for a federal facility. This work involved conducting an independent work to verify whether:</p> <p>(1) Is the savings reasonable?</p> <p>(2) Do savings actually occur?</p> <p>This work involved very little interaction with ESCOs with desk studies and work that was primarily accomplished with metered data.</p> <p>This analysis would be presented to the manager. Sometime ESCO's participated in those meetings. To some extent this was beneficial since ESCO's could point to why certain results were found during the analysis.</p> <p>Fifty to 75% of building the SME has been involved with did not have data and looked at calculated savings. SME believed that having an independent party evaluate the savings improved the quality of the on-going energy management.</p> |

| | |
|-------|--|
| SME 6 | <p>Conduct site walk-through to identify potential retrofits – Send senior level engineer to do this.</p> <ul style="list-style-type: none"> • More specifically, request utility bill, arrange a quick tour of the facility, and arrange a meeting. • ESCOs typically approach the owner and engage the owner to do a performance contract. This requires a longer cycle for sales and marketing period. In many instances, the process would involve a large scale presentation followed by a detailed audit for the construction work to proceed. Detail audits can range from \$20-100 thousand. Will consider utility incentives. <p>Regarding data, do have a toolbox that assist the project manager identify promising retrofits. The toolbox includes (in general) collecting information regarding the following items:</p> <ul style="list-style-type: none"> • Comprehensive control data (may be separate for lighting) • Type of central system (air cooled vs. water cooled) • Building vintage (newer technology may be more efficient) • Operating characteristics of the building • Level of documentation • Monthly utility bills • Short term interval data <p>The company has an internally developed tools for collecting and formulating weather data. The key point during this process is to have an experienced person identify potential saving opportunities that exist even in smaller buildings.</p> |
|-------|--|

ESCO's General Business Process

| Q # 2 | Seeking for Potential | Quick Confirmation | Financial Arrangement | Full Investigation |
|-------|---------------------------|----------------------------|---|--------------------------------|
| SME 1 | Identify Need | Scope Visit | Develop General Contract | Full Audit |
| SME 2 | Prospecting, Benchmarking | Walk-through Audit | Submit, make presentation, decision | Conduct Investment Audit |
| SME 3 | Initial Meeting | Preliminary Energy Audit | Post-audit meeting, submit RFQ, submit "Letter of Intent" | Conduct Investment Grade Audit |
| SME 4 | Respond to RFQ | Quick Walk-through Audit | | Detailed Audit |
| SME 6 | Request Utility Bill | Quick tour of the facility | Arrange a meeting | |

Data Collected at Various Stages of the Project Development Phase

| Q #2 | Seeking for Potential | Quick Confirmation | Financial Arrangement | Full Investigation |
|------|--|---|-----------------------|---|
| 1 | Utility bills, Cost, Rate of return | | | |
| 2 | Age, Condition, Financial situation, Potential obstacles, KW density, Energy density, CBECS, Historical database | | | |
| 3 | Size, Initiatives, Consumption, Performance contracting | Site plan , Floor plan, Identify controls issues, Utility bill, Drawings, Capital asset plans | | Count light & equipment, Rebates from Utility providers |
| 6 | Toolbox: Comprehensive control data, Type of central system, Building vintage, Operating characteristics, Level of documentation, Monthly utility bills, Short term interval data, Internally developed tools for collecting and formulating weather data | | | |

Code tree for question #2

| Code | Code Description | |
|------|------------------|---|
| D | Data | D1. Usage: utility bill, KW density, energy density, consumption, operating characteristics D2. Financial: cost, rate of return, financial situation, performance contracting D3. Internal database or reference: CBECS, historical database, internally developed tools D4. Documentation: site plan, floor plans, drawings, level of documentation D5. Building characteristics: vintage, size, central system D6. Initiative: capital asset plans D7. Risk: potential obstacles D8: Operational characteristics: control issues, comprehensive control data, short term interval data |

Matrix for question #2

| | D | | | | | | | |
|-----|----------|--------------|----------------------|--------------|-------------------|---------------|---------|----------------|
| SME | D1 Usage | D2 Financial | D3 Internal Database | D4 Document. | D5 Bldg. Charact. | D6 Initiative | D7 Risk | D8 Op Charact. |
| 1 | ✓ | ✓ | | | | | | |
| 2 | ✓ | ✓ | ✓ | | ✓ | | ✓ | ✓ |
| 3 | ✓ | ✓ | | ✓ | ✓ | ✓ | | ✓ |
| 6 | ✓ | | ✓ | ✓ | ✓ | | | ✓ |

APPENDIX I

ANALYSIS OF INTERVIEW QUESTION #3

Extract highlighted text from each of the transcriptions for question #3

| | |
|--------------|--|
| Q # 3 | <p>How do you identify retrofits?</p> <ul style="list-style-type: none"> • Pre-determined list • Information required to identify the retrofits • Resources required to identify the retrofits |
| SME 1 | <p>Available spreadsheets experienced people Start with the problems For central plants: efficiency See how the controls are set up Consider staging Understanding how the systems works</p> |
| SME 2 | <p>predetermined list of ECMs sometimes limited to this:</p> <ul style="list-style-type: none"> • Allows customer to evaluate using common scope of work • Constrains their effort <p>Also look at:</p> <ul style="list-style-type: none"> • Existing systems • Discuss with the building operators • Existing conditions <p>Lighting: Existing fixtures each have a code type. Depending on the code type there is a set of available ECMs. Do see more and more opportunities in water conservation technology.</p> |
| SME 3 | <p>Problem area → Lighting → Water use → Automations (building and plant side) → Automations (HVAC water side)</p> <ol style="list-style-type: none"> 1. Focus on problems first 2. Lighting is a big component 3. Water consumption 4. Automations are good candidate projects. 5. Operational savings by replacement of equipment? 6. Look at cooling towers, chiller plant. |
| SME 4 | <p>Identified during the detailed energy audit process. The look at:</p> <ul style="list-style-type: none"> • The quality of operation • Which equipment needs to be replaced? • Ask how much savings will this produce? |
| SME 5 | <ul style="list-style-type: none"> • Payment arrangement: When do ESCOs get paid? • Data collection: How much data needs to be gathered <p>When ESCO's get paid can have an impact on the type of retrofits that can be identified. This includes identifying the following items:</p> |

| | |
|-------|--|
| | <ul style="list-style-type: none"> • Total energy use and demand • Investigate interior environmental conditions (temperature, lighting level) <p>The intent is to identify if there is a problem with the building. Common retrofits identified early in the process may include:</p> <ul style="list-style-type: none"> • Controls • Inefficient windows • Better sensors <p>identify these types of retrofits long before replacing equipment</p> |
| SME 6 | <p>Start with the commissioning efforts. Analyze control system trends and install data loggers to conduct functional tests. Data analysis includes investigating the following components:</p> <ul style="list-style-type: none"> • Temperature set points • AHU Air flows • Chilled or hot water system water flows • Equipment status (on/off) • Chiller loading • Cooling tower cycling <p>Typical process is as follows: Familiarize with the project in the office → Spend a day at the site (install loggers, collect site data such as condition of the facility and operational characteristics of the building, cross check drawings to the actual condition) → Set up trends (typically 2 weeks or more) → Collect the data loggers and document the analysis Important to engage the operational engineer and owner before conducting a full blown audit.</p> |

Table 59. Generic Process of Identifying Retrofits

| | |
|--------------|---|
| Q # 3 | How do you identify retrofits? |
| SME 1 | Problems → Check efficiency → Investigate controls → Understand overall system operations |
| SME 2 | Existing systems and conditions → Discuss with the building operators |
| SME 3 | Problem area |
| SME 4 | Quality of existing operation → Equipment replacement? → Savings? |
| SME 5 | Problem → total energy use and demand → Investigate interior environmental conditions |
| SME 6 | Familiarize → Site (condition and operational characteristics) → Set up trends → Analysis |

APPENDIX J

ANALYSIS OF INTERVIEW QUESTION #4

Extract highlighted text from each of the transcriptions for question #4

| | |
|--------------|---|
| Q # 4 | <p>How do you calculate the savings from the retrofits?</p> <ul style="list-style-type: none"> • List of methods • Specific guideline or standards • Use or adaption of building simulation • Information and parameters required to constructing a building simulation • Advantages and disadvantages of using building simulation approach • Parameters/guidelines used to quantify the savings from lighting and lighting control retrofits |
| SME 1 | <p>Spreadsheets: refined based on experience Based on previous performance data and actual measurement Calculations based on experience Quantify the variables involved</p> <p>Lighting: Typically use spreadsheets and calculations. Do take measurements before and after.</p> <ul style="list-style-type: none"> • Energy use if existing lights: obtain specifications for lamps and ballast • Measure spark reading of electric circuits for instantaneous power • Measure run time with light loggers, 3 weeks measurement with battery operated light logger • Measure on/off, 3 weeks measurement for operating schedule • For dimming capabilities, measure power (check in the field) and look at the specification sheet <p>Simulations are used when complex ECMs are involved or especially when replacing the whole mechanical plants. Use eQUEST program. Need to collect all of the information related to building the simulation model. These include:</p> <ul style="list-style-type: none"> • Full set of blue print • Energy bills (match the monthly energy bills) • Investigate peak demand every month for the building • Calibrate the model using operating schedule (energy management system can help identify this) |
| SME 2 | <p>Use engineering calculation. Past performance is compared to determine how much of the utility bill can be saved. Each ECM has a specific M&V protocol</p> |

| | |
|-------|---|
| | <p>It depends. Simulations are typically used for large buildings with complex air handling system or more sophisticated HVAC systems. Large buildings mean that they are typically over 100,000 sq. ft.</p> <p>Use eQUEST program: worked well.</p> <p>Switching to EnergyPlus takes too much of a learning curve.</p> <p>Collect name plate data & some measured data</p> <p>Challenge with monitoring measurement: time constraint on submitting the report to the client</p> <p>Physical constraint so occupancy data loggers may be installed as the preliminary walk-through audits are being performed.</p> |
| SME 3 | <p>Energy Coalition, SECO Guideline or Texas LoanSTAR</p> <p>Use DOE-2 program.</p> <p>ASHRAE's to build the model</p> <p>Simulations are used as needed</p> |
| SME 4 | <ul style="list-style-type: none"> • Stipulated • Holistic method of calculation • Customized Spreadsheet • Energy Calculation using energy simulation (most likely DOE-2, eQUEST, EnergyPlus): With skilled engineers the ESCOs will probably do a good job of predicting savings |
| SME 5 | <p>“savings” loose definition, salary savings of an operator claimed when an automatic control is installed</p> <p>Recommend firm definition of savings in the contract</p> <p>Installing a lighting logger and look at fixtures and lamps to identify the hours being used and the level of lighting.</p> <p>Optimum is to collect 1 years' worth of data this is in many times not practice, 1 weeks' worth of data that has both the weekday and weekend use at the minimum</p> <p>For large buildings the following items should be considered:</p> <ul style="list-style-type: none"> • Verify the nameplates of the equipment • Take a few days to conduct walk-through audits • Have a knowledgeable person conduct the audits • Make sure individuals have access to the equipment <p>Cannot identify retrofit because:</p> <ol style="list-style-type: none"> (1) Wrong season (2) Industry has forced ESCOs to develop quick analysis and reports of possible retrofits making this impossible. In turn, many ESCOs has involuntarily resorted to non-weather dependent retrofits. <p>Calculated with measured data (which includes monthly or irregular monthly data). Average daily monthly consumption vs. coincident weather data are used to derive the parameters. ASHRAE Guideline 14 also provides a method to determine savings using regression (with pre-retrofit and post-retrofit data). This requires (1) coincident weather data, (2) 12 months minimum consumption</p> |

| | |
|-------|---|
| | <p>data for equal coverage over the independent variable (IV), and (3) reporting the uncertainties in savings.</p> <p>Most time try to do this without simulations : weeks or even months to develop, expensive to build an accurate model</p> <p>Typically perform a whole building energy simulation So recommended but difficult to do.</p> <p>Suspect that many ESPCs will adopt a prototypical building simulation which are uncalibrated to the actual building. If they try to pin this to the building, these might be a pretty good tool to use.</p> <p>Demand savings: no consensus on calculating this value Difficult and perhaps hard to reproduce. Most ESPCs do include demand savings For lighting, can conduct blink test</p> |
| SME 6 | <p>Lighting quantified using the stipulated savings methodology.</p> <p>For lighting control retrofits, need to make assumptions. In addition, need to collect pre and post measurements that are long enough to go through a season.</p> <p>In case multiple lighting/lighting control retrofits are implemented, it will be easier to set up a schedule to look at individual components separately. For example, collecting data regarding OC only, then daylight harvesting only and then dimming only makes it easier to track the data.</p> <p>Project has to be large enough to warrant all of the M&V. Utilities have come up with a lighting tables for that reason. However, there is nothing equivalent for lighting control strategies. One of the energy efficiency technology demonstration project this firm is performing is related to this topic.</p> |

Methodologies to calculate savings

| | |
|--------------|---|
| Q # 4 | How do you calculate the savings from the retrofits? |
| SME 1 | <p>Modified Spreadsheets (M1)</p> <p>Previous performance data (M2)</p> <p>Actual measurement (M4)</p> <p>Calculations based on experience (M3)</p> |
| SME 2 | <p>Use engineering calculation (M3)</p> <p>Past performance (M2)</p> |
| SME 3 | <p>Energy Coalition</p> <p>SECO Guideline</p> <p>Texas LoanSTAR</p> |
| SME 4 | <p>Stipulated (M3)</p> <p>Holistic method of calculation (M2)</p> <p>Customized Spreadsheet (M1)</p> |

| | |
|-------|--|
| | Energy Calculation using energy simulation (M5) |
| SME 5 | Calculated with measured data (M4) ASHRAE Guideline 14, regression (M4) |
| SME 6 | Lighting quantified using the stipulated savings methodology (M3) Pre and post measurement (M4) |

Code tree for question #4

| Code | Code Description | |
|------|------------------|--|
| M | Method | M1. Spreadsheet (modified, customized) M2. Historical database (previous performance data, past performance, holistic method) M3. Engineering calculations (stipulated) M4. Measurement M5. Simulation |

Matrix table for question #4

| | M | | | | |
|----------|-------------------|-------------------------|-------------------|-------------------|------------------|
| SME/CODE | M1 Spreadsheet | M2 Hist. database | M3 Engr. Calc. | M4 Measurement | M5 Simulation |
| 1 | ✓ | ✓ | ✓ | ✓ | |
| 2 | | ✓ | ✓ | | |
| 4 | ✓ | ✓ | ✓ | | ✓ |
| 5 | | | | ✓ | |
| 6 | | | ✓ | ✓ | |

Use of simulation for calculating retrofit savings

| Q # 4 | Do you use simulation methods? |
|-------|--|
| SME 2 | <ul style="list-style-type: none"> Complex simulation program Physical constraint (such as time, industry demand quick analysis and report) |
| SME 5 | <ul style="list-style-type: none"> Definition in the Contract Physical constraint (such as time, access to equipment, audit in the wrong season, industry demand quick analysis and report) Knowledgeable person Unknown factors: demand savings with no consensus |
| SME 6 | <ul style="list-style-type: none"> Unknown factors: For lighting control retrofits, need to make assumptions. Physical constraint (such as time, money: project has to be large enough to warrant all of the M&V) |

APPENDIX K

ANALYSIS OF INTERVIEW QUESTION #5

Extract highlighted text from each of the transcriptions for question #5

| | |
|--------------|--|
| Q # 5 | <p>Do you perform actual measurement?</p> <ul style="list-style-type: none"> • Yes/No with conditional explanation • Actual measurement parameters pertaining to lighting/lighting control measurement |
| SME 1 | <p>Yes, see answer to question #4.</p> <p>This also depends on how the contract is signed.</p> <p>The options are:</p> <ul style="list-style-type: none"> • Multiyear measurement • Some do not perform measurement (stipulated savings in this case) • Measure the 1st year and maintain throughout the contract period |
| SME 2 | <p>Do perform measurement when aspects tend to be unique and uncommon at other locations.</p> <p>For lighting ECMs, do measure sample power and baseline occupancy schedule. Once it is installed do obtain a sample on new fixture (just power). Assume that the baseline occupancy and operating schedule is the same. Recommend 1 year M&V rather than multiple years for lighting.</p> |
| SME 3 | <p>For lighting:</p> <p>Loggers are used to determine on/off and occupancy (typically 1 week)</p> <p>Light level are measured during the audit as well and consider daylight harvesting options as well.</p> <p>Do perform pre and post measurement</p> |
| SME 4 | <p>M&V complex and difficult process to reliably calculate the actual savings</p> <p>a) Stipulated savings: the savings have been contractually pre-agreed to for the life of the contract. Stipulated savings are not recommended since this method pre-establishes the level of savings before the improvements are started.</p> <p>b) Baseline adjustment: generally recommended to hire a third independent party which has skills and experience in M&V to perform these tasks.</p> |
| SME 5 | <p>Yes. Building meter and sub-meter if possible.</p> <p>Collect 9-12 months of hourly data on large piece of equipment.</p> <p>Plant → transformer → lighting</p> |

| | |
|-------|--|
| | <p>For lighting retrofits, running a blink test will probably be the cheapest. Need light loggers and name plate the lights, and collect samples of lighting measurement</p> <p>In-between measuring once to continuously monitoring this.</p> |
| SME 6 | <p>Use data to develop the savings. Then take the same data to justify the savings. Typically look at it from the whole building perspective. Do use sub-meter data if it exists.</p> <p>Occupancy can be harder to track.</p> <p>Do perform measurement for before and after implementation but do not engage in long term contracts.</p> |

APPENDIX L

ANALYSIS OF INTERVIEW QUESTION #6

Step 1: Extract highlighted text from each of the transcriptions for question #6

| Q # 6 | |
|-------|--|
| SME 1 | <p>Focus on large projects rather than smaller pieces of retrofit projects to keep the cost in line</p> <p>Lighting is typically the first ECM that gets identified. Believes that there are still opportunities with the technology changing so fast</p> |
| SME 2 | |
| SME 3 | <p>Payback required is short and that both the client and company should realize quick savings to be successful.</p> <p>Each building is unique and that it varies.</p> |
| SME 4 | <p>ESCO's objectives and the client's objectives can be contradictory. Consider the uncertainties in savings. Try to do the best in quantifying and measure and report how much saving is being realized.</p> |
| SME 5 | <p>Be aware of what the Environmental Defense Fund is doing with City of NY to upgrade 100 million SF of space, State of California has significant requirements on M&V procedures, what is ASHRAE doing with M&V protocols.</p> <p>Investigate NAESCO and AEE. There is also a certification process for people.</p> <p>EnergyPlus is becoming yet more complicated to use.</p> |
| SME 6 | <p>There are advancements in this industry that should be carefully considered. Wireless control and wireless monitoring is an example.</p> <p>Better alignment need to exist between the governing agencies and building operators. This can be achieved by advancement in smart buildings to streamline the process of conserving the building and long term M&V approaches.</p> |

APPENDIX M
IRB FORM APPROVAL

DIVISION OF RESEARCH



Office of Research Compliance and Biosafety

APPROVAL DATE: 05/29/2013

MEMORANDUM

TO: Stuart D Anderson
TEES - College Of Engineering - Civil Engineering

FROM: Dr. James Fluckey
Chair
Institutional Review Board

SUBJECT: Initial Review Submission Form Approval

Protocol

Number: IRB2013-0309

Title: Developing a procedure for improving the uncertainty in energy service projects

Review Type: Expedite

Approved: **05/29/2013**

Continuing

Review Due: 04/15/2014

Expiration Date: 05/15/2014

Document of

Consent: Waiver approved under 45 CFR 46.117 (c) 1 or 2/ 21 CFR 56.109 (c)1

This research project has been approved. As principal investigator, you
assume the following responsibilities

1. **Continuing Review:** The protocol must be renewed by the expiration date in order to continue with the research project. A Continuing Review application along with required documents must be submitted by the

continuing review deadline. Failure to do so may result in processing delays, study termination, and/or loss of funding.

2. **Completion Report:** Upon completion of the research project (including data analysis and final written papers), a Completion Report must be submitted to the IRB.
3. **Unanticipated Problems and Adverse Events:** Unanticipated problems and adverse events must be reported to the IRB immediately.
4. **Reports of Potential Non-compliance:** Potential non-compliance, including deviations from protocol and violations, must be reported to the IRB office immediately.
5. **Amendments:** Changes to the protocol must be requested by submitting an Amendment to the IRB for review. The Amendment must be approved by the IRB before being implemented.
6. **Consent Forms:** When using a consent form or information sheet, you must use the IRB stamped approved version. Please log into iRIS to download your stamped approved version of the consenting instruments. If you are unable to locate the stamped version in iRIS, please contact the office.
7. **Audit:** Your protocol may be subject to audit by the Human Subjects Post Approval Monitor. During the life of the study please review and document study progress using the PI self-assessment found on the RCB website as a method of preparation for the potential audit. Investigators are responsible for maintaining complete and accurate study records and making them available for inspection. Investigators are encouraged to request a pre-initiation site visit with the Post Approval Monitor. These visits are designed to help ensure that all necessary documents are approved and in order prior to initiating the study and to help investigators maintain compliance.
8. **Recruitment:** All approved recruitment materials will be stamped electronically by the HSPP staff and available for download from iRIS. These IRB-stamped approved documents from iRIS must be used for recruitment. For materials that are distributed to potential participants electronically and for which you can only feasibly use the approved text rather than the stamped document, the study's IRB Protocol number, approval date, and expiration dates must be included in the following format: TAMU IRB#20XX- XXXX Approved: XX/XX/XXXX Expiration Date: XX/XX/XXXX.

The Office of Research Compliance and Biosafety is conducting a brief survey for the purpose of programmatic enhancements. Click here to take survey or copy and paste in a browser https://tamu.qualtrics.com/SE/?SID=SV_1CgOkLNU45QebvT

This electronic document provides notification of the review results by the Institutional Review Board.

APPENDIX N

INTERVIEW PROTOCOL

Doctor of Philosophy Dissertation

***Developing a procedure for improving the uncertainty in
energy service projects***
Interview Questions

Information for the Interviewee

Dear participant,

You are invited to be one of the subject matter experts selected to assist in providing input for current practice of quantifying energy service projects. The goal of this work is to conduct research to assist with improving the process of selecting energy service projects.

Interview responses from experts like you will greatly assist in collecting meaningful data.

To ensure confidentiality, all records will be kept private and no respondent identifiers will be included in the report. The interview takes approximately 35-45 minutes to complete. The interview will not be audio recorded but notes will be taken. These notes are measures to ensure that all necessary communications are recorded and transcribed accurately. These notes will remain confidential.

Your participation is voluntary. Refusal to participate will involve no penalty or loss of benefits. If you have any questions about the interview, please contact

me at (630)-670-7062 or email me at
ahimkim@tamu.edu.

Sincerely,

Amy Kim



Interview Questions

The interview is largely divided into two sections: Retrofit Selection Process for Energy Service Performance Contracts (ESPCs) and Identifying and Quantifying Retrofits.

Part I: Retrofit Selection Process for Energy Service Performance Contracts (ESPCs)

- 1) How do you identify and approach potential customers?
- 2) What is the basic process once a potential customer is identified?

Part II: Identifying and Quantifying Retrofits

- 3) How do you identify retrofits?
- 4) How do you calculate the savings from the retrofits?
- 5) Do you perform actual measurement?

Final Comments

- 6) Do you have anything else that you would like to share that may be pertinent for this study which is to improve the current method of selecting and quantifying energy service projects?

APPENDIX O

COOLING ENERGY USE IN THE JBC BUILDING

Regarding the daily chiller use, the sensor for the Chiller 1 was broken. The data points only reflected the total chiller use for Chiller 2. Since Chiller 1 and 2 can be partially be running on any given day, the low chiller use during a high temperature day was verified to be days when Chiller 1 was only partially running. The actual cooling energy use would be much higher since Chiller 2 would be in use. Thus, the data points that did not reflect the total daily chiller use was removed. Figure 53 and Figure 54 shows the daily measured CHW for Chiller 2 and a modified total daily measured CHW for the JBC building.

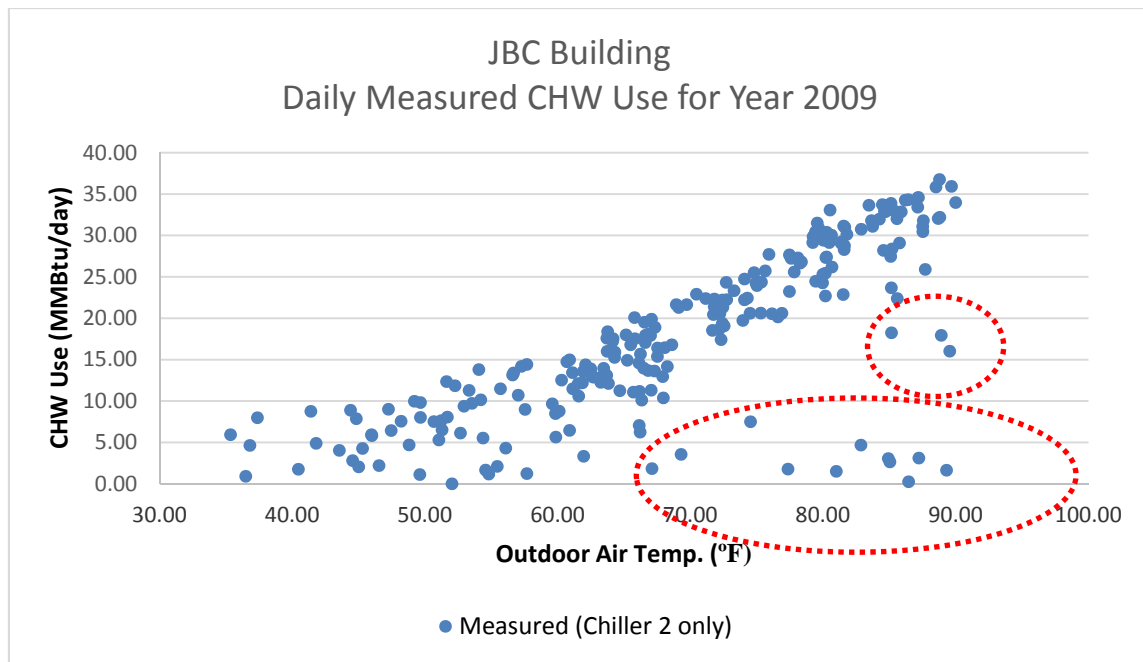


Figure 53. JBC Building Daily Measured CHW Use for Year 2009 for Chiller 2 Only

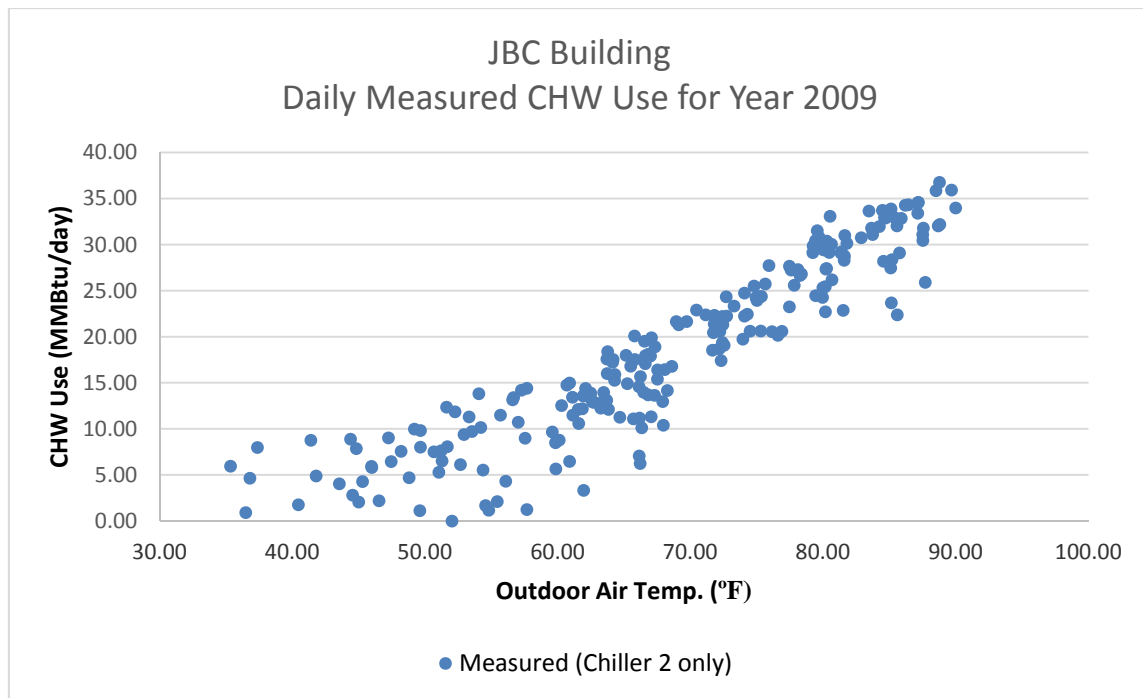


Figure 54. Modified JBC Building Daily Measured CHW Use for Year 2009 to Reflect the True Daily Total Consumption