The Use of Short-Term Measurements to Decompose Commercial Billing Data Into Primary End Uses

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Electricity billing data is a preferred measurement upon which to base estimates of conservation. It is a high quality measurement and is close to the customer's experience--their own electric bill. The information is readily available to utilities. However, this type of data is inherently aggregated across end uses. It is difficult to use as an indicator of savings or as a check on building modeling. Combining a previous year's billing data with short term measurements of two weeks duration, allows these data to be decomposed into four principal end uses. Billing data decomposed in this fashion lends itself to checking modelling results, confirming savings and assisting energy auditors in estimating potential savings.

Discussed are: (a) Key short term measurement targets and the associated measurement techniques with emphasis on the use of small data loggers and event timers used to make such measurements in a production mode. (b) Analytical methods necessary to disaggregate billing data into primary end uses. (c) Classification of total energy use patterns by daytypes. (d) Estimates of non-seasonal lighting and other end uses. Monthly estimates of HVAC energy use are approximated by the difference between these end uses and the actual monthly billing data. These monthly HVAC estimates are correlated with heating and cooling degree-days to characterize the HVAC energy use. The methods are illustrated by the production application to different types of commercial buildings used in parallel to a conventional audit to document the before and after retrofit electricity use.

Introduction

Utilities prefer electricity billing data as the measurement upon which to base estimates of conservation benefits because it is a high quality measurement, and because it is quite close to the participating customer's experience--their own electric bill. Furthermore, the information is readily available to utilities as a simple extension of their metering or load research. However authoritative, this type of data is inherently aggregated across end-uses. It is difficult to use in its raw form as an indicator of savings or as a check on building modelling due to uncertainties in building operation and scheduling. By combining a previous year's billing data and short term measurements (STM) of one or two weeks duration, these data can be decomposed into principal end uses. Billing data decomposed in this fashion can be applied to check modeling results and confirm savings. Such data assist auditors in estimating the customer's post retrofit consumption.

Recent improvements in the cost and performance of data acquisition equipment have greatly simplified the task of site measurements and the associated data analysis. These short term measurements are brief measurements of a building's energy using systems intended to provide specific information about particular equipment or end uses. These measurements are made on-site in a few hours or using a data logger over a time span of up to a few weeks. Short term measurements in a commercial retrofit program help to:

1. Assist the audit. Increased knowledge of energy use at the site allows better determination of savings opportunities and more confidence in audit estimates.

2. Quantify and verify the achieved energy savings. Direct measurements verify key energy savings which are otherwise obscured by occupancy changes at the site.

Combined with the audit, short-term measurements can provide a complete picture of energy-use patterns at the site. STM can produce some types of information not available from an audit, such as equipment operating efficiency and specific end use consumption. Measurements provide accurate data on occupancy and equipment operating schedules which are usually estimated. For impact evaluation, STM can provide savings estimates more objectively than an audit and more explicitly than billing analysis. These measurements can provide documentation of savings otherwise unobtainable and specific information as to how and why the savings do or do not occur.

A potential limitation of STM is that measurements made in one season (winter) may not be applicable to the building in another season (summer). However, this limitation applies only to a portion--usually less than one half--of the building's energy use. Used with billing data, STM can isolate the seasonally variable component of the building energy use.

Other researchers have investigated the application of STM for quantifying savings. Jamison and Qualmann noted the problem in reconciling computer models to a limited set of actual measurements. Lansberg and Amalfi applied STM to measure non-seasonal lighting loads. Haberi et al. noted the application of decomposing whole building consumption to end uses using load shape methods. These studies have tended to be research level analyses of large, complex buildings. Waltz discussed simplified models of small buildings, reconciled to billing data. The current work differs from these studies by emphasis on a simplified method that can be applied routinely on a production basis to a large number of small buildings.

The key development goal is to reduce the cost of STM. Hardware costs have recently decreased dramatically with the development of numerous new metering products. (Pacific Science 1991, Reichmuth 1992). However, practical operation requires reducing the high labor cost associated with data acquisition and analysis. This has been achieved in the field by standardizing the procedures. Specific measurement tools and protocols are specified for key measurements. A standardized data analysis implements a simplified, general approach without attempting detailed review of the idiosyncrasies that tend to occur at each site.

Methodology

Extrapolating a short term measurement to a one year period assumes that non-seasonal loads have a repeating occupancy cycle that can be confidently extrapolated. This assumption has been examined in one case by reviewing a building where hourly pre/post monitoring was available for the lighting end use. The question then is, if lighting consumption is estimated by a one-time "snapshot" or end use breakdown at one point in time, how accurate would that "snapshot" be to annual consumption? For this case, the estimated lighting consumption agreed well with monitored consumption. During three months pre-retrofit, the "snapshot" estimate agreed within 2.6% for the total consumption or 3.3% mean absolute percent error (MAPE) during the period. During five months, post-retrofit the estimate agreed within 2.4% total or 5.5% MAPE. This level of precision is well within the accuracy of field measurement and data normalizing techniques. Therefore, it is possible to extrapolate "fixed" loads with reasonable confidence. The same conclusion was reached by other researchers. (Landsberg and Amalfi 1992.)

A fully rigorous means for extrapolating STM to an annual basis could involve many variables, each separately considered and applied. The statistical noise introduced by this approach is large enough to overcome any benefits of including all the explanatory variables. This suggests that reliance on the simplest annualizing techniques is likely to be the most productive. Accordingly, only simple procedures are applied to identify seasonal-dependent load and correlate to weather variables.

Of more importance than maximizing precision of the estimates, is the need for consistency. A consistent estimation protocol allows savings estimates from early phases of a program to be comparable with savings estimates from later phases. Savings are the difference between the estimated annual energy use before and after the retrofit for the load associated with the subject ECM and normalized to a common occupancy condition. In the following protocol, the pre-retrofit energy use is normalized to post-retrofit occupancy conditions so that the current bill can be explained to the customer.

Field Application

In the early stages of one commercial retrofit program, a sequence of short term measurements is conducted pre/post on candidate buildings. These sequences proceed in parallel with the audit as a check on the delivered program service and as a means of increasing the program yield. The measurements must be made in a timely fashion with the audit. The measurement report is to be completed during the project's design phase so that suggested energy conservation measures (ECMs) can be included. Measurements can provide important feedback to the auditors to resolve uncertain estimates or to test new audit ideas.

After the initial phase, a limited subset of short term measurements will be integrated into the audit and commissioning operations as a quality control feature. An increasing need for physical documentation of savings is anticipated. Currently, the most persuasive approach to this documentation is a hybrid approach employing billing data and selected field measurements. In the future, the capability to undertake the full array of short term measurements would be maintained but used on a limited basis to develop program improvements and to perform statistical spot checks for evaluation.

The estimating protocol is summarized as follows:

1. Review measurement data to assure that data are meaningful, that is, there are no obvious sensor failures or inconsistencies. This is also an opportunity to scan diagnostic indicators that may reveal specific conservation opportunities in the building.

2. Identify day type patterns.

3. Classify end use loads into categories based on variability and seasonal dependence. Baseloads are not seasonally dependent, but are a function of the scheduling and occupancy during different daytypes.

4. Review previous billing history to identify the seasonally dependent load.

5. Apply a simple regression model to seasonally dependent loads. This model allows consumption to be normalized to other weather conditions.

6. Estimate annual end use loads by combination of baseload and seasonal loads as observed during the different daytypes. The combination yields an estimate of annual consumption disaggregated into end uses.

7. Estimates of the savings for each end use are developed for the recommended conservation measures. The newly estimated end uses are summed into a new annual consumption estimate.

8. The resulting new consumption estimates during the short term period are compared against measured consumption following a second or post-retrofit test. If these do not agree, then either the savings estimates must be adjusted or the installation requires repair and corrections.

The strength of STM lies in the hourly nature of the data collected. Our experience shows that two weeks of data can be reviewed for regular occupancy patterns (daytype analysis) to assess the comparability of the pre and post retrofit measurements. The necessity of at least two weeks of hourly data has been noted. (Bronson, et al. 1992) These daytypes are also used as a basis for constructing estimates of annual energy use from a short term snap shot. Daytyping distinguishes between significantly different operating modes for the building. The daytype classification is based on the hourly duty cycle of an occupancy-driven load, such as the load on a major lighting circuit or the total load above a minimum threshold.

The annual estimation protocol restates the obvious: that the annual energy of a load is the load times its annual duration. The subtlety lies in designating loads and in collecting data that will allow measured load energy to be normalized to comparable pre/post occupancy conditions if necessary. The monitored load designations in every STM exercise are structured so that the savings for the ECMs can be estimated.

Loads are classified into four basic types according to variability. Table 1 summarizes the load types, together with the associated measurements needed to document energy savings. Specific measurement protocols are written for each load type. A type 3 measurement, for example, involves a seasonally varying load or more precisely, the sum of all seasonal variations. Type 3 loads are resolved by reference to monthly billing data. In most cases, there is only one significant type 3 load such as the HVAC load or a major refrigeration load. But there are cases such as an air conditioned super market or a restaurant where the type 3 load will include multiple loads of interest. This requires additional measurements to separately monitor the loads.

As a practical matter, similar end uses are grouped into a block, such as total lighting end use. Sometimes the wiring in a building is so chaotic that end uses or even ECM circuits cannot be cleanly broken out. There is a potentially endless variety of measurement situations that could occur. The simplified technique does not attempt to define every possible contingency. The protocol simply specifies that four basic types of measurements will be used. It can be quite complex to normalize a type 3 load for both weather and occupancy. In the interests of simplicity, the savings associated with a type 3 load is reported only as the unnormalized gross savings. However, the key data necessary for a subsequent weather normalization are collected and reported.

An example of this process is demonstrated in Figures 1 and 2. Figure 1 shows a typical daytype load shape derived for one building. The energy consumption is classified into four major end uses. The non-seasonal loads are considered to be relatively fixed throughout the year. (If occupancy or scheduling changes occur, these loads must be normalized for the changes.) When the fixed load assumptions are combined with the annual billing history, Figure 2 results. Figure 2 shows the variation throughout the year due as seasonal loads change. The variation in the seasonal loads can be treated with a simple regression

Table 1. Measurement Types for Annualized Load Estimates

Load Characteristics	Load Type	Measured Data	Pre/Post Occupancy Documentation	Demand Data	Annualized Energy Estimators	Note #	Annual Reference Measure
Constant Power	Type 0	1. Connected load, L 2. Total Duration, D	None, assume occupancy constant	None	QL=52*L*D		QL
Constant Power	Type 1	1. Connected load, L 2. Hourly dutycycle, D_n	pre/post daytype comparison, D_n	load shape by daytype	$QL=52*L*\sum_{n=1}^{week} D_n$	1	QL, daytype by load shape
Varying Power	Type 2	1. Hourly load, QL_n 2. Hourly dutycycle, D_n 3. Peak time, size	pre/post daytype comparison, D_n or QL_n	load shape by daytype	$QL=52*L*\sum_{n=1}^{week} QL_n$	1	QL, daytype by load shape
Seasonally Varying Power	Type 3	1. Hourly total load, QT_n 2. Hourly non-seasonal load, QC_n 3. Monthly total energy from billings, QT_m 4. Average monthly temperature, T_m 5. Peak time, size	pre/post daytype comparison, QC_n or QT_n	non-seasonal load shape by daytype total load shape by daytype peak time, size	$QS=\sum_{m}^{all\ months} QS_m$ QS_m=total - QC_n $QC_m=\sum_{n=1}^{mth\ bill\ cycle} QC_n$	 2	QS, daytypes by load shapes QS_m and T_m, average out temperature by month

NOTES:

Definitions are listed at the end of the paper.

Note 1. Two weeks are averaged to an assumed typical full occupancy interval. If review of the hourly data shows missing data or extraordinary circumstances, then a typical week is synthesized from the constituent daytypes.

Note 2. The hourly non-seasonal energy is summed over the monthly billing cycle. If review of the hourly data shows missing data or extraordinary circumstances, then an estimate of the summed energy over the billing cycle is synthesized from the constituent daytypes.

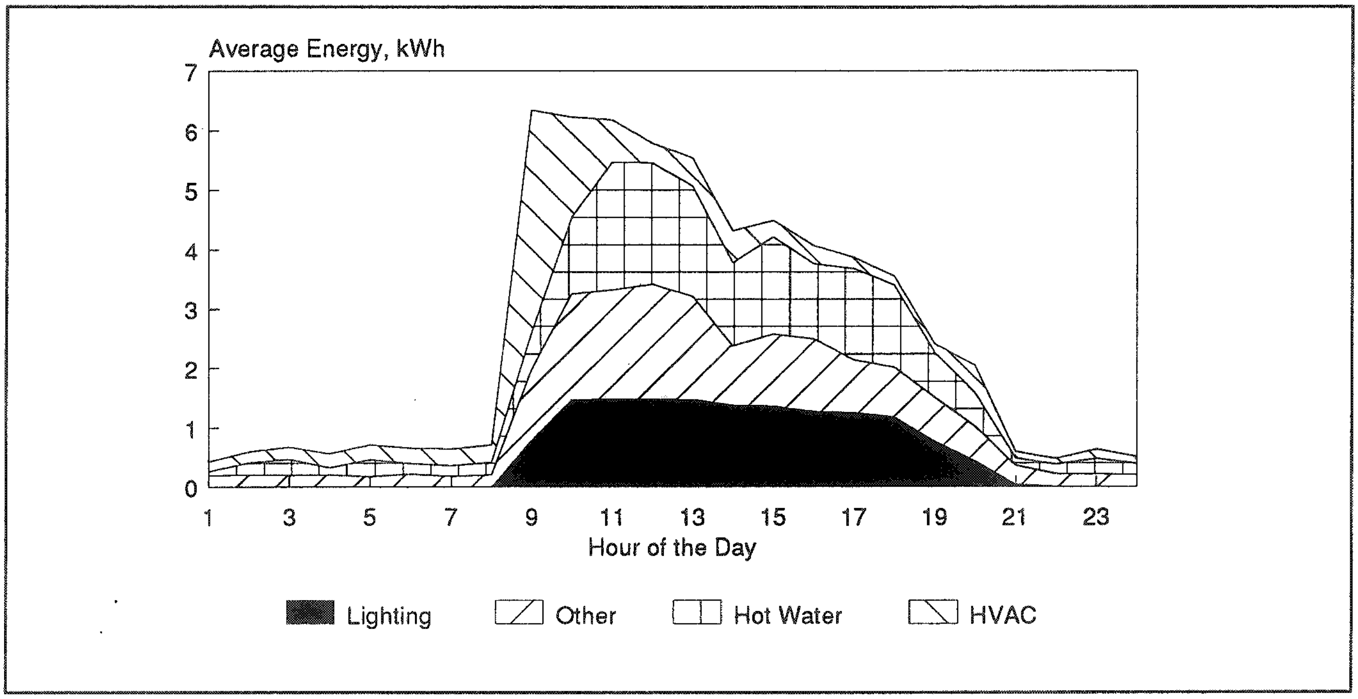

Figure 1. Retail Building Weekday Load Shape

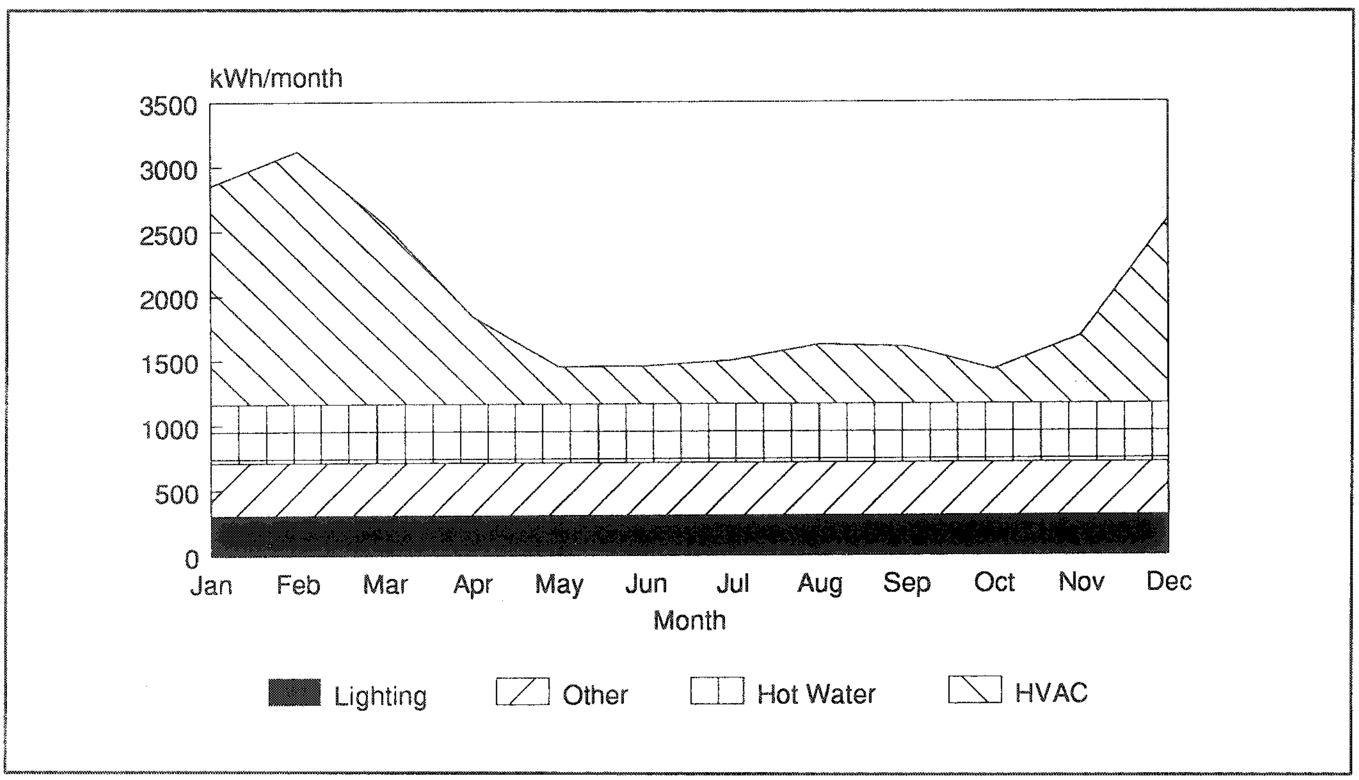

Figure 2. Retail Building Annual Energy End Uses

model as shown in Figure 3. This regression model allows seasonal loads to be normalized for changes in weather, if desired. Estimated changes due to specific ECMs are incorporated into the appropriate end uses and used to derive an estimate of the post-retrofit consumption. The predicted consumption provides an improved savings estimate and a means to track the building performance.

Description of Tools and Equipment

Measurement tools are summarized in Table 2.

Datalogger: Most short-term, and some one-time data is collected using a data acquisition system designed for energy-use monitoring in buildings. With the appropriate sensors connected and channels defined, the datalogger continuously samples each sensor output, accumulates the results, and stores the hourly data for later transfer to computer files via direct connections or modem. Menu-driven software provides access to current and stored data and set-up functions used to specify channel definitions, data storage intervals, etc.

Single-Channel Loggers: Battery powered single-channel data loggers of the "stick-on" type can monitor specific variables more cost effectively and conveniently. Types of loggers include lighting loggers which monitor lighting duty cycles with photocell sensing, and single channel power loggers, temperature loggers and status loggers which monitor duty cycle rather than energy use.

One-time Test Equipment: Equipment available for one-time tests includes the switch scanner loggers and various air and water-flow measurement tools. Illumination sensors, a portable AC power measurement gun, electrical test equipment, and thermometers are used as needed.

Data Analysis Template: The data analysis spreadsheet template speeds the review, analysis, and presentation of the data collected. The various layers of the template include the datalogger channel tables, the hourly data, summary hourly data averaged by day type, graphs for data review, macros for data handling and other chores, and finally a report output layer. Several graphs are automatically programmed to allow quick review of data quality. Examples are:

- Daytype graphs showing a given measurement's daily patterns for weekday and weekend days. These graphs show energy use patterns, temperature setbacks, and schedules.

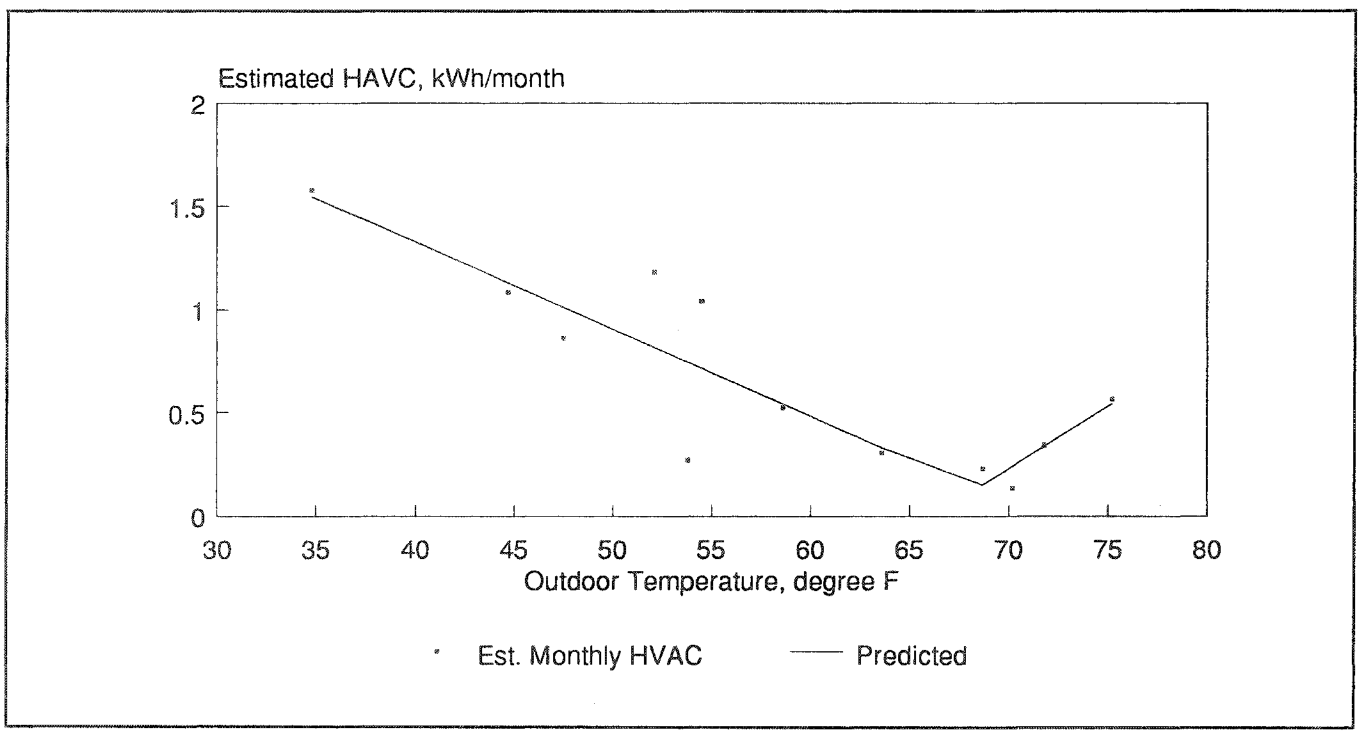

Figure 3. Retail Building HVAC Energy Regression

Table 2. Summary of Measurement Types and Methods

Measurement Type	Instrument/System Used
AC Power--Service Entry	
Various single and three phase combinations	Datalogger with CTs
Pulse meter	Datalogger pulse counting input
AC Power--Branch Loads	
All Types	Datalogger with appropriate CTs
Lighting Loads	Datalogger switch scanner unit
Temperature	
Indoor W/Wireway	Datalogger w/standard AD592 sensor
Other Indoor	Stickon Datalogger
Outdoor	Datalogger w/standard AD592 sensor
HVAC Ducts	Datalogger w/standard AD592 sensor
Meteorological	
Relative Humidity	Datalogger + humidity sensor
Solar Insolation	Datalogger module + pyronometer
Wind Speed	Datalogger frequency input + anomometer
Flow (One-Time Tests)	
Hydronic Water	Ultrasonic flow meter
HVAC Airflow	Flow hood Calorimetric w/resistance heater Pitot scan
Gas Usage	Optical pulse initiator on meter Datalogger + thermocouple flame sensor Relay on gas valve

- Overall measurement versus time graphs that show energy use and temperature maximums, minimums, and patterns. They are useful for choosing daytypes and visualizing the dependencies on weather.

- X-Y plots of one data channel versus another. For example, a plot might show the relationship between HVAC parameters and outdoor temperature to illustrate control patterns.

Analysis Procedures

As mentioned, a key to implementation is standardization of the data review and analysis. A generic method is applied. It has the advantage that it can be implemented quickly on an near-automated basis. The following steps describe the process:

1. Pre-retrofit procedure

   a. Review data and provide quick feedback to auditors. Incoming data is checked for consistency with a series of standard visual graphs. A set of diagnostic checks can be applied to buildings. Checking the outside air mix gives a quick indication of ventilation problems. Buildings with multiple heating units should be scanned for evidence of battling controls. Equipment efficiency or COP can be checked if appropriate measurements are implemented. The results of these reviews are reported back to auditors if unusual circumstances are noted and changes in recommended ECMs indicated.

b. Determine daytypes and document operating schedule. Graphical review verifies daytype determinations. Occupancy schedule is documented in case it changes after the study period.

c. Determine average end use load shapes for typical daytypes as in Figure 1.

d. Aggregate daytypes for monthly consumption estimates.

e. Compare to billing history. Decompose consumption into end uses as in Figure 2.

f. Correlate seasonal-dependent loads for annual prediction model, if needed.

2. Repeat the sequence after the retrofit. Normalize the pre-retrofit baseline to the post-retrofit occupancy conditions, if needed. Estimate savings as the difference between the pre and post-retrofit annual consumption estimates.

This operation produces three documentation reports:

1. A pre-retrofit report summarizes and documents baseline energy use measurements taken before the retrofit and highlights any measurement information which may have bearing in the project design phase. Sections include seasonal analysis, daytype analysis, end use analysis, assessment of HVAC performance, and any significant ECM loads.

2. A post-retrofit report repeats these results from a similar set of measurements. It summarizes and documents energy use measurements taken after the retrofit and annual savings estimates for all the non seasonal loads and ECMs.

3. The installation report is for an engineer's use. It is made after each installation of monitoring equipment (pre and post retrofit) itemizing the monitoring strategy and the building features monitored. All sensors left on site between the pre and post monitoring are itemized in this report for convenience in planning the post monitoring effort. This report also contains the results of any auditor requested one time measurements (air flow, COP, etc.) used in the audit or commissioning context.

Results

In a typical case study, savings are estimated in Table 3. Note the difference between the auditor's estimate of ECM savings and that derived from STM. The auditors overestimated the amount of lighting and consequently, the savings from this end use. Savings from hot water conservation were underestimated. Total savings are close to the auditor's estimate, but distributed differently between end uses. Similar results are apparent in other buildings.

At this writing only four buildings have been through the full pre- and post-retrofit measurement cycle. For these buildings, the savings estimates based on STM and audits are compared in Table 4. Even this small sample of buildings reveals important changes in the estimates. In the warehouse, the existing condition was seriously underlit. Improved lighting levels were achieved with efficient fixtures. The higher amount of savings reflects the energy consumption that would have been required to obtain the same lighting level using inefficient fixtures. In the retail building, noticeable savings are due to the occupants becoming more conscious of energy consumption and reducing lighting usage accordingly. In the public building, measured savings are significantly higher because the

Table 3. Example of STM Savings Estimate

	Pre-Retrofit Annual End use Estimate, kWh/yr	Post-Retrofit Annual End use Estimate, kWh/yr	Audit Savings Estimate, kWh/yr	Annual STM Savings Estimate, kWh/yr
Lighting	4,068	2,699	3,203	1,369
Hot Water	5,676	3,506	876	2,170
Total			4,079	3,539

Table 4. Audit and STM Savings Estimates, kWh/year

Building		Inside Lights	Outside Lights	Hot Water	Other
Retail	STM	1,369	NA	2,170	NA
	Audit	3,203	NA	876	NA
Warehouse	STM	31,848	NA	NA	NA
	Audit	5,725	NA	NA	NA
Retail	STM	8,398	6,500	NA	1,768
	Audit	0	8,875	NA	945
Public	STM	144,924	NA	NA	NA
	Audit	93,821	NA	NA	NA

occupancy schedule was determined to be a 17 hour day instead of the 12 hour day assumed by the audit. Measured savings for this limited set of buildings is about 75% larger than the audit estimates. In several other buildings for which only pre-retrofit measurements have been completed, significant savings opportunities have been observed which would otherwise have escaped notice during the audit or commissioning process.

Cost of STM Procedures

Based on current experience, costs to implement these procedures are estimated in Table 5. These cost estimates assume that there are at least three jobs/week, allowing a full-time technician to be assigned to the project. Projects are expected to be located nearby to minimize travel cost. Costs are compared for the full building sequence and for a single test series to isolate a single end use or ECM. In some cases, single end use tests can be integrated into the energy audit for further cost savings.

Value of STM Procedures

The benefit of STM arises from the value of improved energy savings estimates at the initial audit stage or later as part of commissioning new installations. Of twelve buildings, the measurements have not improved the initial audit estimates in six cases. However, in six other cases useful feedback has been observed, allowing improved energy estimates. Two instances with a combined savings implication of in excess of approximately 100,000 kWh per year were observed. Some of the most significant observations follow:

a. Motel--A baseload of approximately 13 kw is not explainable in terms of guest usage. This is not evident in audit observation and is probably a target for ECMs. There also appears to be a strong temperature correlation for electrical loads--several malfunctioning room thermostats could cause such loads.

b. Office Building--There is significant HVAC energy use, approximately twice the audit estimate. Fans are on 24 hours/day. Controls on multiple units are "battling" each other. The auditors estimated 10,000 kWh/yr savings from HVAC controls: They would have estimated 30,000 kWh/yr if they had known the true magnitude of HVAC energy use.

c. Police Station--Improperly set outside air controls require unnecessary heating of approximately 100,000 kWh/yr. This ECM was also observed by the auditors, but the short term measurements allowed an estimate of the magnitude.

d. Retail--Significant internal gains coincide with hot water use. A heat recovery water heater is a possible ECM. This connection was not evident to the auditors for lack of end use measurements.

f. Retail--Outdoor lighting savings proposed for this building are an insignificant portion of this building's overall energy use, which consists primarily of indoor lighting. The auditor did not identify the best ECM.

g. Medical Clinic--Poor HVAC controls account for significant electrical consumption. The ventilation fan

Table 5. Current Cost Estimate for STM

Independent Whole Building End Use		
Site Visit and Installation	4 hrs @ $40/hr	$160
Equipment and Data Retrieval	3 hrs @ $40/hr	$120
Data Checking and Entry	3 hrs @ $40/hr	$120
Data Review and Analysis	4 hrs @ $60/hr	$240
Report Preparation	2 hrs @ $60/hr	$120
Equipment Depreciation		$40
Total		$800
Single ECM Measurements		
Site Visit and Installation	2 hrs @ $40/hr	$80
Equipment and Data Retrieval	1.5 hrs @ $40/hr	$60
Data Review and Report	1.5 hrs @ $60/hr	$90
Equipment Depreciation		$15
Total		$245
Audit Integrated Single ECM		
Site Visit and Installation	1 hr @ $40/hr	$40
Equipment and Data Retrieval	1.5 hrs @ $40/hr	$60
Data Review and Report	0.5 hr @ $60/hr	$30
Equipment Depreciation		$15
Total		$145

represents about 26% of the building electrical energy use because it is running 24 hours per day. Evidence from the same building HVAC temperatures shows that the fan is not ventilating (introducing outside air). Improving fan control alone could reduce energy use by about 8-10%. A heat pump is in use at temperatures in the 30-45 degree F range although it operates with poor efficiency. Controls are supposed to switch heating to natural gas under these conditions. The heat pump lockout temperature setting should be raised from about 30 to 45 degree F to constrain the heat pump to operate in the most efficient range. In this case, control reset would save about 30-40% of the winter heat pump energy leading to annual electric savings of the order of 10%.

Conclusions

The work described here demonstrates the value of Short Term Measurements (STM) to improve auditor's estimates of energy savings. Auditors usually apply standard assumptions to estimate key operating parameters. Measurement of those parameters can improve the accuracy of the estimate. In about half of the cases, STM uncovered significant errors in audit assumptions.

Methods have been developed to perform field measurements and associated data analysis on a routine basis. The ability of this methodology to correctly estimate annual energy consumption based on measurements made at a single point in time has yet to be confirmed. Verification is underway but will require a full year's consumption history.

Significant cost reductions have been achieved for STM. The key features for reducing cost are to standardize field procedures and develop automated analysis procedures.

Definitions

The following definitions are used in Table 1.

D	=	accumulated load duration in one week
D_n	=	fraction of hour that subject load was operating
L	=	connected load, true power measured at load or by difference when load is turned off and on
QC_n	=	hourly energy of non-seasonal load either measured directly or measured by difference when load is turned off and on
QC_n	=	monthly energy of non-seasonal load
QL_n	=	hourly energy of load, true power or current ratioed to true power
QL	=	estimated annualized load energy
QS_m	=	estimated monthly energy of seasonal load
QS	=	estimated annual energy of seasonal load
QT_n	=	hourly energy of total load
QT_m	=	monthly energy of total load
T_m	=	mean monthly outside air temperature

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