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# Guidelines for Residential Sub Metering

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## Abstract

This report outlines a protocol for the collection and analysis of residential sub metered data. It provides concise guidelines on current best practices for measurement, analysis, diagnostics, and documentation of residential end-uses. End-use monitoring offers interested parties the ability to make informed decisions by providing direct feedback for design decisions and occupant behavior.

The protocol outlines levels of objectives, what to measure, how to measure it, analysis guidelines, and best practice documentation methods. This protocol is a universally beneficial tool for all parties associated with the built environment including designers, builders, owners, building operators, city bodies, and policy makers. These guidelines are a tool to increase the likelihood of producing beneficial data in a sub metered project.

Keywords: *Residential, energy monitoring, post occupancy evaluations, disaggregated energy, sub metered monitoring*

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## 1. Introduction

This paper offers concise guidelines for residential sub metering. It is intended for parties associated with the residential environment including designers, builders, owners, building operators, city bodies, and policy makers. As a diagnostic tool, the protocol can be used to reduce monthly energy use and cost, to identify maintenance concerns, and to measure retrofit opportunities. For policy makers, it enables informed conservation programs. For designers, it is a learning and feedback tool for design assumptions and modeled predictions.

Sub metering is a form of disaggregated electrical monitoring, referring to the ability to measure electrical consumption at the breaker level for specific end-uses. End-use consumption can be either directly measured or estimated. Although promising, no current estimation models are able to accurately replace sub metering as they do not meet the "90 rule" yet (90% accuracy, 90% of the time, for 90% of the circuits) (Fisher, personal communication, 2015). The vast majority of sub meter installations are currently for commercial projects. This practice is newly adapted to residential application with few existing guidelines. As such, this paper proposes a protocol specifically developed for residential collection and analysis of sub metered data based on relevant case studies and existing guidelines.

The protocol outlines what to measure, how to measure it, analysis, and best practice documentation. Scope of measurement includes energy use, energy cost, gas, water, and independent variables, such as climate, occupancy habits, etc. Guidelines for measurement include sensor types, data storage and transmission, scanning and logging intervals, collection spans, and verification and calibration. Analysis guidelines include accuracy and normalizing, missing data, and metric selection and comparison. An overview of best practice documentation methods is also included.

## *2.* What to Measure

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Goals should be clearly identified at the start of each project to define the level of collection and analysis required (Singh, 2011). For example, a project could seek a detailed understanding of how the building is functioning, or a general overview of the largest end use consumers. The levels of variables and analysis should be tailored to the level of depth required for the goals of the project. As with all systems, creating as simple of a system as effectively possible can greatly aid in producing helpful results.

### *2.1 What to Measure: Energy Use*

The common measurement for energy use is recorded in kWh. Additional measurements of electricity can be recorded if the specific goals of the project necessitate, including voltage and amps (U.S. EIA, 2015).

#### *2.1.1 Whole Electric Consumption*

Monitoring whole-house electrical consumption is always recommended (Chasar & Withers, 2012; Sherwin et al., 2010; Wahlstrom & Harsman, 2015). Whole-house use can be measured by monitoring the main meter. If more than one meter exists, the sum of the meters may be referred to as the main meter (ASHRAE, 2002).

#### *2.1.2 Utility Totals*

Utility totals can provide additional verification for the accuracy of onsite measurements. Historical utility bills may provide a comparison to current energy usage. Generally, 12 to 24 months of historical data is recommended (ASHRAE, 2002; Chasar & Withers, 2012; U.S. EIA, 2015). The majority of electrical utility companies do not collect interval data on residential usage and are only able to provide total monthly consumption (U.S. EIA, 2011). Some utilities are able to provide daily or hourly totals of consumption.

#### *2.1.3 Disaggregated Electric Consumption*

The level of end use monitoring should develop from the objectives of the project. All end use disaggregated electricity should be time-stamped (U.S. EIA, 2015).

##### *2.1.3.1 Measuring Dominant Loads*

Dominant residential end uses have been traditionally grouped into four categories – heating, air conditioning, water heating, and plug loads consisting of appliances, electronics, and lighting. As dominant loads are installed on individual breakers, each dominant load can be identified and monitored independently. For this level of analysis, specific appliance and plug loads are not separately measured (Sherwin et al., 2010). Any additional dominant loads should also be addressed, including but not limited to, electric vehicle charging stations, solar panel production, solar hot water production, and swimming pools.

##### *2.1.3.2 Sub Metering Specific Loads*

Systems with multiple components can be sub metered for a detailed understanding of performance (Estes & Santoso, 2015). If in an environment dominated by heating and/or cooling concerns, it is often recommended to sub meter the HVAC system into comprising components to monitor the performance of each component, such as the air handlers, condensers, or heat pumps (Chasar & vonSchramm, 2012; Chasar & Withers, 2012; Sherwin et al., 2010). Further, if the residence utilizes a less conventional system, such as solar hot water heating, detailed sub metering of each component is recommended to ensure the correct installation and calibration.

##### *2.1.3.3 Comprehensive Sub Metering*

Comprehensive sub metering includes dominant loads and the detailing of specific plug, appliance, and lighting loads. This level of sub metering is to understand the detailed performance of the house as a whole system. In general, this level of sub metering includes lighting, receptacles, individual appliances, and house systems including garage door openers, security systems, etc (Christian et al., 2010; Stawitz et al., 2008). While appliances and some lighting systems are installed individually on breakers, most lighting and plug loads will be indistinguishable. If necessary for this level of analysis, monitors may be added to individual receptacles and labeled for use to determine accurate loads individual to lighting and plug loads.

### *2.2 What to Measure: Energy Cost*

As most projects are driven by cost comparative and savings initiatives, recording actual monthly residential rates at the time of measurements enables accurate costs to be associated with consumption (Christian et al., 2010). Cost could be measured as total cost per day for whole-house consumption, or for specific end use consumption to understand the cost of individual house systems (U.S. EIA, 2015).

### *2.4 What to Measure: Gas & Water*

If outlined by the goals and objectives of the project, additional house consumptions, including gas and water, can be measured on site (Chasar & vonSchramm, 2012; Christian et al., 2010; Stawitz et al., 2008; U.S. EIA, 2015). Although outside of the scope of this set of guidelines, the identification of a level of detail complimentary to the energy analysis is recommended.

### *2.5 What to Measure: Independent Variables*

Independent variables for residential sub metering are defined as factors that affect the energy use of a building but cannot be controlled. These variables most commonly consist of climate, occupancy, and household demographics (ASHRAE, 2002; U.S. EIA, 2011).

### *2.5.1 Climate*

Common conditions collected include temperature and relative humidity, with solar radiation and carbon dioxide levels collected as necessitated by the project (Chasar & vonSchramm, 2012; Chasar & Withers, 2012; Kansara et al., 2011; Parker & Sherwin, 2012; Sherwin et al., 2010; Stawitz et al., 2008). Climate measurements are collected as an additional verification of performance. Interior conditions can be used to test the performance of HVAC systems and to measure indoor air quality. Exterior conditions can be used to provide accurate measurements of exterior climactic conditions, both for use as efficiency performance verification and to normalize for extreme weather conditions.

### *2.5.2 Occupancy Habits*

Occupant habits can have a substantial impact on the consumption of residential end uses. Although currently relatively unusual, basic occupant surveys can be beneficial to understand variations of end use consumption from standard benchmarks. Simple occupant answers regarding thermostat settings, usage habits, and satisfaction rates may be beneficial in identifying reduction strategies (Edwards et al., 2012; Stawitz et al., 2008). Additional information may be beneficial specific to project end goals. For example, if an electrical car is included in analysis, information regarding work schedules and mileage driven should be collected.

### *2.5.3 Demographics*

Simple demographics are necessary to understand household consumption. The number of residents and the type of occupancy (primary residence, vacation house, etc.) are required to calculate basic metrics. For further analysis and educational objectives, additional characteristics can be surveyed including the age of residents, the status of residents (single, married, etc.), the disposable income, and information regarding head of household (U.S. EIA, 2015).

### *2.5.4 Household Attributes*

The most basic level of residential analysis requires noting the conditioned floor area and the type of energy systems used for heating and cooling. For most levels of analysis, attributes to record include the above plus the type of housing (detached, semi-detached, etc.), the year constructed, the number of floors, any electrical production on site, and any pools included in the analysis. For detailed energy audits, collect information regarding façade elements, window types, roof, wall construction, and other home details affecting energy consumption (Wahlstrom & Harsman, 2015).

## 3. How to Measure

Exploration of an appropriate combination of sensor types can provide accurate data detailed at the necessary level. An appropriately sized sampling method can answer project questions while minimizing costs associate with analysis (ASHRAE, 2002).

### *3.1 How to Measure: Sensor Types*

#### *3.1.1 Circuit Level & Whole House Meters*

Multiple circuit and whole house meters are available for market purchase, including whole-house Building Management Systems for integrated and detailed feedback, mid-level energy monitoring systems suitable for most projects, and small-scale systems such as a 5-appliance load system (Kansara et al., 2011; Levasseur et al., 2012). Common metering systems utilize volt and amp measurements for resistant loads, currently the most common loads found in residential applications. However, if the project goals necessitate great detail and accuracy, a system utilizing measurement with true rms wattmeters is suggested in order to provide increased measurement accuracy for equipment with reactive loads, such as fluorescent lighting and motors (Efficiency Valuation Organization, 2012).

#### *3.1.2 Outlet Sensors*

If the project goals require a more comprehensive level of monitoring than available to circuit based monitoring, outlet sensors are able to provide a more detailed understanding of residential consumption (Levasseur et al., 2012). Outlet wall monitors can be used in conjunction with circuit level and whole house monitoring systems to provide measurement of specific appliances (Ozturk et al., 2012; U.S. EIA, 2015). Outlet sensors enable the measurement of specific residential uses, such as plug-based lighting, televisions, and window-unit air conditioners, usually indistinguishable in circuit level monitoring.

#### *3.1.3 Runtime Sensors*

For some residential electrical usage, a runtime sensor may suffice in providing an estimate of overall usage. For example, certain lighting and motors can be measured by runtime to provide a usage estimate and an understanding of usage patterns. Dependant on the goals of the project, runtime sensors may offer a more affordable and easily installed alternative to circuit level systems (ASHRAE, 2002).

### *3.2 How to Measure: Data Storage & Transmission*

The majority of electrical monitors use a wireless network system to transfer collected data to a storage server (Levasseur et al., 2012). Data storage capacity can vary and should be approximated to fit the logging intervals and collection span of the project. Data services are generally free to low cost. For ease of collection, data is recommended to be available online to authorized users only. Consent of the residents and owner is necessary. The majority of systems allow for data collection by downloading from web interfaces (U.S. EIA, 2015). As data transmission and storage can be dependant on existing household internet, a review of internet reliability prior to system instillation may provide an increased project performance at a low cost.

### *3.3 How to Measure: Scanning & Logging Intervals*

#### *3.3.1 Scan Rate*

Common energy monitoring systems scan data either continuously or in 10-second intervals (Christian et al., 2010; Efficiency Valuation Organization, 2012; Levasseur et al., 2012; Sherwin et al., 2010). Continuous scanners offer real-time system feedback to allow for immediate problem detection or instant behavioral feedback (Stawitz et al., 2008). In the majority of projects, 10-second scanning is effective.

#### *3.3.2 Logging Intervals*

Logging intervals should be selected to fit specific project questions and goals. Appropriately sized logging intervals allow for efficient and timely data analysis while providing useful project information. Monthly integration is recommended for all projects. Data can be reported at intervals of daily, hourly, 15 minute, 1 minute, and 15 second intervals.

Two to three logging intervals are recommended. The first, if needed for project goals, is to log intervals mirroring the electric-demand measurement method of the electric utility to allow for comparable peak-demand profiles (Efficiency Valuation Organization, 2012). The second logging interval should be at the level identified as the primary level of analysis for the project. Thirdly, one order of magnitude more detailed than intended baseline analysis is recommended to allow for deeper exploration if problem solving occurs.

Monthly collection of data can be used to answer systems seasonal efficiency questions, weather-related consumption, and broad overviews of performance. Daily data collection allows for an overview of behavior-based residential consumption and the location of peak-day consumption. Hourly collection of data represents the typical utility sampling rate of advanced metering infrastructures and correlates well with commonly collected hourly weather data as well as designed engineering load profiles (U.S. EIA, 2015). Hourly data allows for the most appropriate understanding of power factors and daily peak load profiles and peak pricing events (Christian et al., 2010; Fisher, personal communication, 2015). For the majority of projects, this level of data is sufficient without overwhelming the file size (U.S. EIA, 2015).

Fifteen-minute logging intervals are appropriate for detailed analysis of the performance of specific systems in question (Christian et al., 2010; Parker & Sherwin, 2012). Some residential modeling applications, including machine learning algorithms, benefit from this level of sampling (Edwards et al., 2012). One minute and fifteen-second level data logging is generally used to capture the most detailed level of analysis available for residential consumption modeling. With this level of granularity, specific system diagnosis is available including identifying air conditioner short-cycling and detailed understanding of electric vehicle use (Fisher, personal communication, 2015).

### *3.4 How to Measure: Collection Span*

The duration of the measurement should span the full range of independent variables, including weather patterns, occupancy schedules, and all operating modes from minimum to maximum in order to provide an intended level of certainty (ASHRAE, 2002; Efficiency Valuation Organization, 2012). As whole building energy use can be significantly affected by weather conditions, generally a whole year of measurement is recommended (Efficiency Valuation Organization, 2012). Two years of monitoring data can provide seasonal and residential variation (Kansara et al., 2011). If extensive analysis is required, up to four years of data can account for weather and occupancy variations. For the most holistic and continuous understanding of the performance of a residence, continuous monitoring and yearly analysis can provide feedback for alterations in housing characteristics and occupant habits (U.S. EIA, 2015).

For some projects, yearlong monitoring may be out of the scope and budget of the project. Normally, a full year of energy use and weather data are required to determine actual energy use. For short term monitoring, it is recommended to determine the best time and duration based on the ambient temperature of the location, and the closeness of the dataset's mean temperature to the annual average. Research has shown that an average of three to four months of monitored data is adequate to estimate an approximate annual building energy use if monitored at the appropriate time, and if the data set is able to capture seasonal and daily variations (Singh, 2011).

### *3.5 How to Measure: Verification & Calibration*

Verification and calibration of equipment is a vital step often forgotten for time or budgetary constraints. To ensure the proper function and intended accuracy of measurement, equipment should be verified as functioning properly and monitored to resolve unexpected occurrences in order to allow for the best possible data set for the given monitoring period (ASHRAE, 2002). Equipment can be verified through a four-step operation approach. Firstly, a visual inspect can serve to verify the proper installation of equipment. Secondly, sample spot measurements of key systems can provide immediate feedback for the current accuracy of the equipment. Thirdly, a short-term performance testing period can ensure proper performance as a system before long spans of time are invested into the project. Fourthly, data trending and review can provide approximate measurements of accuracy and general guidelines appropriate to relevant benchmarks in order to quickly calibrate installed systems (Efficiency Valuation Organization, 2012). For long-term monitoring, equipment should be routinely recalibrated at critical measurement points. A minimum of sixth month recalibration is recommended to calibrate instruments, measure system accuracy, and provide data validation (ASHRAE, 2002). If the project relies on a high level of detail and accuracy, to ensure less data loss, redundant sensors and frequent on-line checks are recommended to reduce the impact of sensor failure.

## 4. Analysis

### *4.1 Analysis: Accuracy & Normalizing*

No data set is without error. Errors are identified through data validation by comparing the collected data to internal or external benchmarks (ASHRAE, 2002). If the project entails whole house monitoring, an internal benchmark would be the sum of the sub metered systems compared to the total electrical consumption measured at the main meter. For an external benchmark, the sum of the system can be compared to the power bill (Stawitz et al., 2008).

Typical accuracy found in commercial projects range from <1%, to average values of <4%. The greatest range in the values found in the reviewed case studies found a percent error of just under 10% (Efficiency Valuation Organization, 2012; Stawitz et al., 2008). Data outside the desired level of accuracy or project norms may be omitted, adjusted through calibration, interpolated from preceding and following data, adjusted to an average value, or ignored (ASHRAE, 2002).

Data can be normalized for independent variables, including weather and occupancy. Normalization for weather is recommended if comparing to predicted energy use and heating or cooling degree days differ significantly from the weather data set used to generate the prediction (Christian et al., 2010). If needed, data can be normalized using linear regressions, including least squares and best-fit linear regressions (Chasar & Withers, 2012). Accuracy and normalizing should be reported with the final level of analysis.

### *4.2 Analysis: Missing Data*

Generally, missing data can be handled by omission, or by substituting replacement data from interpolated or calculated values. However, this is only recommended for small omissions. Large gaps in data are difficult to restore with accuracy (ASHRAE, 2002). From the reviewed case studies, an average of 0.01% to 0.66% of data was reported missing from collections spans 92 days to one year long (Chasar & vonSchramm, 2012; Stawitz et al., 2008). Missing data removed from the analysis should be noted within the final report.

### *4.3 Analysis: Metrics*

#### *4.3.1 Load Factors & Peak Times*

A load factor, or power factor, is the ratio of average over peak consumption (Christian et al., 2010). Load factors can be calculated for peak days out of a month, or for peak hours within a single day (Singh, 2011). For the most basic of projects, peak electric consumption can be noted for the winter and summer season. For the majority of projects, the largest consuming day of each month of data available should be noted (ASHRAE, 2002; Christian et al., 2010). This enables an understanding of loads associated with seasonal variation. For projects concerned with detailed analysis of specific systems or whole house electrical supply and demand, the peak hour of each day can be recorded (Fig. 1). Recording and understanding load demand during peak times enables the strategic application of efforts to reduce critical peak pricing events.

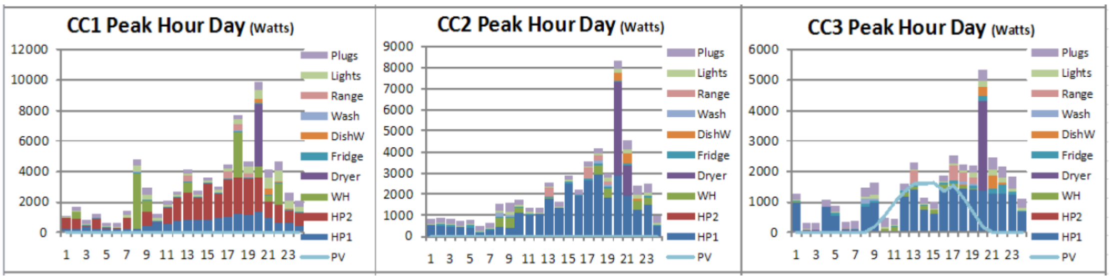

**Fig. 1: Comparison of peak days (Christian et al., 2010)**

#### *4.3.2 Energy Per Person*

Although a less common metric, calculating the energy per occupant may allow for a more direct representation of individual habits on residential consumption. Occupancy habits must be accounted for in order to provide a basis for comparison. For the most accurate comparison, and to account for seasonal changes, the energy per person should be calculated for an entire year. If consistent data is unavailable, the energy per person may be calculated and compared per month (Sherwin et al., 2010).

#### *4.3.3 Energy By Size*

Energy by size, known as the Energy Usage Intensity (EUI), is the most common metric for comparison. The energy consumption is calculated for the amount of conditioned space within the building (Sherwin et al., 2010). A complete year of data is needed for the calculation of a true EUI to allow for seasonal variation. For an approximate comparison to yearly benchmarks, if a full year of consistent data is not available, extrapolation or modeling is required to supplement the data. If a full year of data is unavailable, the EUI may be calculated and compared per month.

### 4.3.4 Energy Cost

An Energy Cost Index (ECI) can be calculated by dividing the net annual energy cost by the gross floor area to provide a metric for comparison (Singh, 2011). For a retrofit project, as savings cannot be directly measured, the savings of a project can be determined by comparing the pre and post energy costs of a project, compensating for any appropriate adjustments for a comparable time period (Efficiency Valuation Organization, 2012). If multiple comparable homes are included in the project, direct monthly energy costs can be compared to demonstrate for costs associated with various levels of construction or occupant habits (Christian et al., 2010).

### 4.3.5 Whole Building Consumption

Total site consumption can be calculated by the year, the month, the day, and the hour, depending on the needs of the project. For example, multiple homes compared in the same region will benefit from yearly and monthly comparisons (Christian et al., 2010; Sherwin et al., 2010; Singh, 2011). For a detailed understanding of the performance of a home, total and average hourly consumption can be charted throughout an average daily usage profile to provide a visualization of the performance over the course of a day (Fig. 2) (Christian et al., 2010; Stawitz et al., 2008).

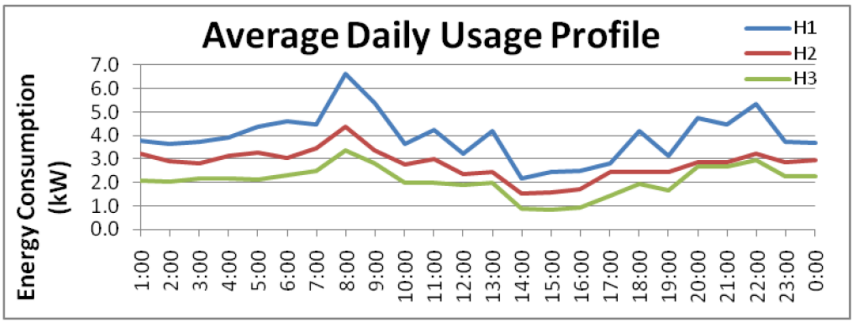

**Fig. 2: Average daily usage profiles for February 2010 (Christian et al., 2010)**

### 4.3.6 Major End Uses

The most common analysis of disaggregated whole building consumption is in the form of calculating and visually representing major end uses. End uses can be represented as a percentage of the total consumption to provide an understanding of a single building or in the form of kWh to provide comparison to other buildings within the same project. The most common form of end use comparison is by breaking the major end uses into four general categories: air conditioning, water heating, space heating, and appliances, electronics and lighting. Additional major systems, including pools, should be included. If a more detailed analysis of the project is fit, end uses can be broken further to represent specific appliances or house systems (Christian et al., 2010). If a detailed analysis of one system is performed, each component of the system should be represented. For a holistic understanding of building performance, it is important to indicate if any systems rely on additional forms of energy, including as natural gas, for end uses such as space heating, water heating, cooking, etc. (U.S. EIA, 2013).

### 4.3.7 Energy Production

If energy production is available, the energy production should be calculated and graphed to track system costs and savings, compare to whole house consumption, and plot for production for time of day (Christian et al., 2010).

### 4.4 Analysis: Comparison

### *4.4.1 Compare Uses*

A visual representation can provide an aid in understanding how each system in the home consumes in comparison to other systems (Fig. 3). If individual systems within an end use are analyzed for performance, such as the components of an HVAC system, it is recommended to display the performance of the components of the systems as percentages of the whole system, as well as in a visual representation of the entire consumption of the home (Stawitz et al., 2008).

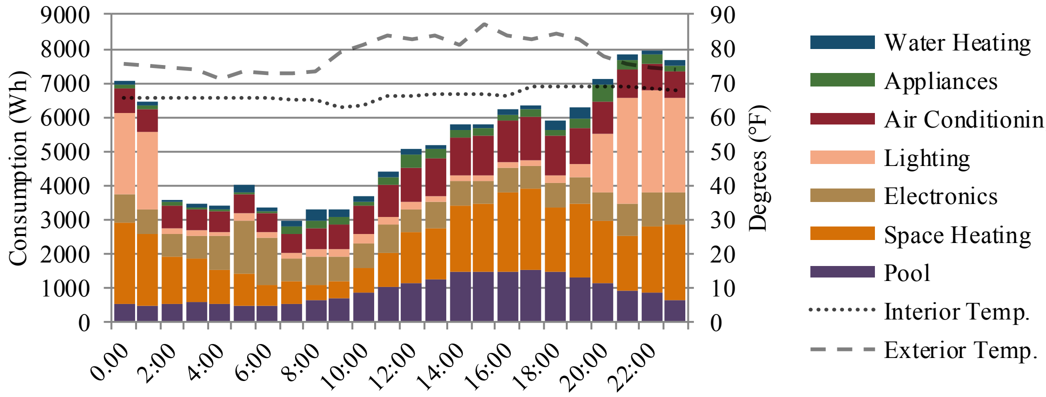

**Fig. 3: Hourly average from June 2015 for Case Study A (Hatch & Rashed-Ali, 2016)**

### *4.4.2 Comparable Homes*

A common set of conditions, including behavior patterns, must be selected to allow for the comparison of similar studies or homes (Edwards et al., 2012). Whole house systems and major systems in each house can be compared for performance. If one residence has efficient systems installed and other variables are the same or similar, these systems can be compared to establish an annual energy savings for each major energy user (Fig. 4). The comparison in cost and energy consumption can be broken down from yearly, to monthly, to daily (Christian et al., 2010).

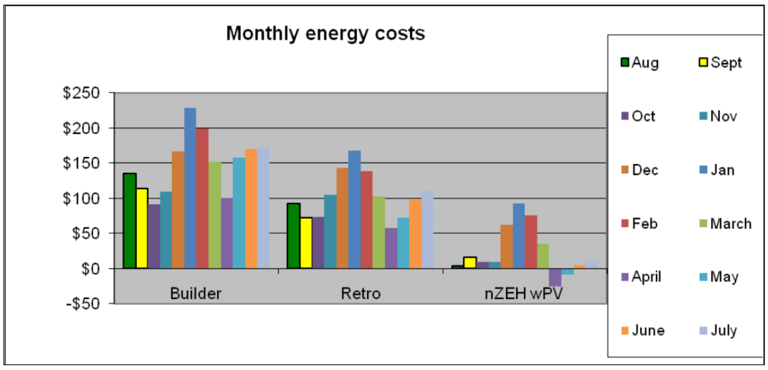

**Fig. 4: Monthly energy cost for each house, August 2009-July 2010 (Christian et al., 2010)**

### *4.4.3 Pre and Post Retrofit Comparison*

Pre and post-retrofit monitoring and analysis allows for measured energy savings for whole house consumption as well as individual end uses (Chasar & Withers, 2012; Christian et al., 2010). Stable behavioral patterns must be determined to allow for comparable consumption from pre and post-retrofit analysis (Edwards et al., 2012).

### *4.4.4 Compare to Simulated Predictions*

Actual monitored consumption values can be compared with end use and whole building predicted consumption (Christian et al., 2010; Stawitz et al., 2008). These values can be compared and adjusted to identify the source of discrepancies within the prototype computer simulations (Sherwin et al., 2010). If only a short data set is available, hybrid inverse modeling has been explored as a modeling method to predict energy use for the year by combining the short data set with a year of utility bills (Singh, 2011). Regression models may also be applied to uncover any statistical correlations on household consumption to building characteristics or occupant behavior (ASHRAE, 2002; U.S. EIA, 2011, 2015).

### *4.4.5 Compare to Benchmarks*

The purpose of the benchmarks is to provide a comparison of energy measurement with a base case or a standard (Meir et al., 2009). Comparison to a benchmark enables a percent savings relative to the benchmark and well as comparison to regional and national averages (Sherwin et al., 2010).

### *4.6 Analysis: Residential Benchmarks*

Residential benchmarks fall into three general categories based on how the benchmark is determined. The first category of benchmark is created by an educated estimate of dominant end uses based on occupant surveys. The most prominent is the Residential Energy Consumption Survey provided by the U.S. Energy Information Administration. Although an approximation, estimated uses are available for each state in the U.S. and offer a great starting point for understanding expected performance (Fig. 5).

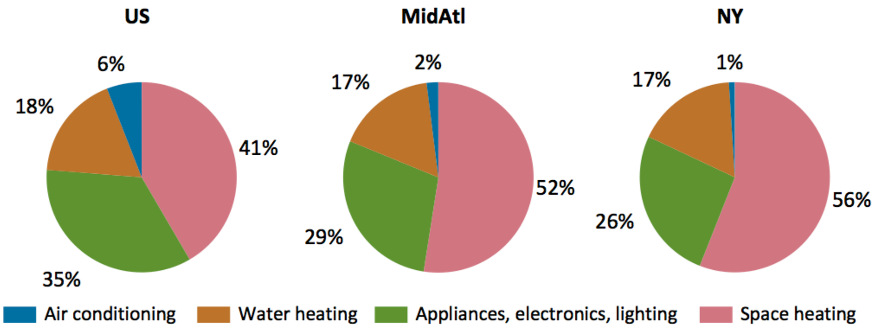

**Fig. 5: New York RECS 2009 (U.S. EIA, 2009)**

The second category of benchmark is developed by using recorded end use data from comparable residences. Although finding specific projects appropriately comparable can be difficult, measured data from specific regions provide a more accurate estimate for comparison. Pecan Street's Dataport is currently the largest source of disaggregated customer energy data. It provides raw data, visualizations, and reports for energy and water consumption based in Austin, Texas, narrowed by home characteristics.

The third category of benchmarking is a benchmark developed specifically for an individual project through predictive software modeling. Software modeling can take extra time, but is an alternative to provide contextually specific estimates if comparable homes are not available. To track progress towards whole-house energy savings goals, the Building America Research Benchmark represents mid-1990's standard construction as a fixed point in time to provide a set comparison of energy (Hendron & Engebrecht, 2010).

### *4.7 Analysis: Anomalies/Improvements*

Once common metrics have been created and results have been compared to benchmarks, anomalies and improvements can be investigated in the project. Anomalies and improvements should be identified by the largest deviation from comparable benchmarks and projects. The more regional and comparable the benchmark, the more comparisons will enable insightful and diagnostic analysis for areas of improvement. The data should be examined for anomalies from the largest scale to the most specific scale necessitated.

## 5. Documentation

Documentation of a project allows for timely analysis and increased accuracy in achieving project goals. Documentation recommendations have been divided into three phases naturally corresponding to the progression of any project.

### *5.1 Phase I: Goals, Scope, & Intent*

A specific set of goals for a project allows for targeted implementation of resources within project limitations, such as the time available, the accuracy necessary, and the budget available (ASHRAE, 2002; Efficiency

Valuation Organization, 2012). These goals, as well as the limitations, should be developed and documented at the start of the project. Through documentation, the method appropriate for obtaining the required information will become apparent. Alternative methods should be identified if high levels of accuracy are required. As time is often the most restricted commodity, a minimum level of performance should be outlined to dictate if and when systems require unplanned maintenance or replacement. The method and rigor of systems, scheduled calibrations, and responsibilities should be outlined and agreed upon (ASHRAE, 2002).

### *5.2 Phase II: Measurement & Documentation*

Phase II begins with the instillation and documentation of measurement equipment. Baseline conditions should be recorded, including the condition of the residence and major systems. A description of the measurement system should be included, along with a description of the installation method, location, and system installer (ASHRAE, 2002; Efficiency Valuation Organization, 2012). The monitoring schedule and associated responsibilities should be documented as performed, including predicted maintenance and data management, as well as unexpected repairs (ASHRAE, 2002; Efficiency Valuation Organization, 2012). This enables a timeline of system performance and repair to be compared with later analysis. Once data is pulled and analysis begins, the complete reporting period should be noted (ASHRAE, 2002).

### *5.3 Phase III: Method of Analysis*

Analysis procedure should be documented to detail exactly how the analysis was performed, what assumptions were present, and what variables were considered (Efficiency Valuation Organization, 2012). Identified criteria, developed methodologies, and calculation steps should be recorded (ASHRAE, 2002). Any adjustments or omissions to the data set are to be noted, as well the determination of actual levels of accuracy (Christian et al., 2010; Efficiency Valuation Organization, 2012). All final comparisons and suggestions are best represented graphically.

## 6. Conclusion

This protocol is a universally beneficial tool for designers, builders, owners, building operators, city bodies, and policy makers. Benefits of collection include a detailed, in-depth understanding of the operations of a building, or a general overview of the largest end-use consumers. As a diagnostic tool, the protocol can be used to reduce monthly energy use and associated costs, to identify maintenance concerns, and to measure retrofit opportunities. For policy makers, it enables informed conservation programs and utility electrical production. For designers, it is a learning and feedback tool for design assumptions and modeled predictions. This protocol can be utilized by any of the outlined parties to assist in implementing a sub metering project by outlining development steps to increase the likelihood of producing beneficial data.

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