NATIONAL RENEWABLE ENERGY LABORATORY

Chapter 10: Peak Demand and Time-Differentiated Energy Savings Cross-Cutting Protocols

The Uniform Methods Project: Methods for Determining Energy Efficiency Savings for Specific Measures

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1 Introduction

Energy efficiency savings are often expressed in terms of annual energy, presented as kilowatt-hour (kWh)/year. However, for a full assessment of the value of these savings, it is usually necessary to consider peak demand and time-differentiated savings.

2 Purpose of Peak Demand and Time-differentiated Energy Savings

Energy efficiency may reduce peak demand and, consequently, the need for investment in new generation, transmission, and distribution systems. This reduction in the need for new investment —also called "avoided capacity costs"—has value, and to estimate this value, it is necessary to estimate peak demand savings. Peak demand savings are typically expressed as the average energy savings during a system's peak period.

Avoided capacity costs can be a substantial portion of the value of an energy efficiency measure, particularly for measures that produce savings coincident with the system peak. The need to estimate peak demand savings is becoming more important as regional transmission organizations (RTOs, such as PJM and Independent System Operator [ISO]-New England) allow energy efficiency resources to bid into the forward capacity markets and earn revenues.[1]

In addition to considering peak demand savings, evaluators often must calculate time-differentiated energy savings. This is because avoided energy costs are typically provided in terms of costing periods. These costing periods divide the 8760 hours of the year into periods with similar avoided energy costs. These costing periods, which are utility/RTO/ISO specific, tend to vary monthly, seasonally, and/or in terms of time of day (peak, off-peak, super-peak).[2]

Calculating load impacts on an hourly basis provides flexibility in applying the results to a variety of costing period definitions. The cost period used can significantly affect the value of the energy savings. For example, a measure that reduced energy mostly at night is not as valuable as one that reduced energy mostly during summer afternoons, as shown in Figure 1.

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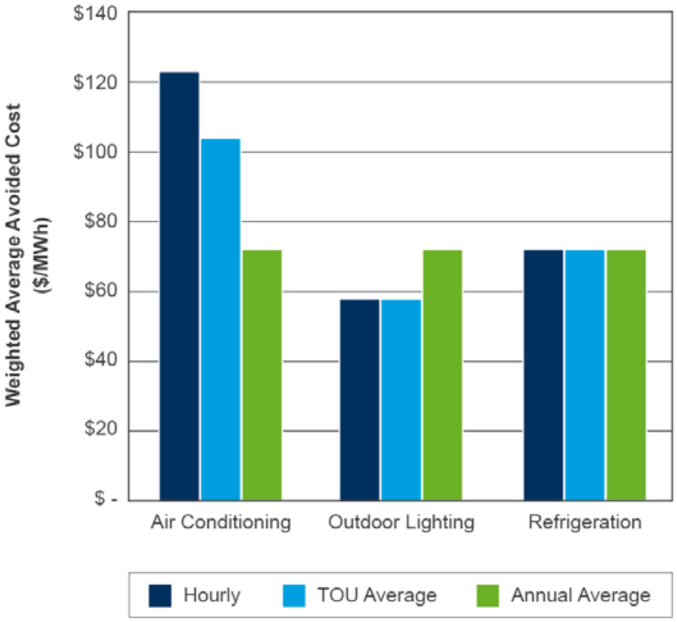
[1] These are where the regional transmission markets obtain the resources for ensuring system reliability. Providers of energy efficiency can bid into these markets on an equivalent basis to supply-side resources. Bids must be supported by measurement and verification.

[2] Avoided energy costs tend to be higher during periods of higher demand because generating units available during those times tend to have lower efficiency and higher operating costs.

Figure 1: Consideration of Time-Differentiation in Energy Savings Significantly Affects Estimates of the Value Savings



Source: (U.S. Environmental Protection Agency and U.S. Department of Energy 2006)

As another example, air-conditioning efficiency has higher value when hourly savings and costs are considered, because usage is higher when avoided costs are higher. Outdoor lighting, however, has lower values when hourly savings and costs are considered, because that usage is typically off-peak.

Peak demand and time-differentiated energy impacts are more difficult to measure than annual energy savings impacts (York 2007), so additional metering or simulation analysis may be needed to estimate these impacts accurately. Peak demand savings and time-differentiated energy savings can be estimated with:

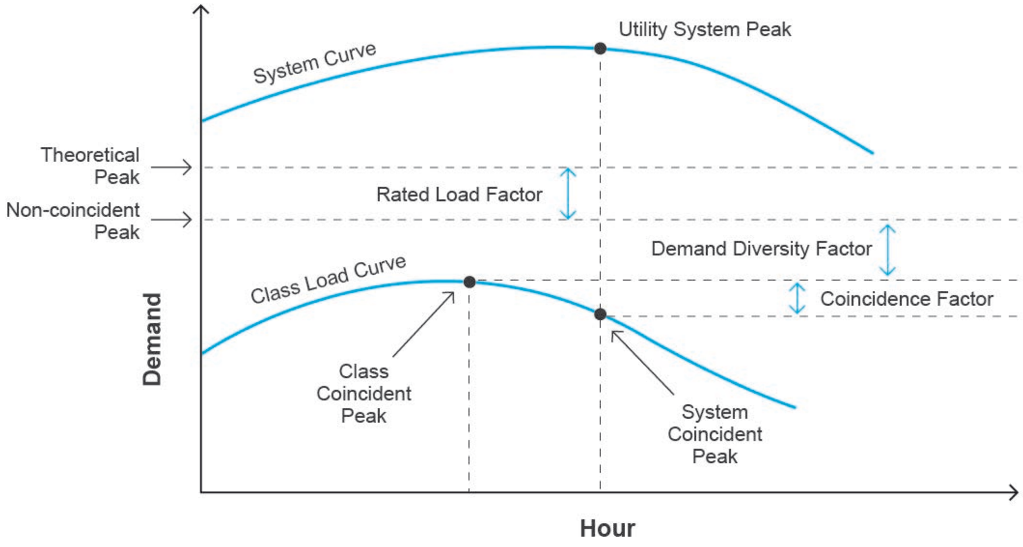
- Engineering algorithms
- Hourly building simulation modeling
- Interval meter data analysis
- End-use metered data analysis
- Survey data on hour of use
- Combined approaches.

Peak savings are estimated over a peak period. This period can range from one hour per year to several hours per day during a season.

3 Key Concepts

Understanding demand savings requires understanding the relationship between several factors, as shown in Figure 2.

Figure 2: Demand Savings Relationships



Source: (Jacobs 1993)

Note: Rated load factor, demand diversity factor, and coincidence factor are sometimes combined and referred to as "coincidence factor."

These brief definitions describe the key factors:

- **Peak period** is the period during which peak demand savings are estimated. (As previously noted, this period can range from one hour per year to several hours per day during a season.) Some utilities have a winter and summer peak period.
- **Theoretical peak** is the usage of a population of equipment if all were operating at nameplate capacity.
- **Non-coincident peak** is the sum of the individual maximum demands regardless of time of occurrence within a specified period.
- **Rated load factor (RLF)** is the ratio of maximum operating demand of a population of equipment to the nameplate power/capacity. It is the ratio of non-coincident peak to theoretical peak. For example, a building that dims its lamps to 90% of their output has a RLF of 0.9.
- **Demand diversity factor** is the ratio of the peak demand of a population of units to the sum of the non-coincident peak demands of all individual units. While an individual efficiency technology may save a certain amount of demand, those technologies are not all operating at the same time across all buildings throughout the

region. For example, if a maximum of 7 of 10 installed CFLs are on at any given time, then the diversity factor is 0.7.

- **Coincidence factor** is the fraction of the peak demand of a population that is in operation at the time of system peak. Thus, it is the ratio of the population's demand at the time of the system peak to its non-coincident peak demand. The peak demand use for a given building and end use are typically not aligned exactly with the utility system peak, which is how the avoided peak demand is defined. For example, if at the time of system peak, only 3 of the 7 CFLs mentioned above are on, then the coincidence factor is 3/7.

Some technical references use the term "coincidence factor" to mean the product of rated load factor, demand diversity factor, and coincidence factor. Northeast Energy Efficiency Partnerships (NEEP) defines it as, "The ratio of the average hourly demand during a specified period of time of a group of electrical appliances or consumers to the sum of their individual maximum demands (or connected loads) within the same period." (NEEP 2011).

The following terms are also are important to understanding the concepts of peak demand.

- **Average (or Annual Average) megawatt (MWa or aMW).** One megawatt of capacity produced continuously over a period of one year. 1 aMW = 1 MW x 8760 hours/year = 8760 MWh
- **Load factor.** The ratio of average energy savings to peak energy savings. This is also known as "peak coincidence factor" (NYSERDA 2008). More generally, load factor is the average demand divided by any number of peak demands, such as load factor at the time of system peak and load factor at the time of non-coincident peak.

$$Conservation\ Load\ factor = \frac{Energy\ savings}{Peak\ demand\ savings \times 8760\ hours}$$

- **Loss of load probability (LOLP).** The likelihood that a system will be unable to meet demand requirements during a period. LOLP can be used to distribute avoided capacity costs to each hour of the year.

4 Methods of Determining Peak Demand and Time-Differentiated Energy Impacts

Estimating peak demand and time-differentiated energy savings may require different techniques than estimating annual energy savings. For example, the method used to estimate demand savings may not be the most appropriate method to estimate energy savings—and vice versa (Fels 1993).

Approaches can also be combined to leverage available information. Some approaches for estimating annual energy savings (such as monthly billing data analysis) do not provide peak demand savings directly. However, these other approaches can be used with load shapes for analyzing peak impact.

4.1 Engineering Algorithms

Peak demand savings can be estimated using algorithms, as shown in Equation 1. This equation is similar to those used for energy savings (shown in Equation 2), except that the demand equation has diversity factor and coincidence factor in place of the full load hours.

Equation 1. Basic Demand Savings Equation

$$\Delta kW_{gross} = units \times RLF \times \left[\left(\frac{kW}{unit}\right)_{base} - \left(\frac{kW}{unit}\right)_{ee}\right] \times DF \times CF \times (1 + HVAC_d)$$

Where:

ΔkW_{gross} = gross demand savings
Units = units of measure installed in the program
RLF = rated load factor
kW/unit = unit demand of measure
DF = diversity factor
CF = coincidence factor
$HVAC_d$ = HVAC system interaction factor for demand

Source: (TecMarket Works 2004)

Equation 2. Basic Energy Savings Equation

$$\Delta kWh_{gross} = units \times RLF \times \left[\left(\frac{kW}{unit}\right)_{base} - \left(\frac{kW}{unit}\right)_{ee}\right] \times FLH \times (1 + HVAC_c)$$

Source: (TecMarket Works 2004)

4.2 Hourly Building Simulation Modeling

Hourly building simulation modeling (International Performance Measurement and Verification Protocol [IPMVP] Option D) can produce hourly savings estimates for whole buildings as well as for specific end uses. Consequently, it is an excellent means of estimating peak demand and time-differentiated energy savings. A building energy simulation model combines building characteristic data and weather data to calculate energy flows. While hourly models calculate energy consumption at a high frequency, non-hourly models may use simplified monthly or annual degree day or degree hour methods.

Simulation models are most applicable for heating, ventilating, and air-conditioning (HVAC), shell measures, and the interactive effects of HVAC with other measures. Simulation modeling requires an experienced modeler with an understanding of energy engineering. Hundreds of building energy simulation programs have been developed over the past 50 years (Crawley 2005).

Note that using this method does not necessarily provide an estimate of diversified demand. If a single, typical building is used, demand savings would be overstated due to lack of consideration of diversity, which tends to smooth out spikes in usage seen in individual buildings. Consideration of diversity requires either using average schedules or simulating a sample of buildings with different sizes, climate, and schedules.

4.3 Billing Data Analysis

Billing data analysis (IPMVP Option C) can be used to develop monthly estimates of savings. (Billing analysis is discussed in Chapter 8: *Whole-Building Retrofit Evaluation Protocol* chapter.) This type of analysis entails statistical comparison of pre- and post-participation and/or participant and nonparticipant billing data to estimate savings. Complex statistical analysis may be required to control for non-programmatic influences, such as weather and economic conditions. Also, isolating the impacts of a specific measure can be difficult because the meter measures usage for an entire building.

Although the coincident peak is usually not reported, billing analysis is useful in estimating non-coincident peak demand when the data include monthly building peak demand for each costing period. In addition, billing data analysis can be used to derive a realization rate on an engineering algorithm for energy savings that may also be applied to a demand savings algorithm.

4.4 Interval Metered Data Analysis

Utility revenue interval meters can measure usage at in increments of 15 minutes or less. Because consumption during different periods may be billed at different rates, these meters provide a means for analyzing a customer's load pattern. Interval meter data analysis is essentially the billing data analysis discussed above but with a finer time resolution.

As with billing analysis, isolating the impacts of a specific measure can be difficult, and statistical analysis may be required to control for non-programmatic influences. With the advent of advanced metering infrastructure and the availability of obtaining hourly information, there may be additional statistical approaches (such as conditional demand type analysis on hourly data) that could be used to help develop estimates of demand savings.

4.5 End-Use Metered Data Analysis

End-use metering data analysis (IPMVP Option A and Option B) can be an excellent means of estimating peak demand or time-differentiated energy savings. As with billing and interval data analysis, end-use metering data analysis entails a statistical comparison of pre- and post-participation and/or participant and non-participant billing data. However, end-use metering eliminates most—if not all—of the difficulty of isolating the impacts of specific measures.

There are several cautions to consider:

- Savings should be normalized for weather and other confounding factors.

- Pre-installation meter data is difficult to obtain because of the logistics entailed in coordinating with customers. Without pre-installation data, baseline conditions must be estimated with engineering algorithms.
- End-use metering is costly, so it should be conducted strategically.
- An impact load shape may be different than a post-participation load shape. For example, lighting control impact shapes are different from the shape of the controlled lighting. (End uses have shapes with and without the efficiency measures in place and the difference is the impact shape.) Determination of some energy efficiency shapes may require either pre-installation metering or reconstruction of the baseline shape.
- Sampling must be done carefully—see Chapter 11: *Sample Design* protocol.
- The evaluator must consider the period over which to meter. How much time is required? Is a certain time, such as summer, critical?

The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) has developed a methodology to derive the diversity factors and provide the typical load shapes of lighting and receptacle loads for office buildings using end-use metered data (Abushakra 2001).

4.6 Survey Data on Hours of Use

Evaluators may conduct hours-of-use surveys to identify the times of day when equipment is used. For example, a survey might ask if residential compact fluorescents are used during the summer from 3:00 p.m. to 6:00 p.m., a typical period for system peak. If the results indicate that 5% of lights were in use at that time, then the combination of the coincidence and diversity factors would be 5%.

Survey sampling should be done in conjunction with the techniques described in Chapter 11: *Sample Design* chapter. However, relying on customer perception may result in significant inaccuracy.

4.7 Combined Approaches

Applying a combination of approaches facilitates using data from several sources to provide the best estimates of demand savings. For example, for a low-income program, billing data may be the best approach for estimating energy savings. Engineering algorithms can be used to develop energy and demand savings for each participant, and these participant energy savings can be the independent variables in a statistically adjusted engineering (SAE) billing analysis. (See Chapter 8: *Whole-Building Retrofit Evaluation Protocol*) The realization rate from the SAE analysis can be then applied to the population demand estimate from the engineering model.

Combined approaches also include nested samples where a smaller number of metered sites is used to calibrate telephone surveys from a much larger population. For example, a sample of 30 metered sites may yield a combined coincidence and diversity factor of 6.1%, while the telephone survey produced an estimate of 5.0% for the metered sample and 5.5% for the entire telephone sample. The ratio of 6.1% to 5.0% would be applied to the 5.5% telephone sample estimate, resulting in an adjusted factor of 6.7%.

4.8 Summary of Approaches

Table 1 presents a summary of the approaches in terms of relative cost and relative potential accuracy. In all cases, the accuracy achieved depends on the quality of the analysis.

Table 1: Summary of Approaches

Approach	Relative Cost	Relative Potential Accuracy	Comments
Engineering Algorithms	Low	Low-Moderate	Accuracy depends on the quality of the input assumptions as well as the algorithm
Hourly Simulation Modeling	Moderate	Moderate	Input assumptions are again important—garbage in, garbage out. Appropriate for HVAC and shell measures and HVAC interaction
Billing Data Analysis	Moderate	Moderate	Typically not useful for peak demand or on/off peak energy analysis
Interval Meter Data Analysis	Moderate	High	Interval meter data not available for many customers. Becoming more feasible with proliferation of advanced metering infrastructure (AMI)
End-Use Metered Data Analysis	High	High	Requires careful sampling and consideration of period to be metered

5 Secondary Sources

Because of budget or time constraints, evaluators may choose to rely on secondary sources, rather than on the primary sources listed above.

5.1 Technical Reference Manuals

A technical reference manual (TRM) specifies savings or protocols for common energy efficiency measures. A TRM is not a method for estimating savings, but a source of estimates or methods. Typically, TRMs provide deemed savings values that represent approved estimates of energy and demand savings. These savings are based on a regional average for the population of participants; however, they are not savings for a particular installation.

Although TRMs often provide industry-accepted algorithms for calculating savings, users should not assume that because an algorithm has been used elsewhere it is correct. Mistakes are common and should be expected.

5.2 Application of Standard Load Shapes

By applying load shapes to allocate energy consumption into costing period, peak demand and time-differentiated energy savings can also be estimated from energy impacts. A key resource of load shape data is the California Database for Energy Efficiency Resources (CPUC 2011). These shapes may be derived from metering or simulation. The evaluator must consider the applicability of the shapes when climate-sensitive end uses are involved.

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