B O N N E V I L L E   P O W E R   A D M I N I S T R A T I O N

Estimating Peak Demand Impacts Application Guide

May 2024




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Version 3.0

May 2024

Prepared for

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SBW Consulting

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2. Introduction

2.1. Purpose

The Bonneville Power Administration (BPA) Measurement and Verification (M&V) protocols provide guidance on developing and implementing an M&V plan for custom energy efficiency projects. The existing protocols focus on estimating the energy savings (kWh) resulting from incented upgrades. Energy efficiency projects that save energy during the periods when the electrical system is most constrained also deliver peak demand (kW) or capacity savings. This document provides guidance on the estimation of peak demand impacts.

Peak demand savings analysis is an exercise in time-differentiation. Instead of quantifying how much energy is saved, which is the focus of the other BPA M&V protocols, peak demand savings analysis asks the question, "When is energy saved?" We are specifically interested in the average savings during a very narrow portion of the year.

The capacity savings from energy efficiency have important implications for long-term system planning. Peak demand savings are also important for project cost-effectiveness. The value of energy savings is typically monetized using the power system's volumetric cost components, which are driven by the price of fuel. In contrast, the value of peak demand savings is determined by the fixed cost components of the system. Peak demand impacts can reduce the need for three types of capacity:

- ➡ **Generation Capacity** – the ability to produce electric power. Reductions in peak demand can reduce the need to build new power plants to meet maximum power demands.
- ➡ **Transmission Capacity** – the ability to move power at high voltage for long distances from the generation source to load. Peak demand reductions can relieve transmission constraints and avoid or defer the need for upgrades to transmission infrastructure.
- ➡ **Distribution Capacity** – the delivery of power at secondary levels to homes and businesses. Capital investments in distribution infrastructure are driven by peak loads and can be avoided or deferred through conservation.

It is possible that these system components could have different peaking profiles, but for M&V purposes, common practice is to calculate a single estimate of the average reduction in electrical demand during a single defined period of system peak.

Peak demand impacts are also relevant for participating customers. Many large commercial and industrial customers have billing determinants that are based on coincident or non-coincident demand levels to allocate and recover the fixed costs of the power system's equipment.

Definitions of system peak vary widely across North America. Some power systems peak in the summer; others peak in the winter. Some jurisdictions use a weather-based definition that assumes the system peak occurs at a given ambient temperature. Other jurisdictions use a seasonal definition. For example, the PJM transmission organization defines its peak period as non-holiday weekdays from 2:00 PM to 6:00 PM June through September.[1]

2.2. Protocols Version 3.0

BPA revised the protocols described in this guide in 2024. BPA published the original documents in 2012 as Version 1.0, which were updated to Version 2.0 in 2018. The current guides are Version 3.0.

2.3. How is M&V Defined?

BPA's *Implementation Manual* (the IM) defines measurement and verification as "the process for quantifying savings delivered by an energy conservation measure (ECM) to demonstrate how much energy use was avoided. It enables the savings to be isolated and fairly evaluated."[2] The IM describes how M&V fits into the various activities it undertakes to "ensure the reliability of its energy savings achievements." The IM also states:

> *The Power Act specifically calls on BPA to pursue cost-effective energy efficiency that is "reliable and available at the time it is needed."[3] […] Reliability varies by savings type: UES, custom projects and calculators.[4,5] For UES measures and Savings Calculators, measure specification and savings estimates must be RTF approved or BPA-Qualified […].[6] Custom projects require site-specific Measurement and Verification (M&V) to support reliable estimates of savings. BPA M&V Protocols[7] direct M&V activities and are the reference documents for reliable M&V.*

M&V is site-specific and required for stand-alone custom projects. BPA's customers submit bundled custom projects (projects of similar measures conducted at multiple facilities) as either an

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1 PJM Interconnection LLC (PJM) is a regional transmission organization serving all or parts of Delaware, Illinois, Indiana, Kentucky, Maryland, Michigan, New Jersey, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia, and the District of Columbia. PJM is derived from Pennsylvania-New Jersey-Maryland, its name in 1956. The organization continues to add additional utility transmission systems into its operations.

2 *2024-2025 Implementation Manual*, BPA, April 1, 2024. https://www.bpa.gov/-/media/Aep/energy-efficiency/document-library/24-25-im-april24-update.pdf

3 Power Act language summarized by BPA.

4 UES stands for Unit Energy Savings and is discussed subsequently. In brief, it is a stipulated savings value that region's program administrators have agreed to use for measures whose savings do not vary by site (for sites within a defined population). More specifically UES are specified by either the Regional Technical Forum – RTF (referred to as "RTF approved") or unilaterally by BPA (referred to as BPA-Qualified). Similarly, Savings Calculators are RTF approved or BPA-Qualified.

5 Calculators estimate savings that are a simple function of a single parameter, such as operating hours or run time.

6 https://www.bpa.gov/-/media/Aep/energy-efficiency/document-library/24-25-im-april24-update.pdf , page 1.

7 Protocols include: M&V Protocol Selection Guide; reference guides for sampling, regression, and glossary; protocols on metering, engineering calculations with verification, energy modeling, and existing building commissioning

M&V Custom Program or as an Evaluation Custom Program; the latter requires evaluation rather than the site-specific M&V that these protocols address.

2.4. Background

BPA contracted with a team led by Facility Energy Solutions to assist the organization in revising the M&V protocols used to assure reliable energy savings for the custom projects it accepts from its utility customers. The team conducted a detailed review of the 2018 M&V Protocols and developed the revised version 3.0 under Contract Number BPA-2-C-92283.

The Facility Energy Solutions team is comprised of:

- Facility Energy Solutions, led by Lia Webster, PE, CCP, CMVP
- Stillwater Energy, led by Anne Joiner, CMVP
- SBW Consulting, led by Santiago Rodríguez-Anderson, PE

BPA's Todd Amundson, PE, PMVE was project manager for the M&V protocol update work. The work included gathering feedback from BPA and regional stakeholders, and the team's own review to revise and update this 2024.

3. Concepts and Definitions

3.1. Peak Demand Definitions for BPA M&V

BPA's service territory is geographically large and encompasses multiple smaller systems with varying capacity considerations leading to varying localized peak demand periods. M&V practitioners should always seek to understand the local definitions and requirements of the program or utility they support and customize their analyses accordingly. Local variations aside, the BPA system as a whole is winter-peaking and those peaks are driven by cold weather. Figure 2-1 shows the daily peak loads of BPA's system for 2017 and 2018, by day of week, plotted against the average temperature for the day. [8] Winter peaks tend to be several thousand MW higher than summer peaks and weekday peaks tend to be higher than weekend peaks.

Figure 2-1: Daily Peaks (MW) of BPA Balancing Authority 2017-2018

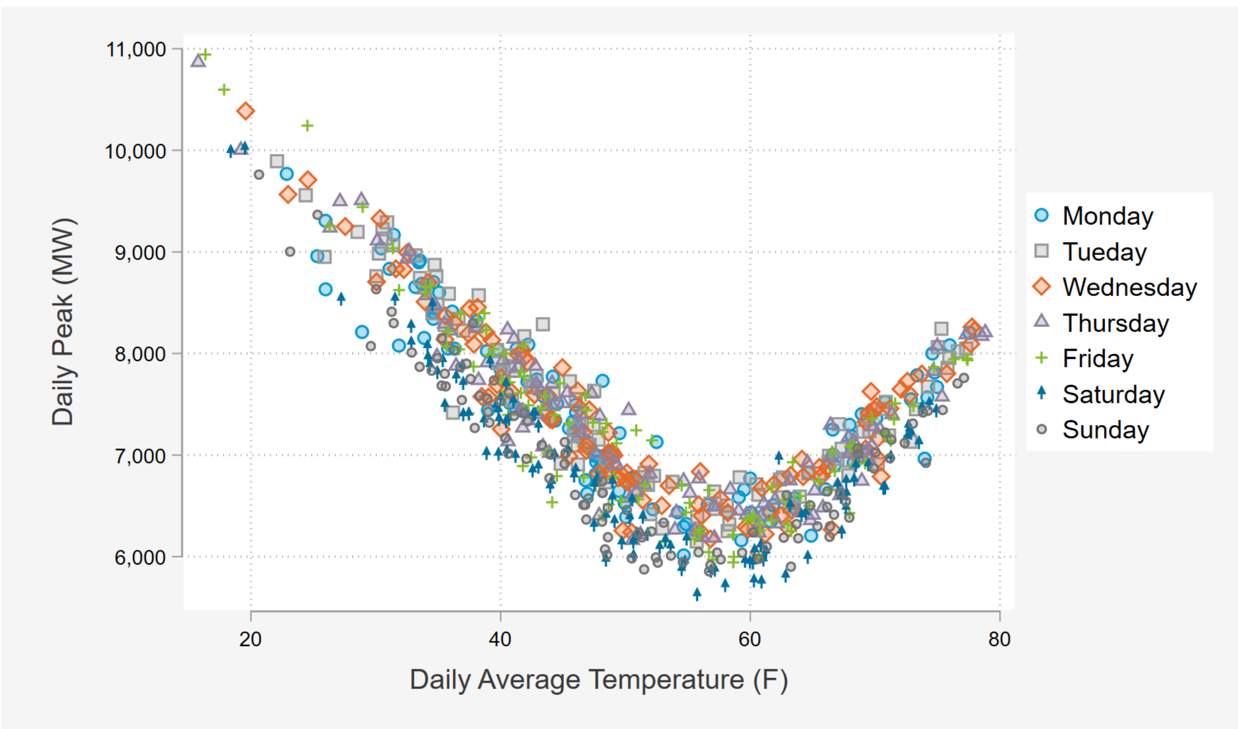


Figure 2-2, which is taken from a presentation on BPA's 2020-2021 Energy Efficiency Implementation Plan,[9] shows how, during winter months, demand for electricity exceeds BPA's

8 BPA system weather was calculated from an average of the Everett, Tacoma, Vancouver, Eugene, Yakima, The Dalles, Bend, Spokane, and Flathead NOAA weather stations.

9 *https://www.nwcouncil.org/sites/default/files/2019_0115_p3.pdf*

generating capabilities and requires purchases of power. The figure also alludes to the fact that energy efficiency lowers power consumption and reduces how much power must be purchased.

Figure 2-2: Northwest Power and Conservation Council Monthly Energy Profile

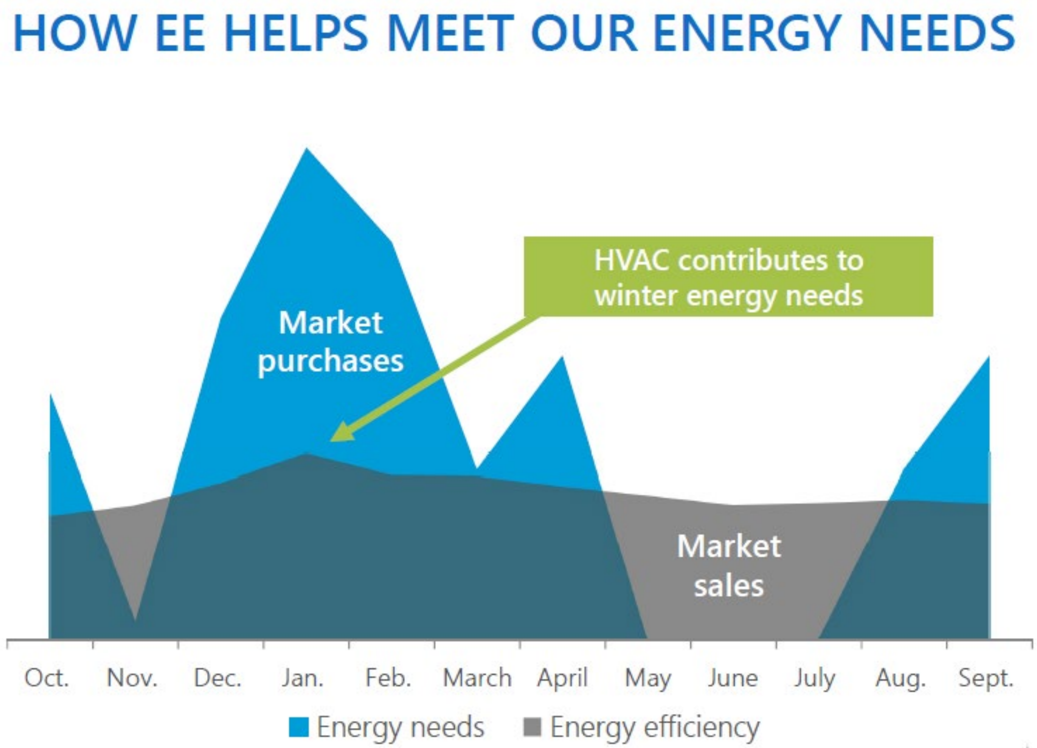
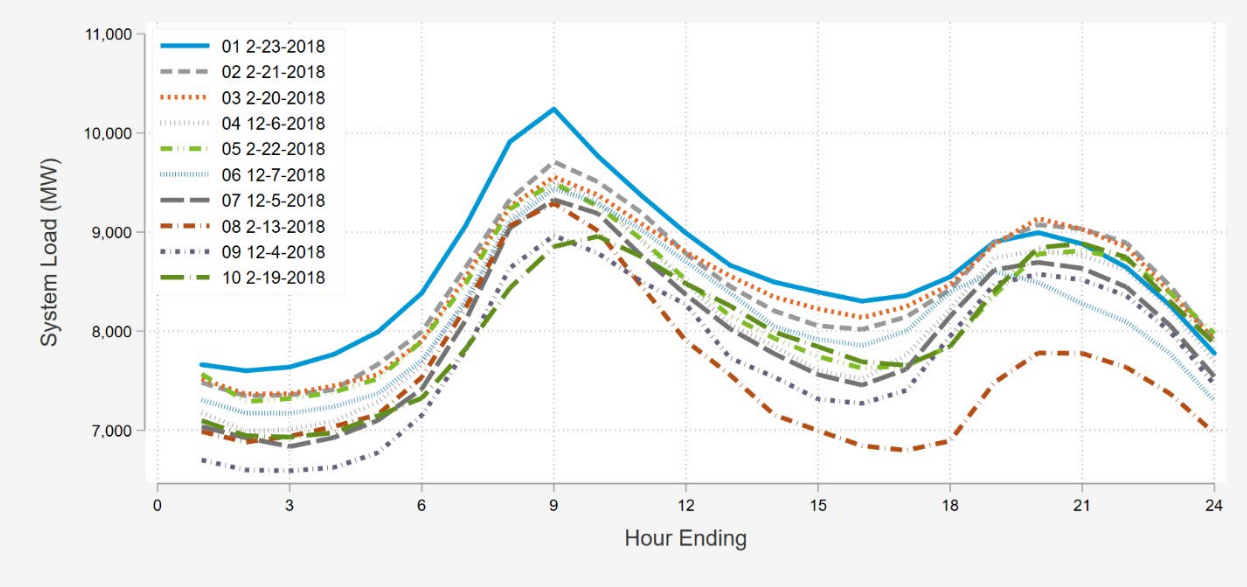


Figure 2-3 shows the average hourly load shape for the BPA balancing authority on the ten days in 2018 with the highest peak loads. All ten days occurred during winter months. These extreme winter days exhibit a double peak with loads peaking in the morning and again in the early evening. The daily peak is generally set in the morning hours.

Figure 2-3: Hourly Load Profiles for Top 10 Days of 2018



Based on a review of system characteristics and discussion with BPA staff, we established that a definition of 6:00 AM to 10:00 AM on cold winter weekdays is a reasonable definition for use in the examples in this application guide. Users should always familiarize themselves with the peak demand savings definitions for the utility or program they support as definitions will vary. For example, the Regional Technical Forum (RTF) uses a 6pm winter weekday definition for capacity savings when calculating energy efficiency cost-effectiveness. For weather-dependent savings, the practitioner estimating capacity impacts might want to also factor in expectations of the typical weather conditions during system peak conditions. Section 4.2 illustrates an analysis including temperature during system peak.

3.2. Core Concepts

As with the selection of the appropriate BPA M&V protocol for energy savings estimation, the appropriate approach for estimating peak demand savings is driven by the data available and falls into two broad categories:

➡ **Direct estimation with primary data:** requires the availability of hourly or sub-hourly measurements of the parameter(s) of interest. For example, practitioners using the *Energy Modeling Protocol* to estimate energy impacts from hourly or sub-hourly data typically can directly estimate demand savings using primary data.

➡ **Estimation using secondary sources:** uses secondary information along with inputs or outputs of energy savings calculations to estimate average savings during the peak demand window. Consider that a regression analysis of monthly or daily billing records is unable to differentiate when the savings occurred within those months or days. Secondary resources can be used to estimate how energy consumption and estimated savings might be distributed throughout the day for that type of business or end-use. Practitioners using the *Engineering Calculations with Verification Protocol* to estimate energy impacts, for example, need to use secondary sources to estimate demand savings.

Direct estimation will generally involve creating mathematical models of the affected loads within the measurement boundary before and after implementation of the energy improvement project. Capacity savings are estimated as the difference in demand between the average before and after predictions during the peak-period time and/or weather conditions. This modeling approach is functionally similar to the normalized savings procedure described in the *Verification by Energy Modeling Protocol*.

The concepts or tools a practitioner might leverage for estimation using secondary sources include:

- ➡ **Load shape:** a table or chart showing average distribution of consumption or savings across some period. Load shapes might show the profile on a daily, weekly, or even annual (8760) basis.
- ➡ **Coincidence factor:**[10] a value ranging between zero and 1.0 that represents the ratio of the equipment's average load during the peak demand period to the full power draw of the equipment when operating. For a constant load (such as a lighting fixture), the coincidence factor is equivalent to the probability that the equipment is operating during the peak demand period. For a variable load, the average load is equal to the product of the probability that the equipment is operating and the ratio of its average power draw to full connected load.
- ➡ **Energy to demand factor:**[11] the ratio of peak demand savings to annual energy savings for a measure type or end-use. For a load that is perfectly flat all hours of the year, the energy to demand factor is equal to 1/8760 = 0.000114.

When using secondary values such as coincidence factor or energy-to-demand factor obtained from a jurisdiction other than BPA, it is important the practitioner verify that the other jurisdiction defines the peak period similar to BPA.

3.3. Load Shape Resources

Load shapes have wide-ranging application across electric utility activity including establishing cost-of-service, designing rates, and planning system upgrades. This application guide focuses on estimating peak demand impacts from energy efficiency projects; however, practitioners can use methods like those presented here to differentiate energy savings into periods that align with the marginal system cost of energy throughout the year.

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10 For additional discussion see National Renewable Energy Laboratory. 2017. Uniform Methods Project: Methods for Determining Energy Efficiency Savings for Specific Measures – Chapter 10: Peak Demand and Time-Differentiated Energy Savings Cross-Cutting Protocol. Available at: *https://www.nrel.gov/docs/fy17osti/68566.pdf*

11 The Pennsylvania Technical Reference Manual uses energy to demand factors (ETDF) to calculate peak demand savings based on the annual energy savings of many domestic hot water and agricultural efficiency measures. *http://www.puc.pa.gov/pcdocs/1614951.docx*

The list below provides a few resources M&V practitioners may use as secondary resources to time-differentiate energy savings and to estimate capacity savings when demand impacts cannot be estimated directly from the M&V data.

- **Class load shapes:** Electric utilities often maintain load research samples to understand the timing of use, diversity, load factor and other key metrics for a customer class. These data are used for cost allocation and rate design.
  - **Pros:** Local data. A load shape from the customer class of a participating facility will reflect the billing determinants the participant faces, such as weather and geography.
  - **Cons:** (1) A given facility does not always resemble the class average. (2) Class load shapes will typically be at the premise level rather than the end-use level. An energy efficiency project that impacts refrigeration loads, for example, might be poorly represented by a premise load shape.
- **Northwest Power and Conservation Council Library:** In recent years, the Regional Technical Forum (RTF) has invested resources in organizing and reviewing hourly load profiles of energy efficiency measures[12] to support the calculation of capacity benefits from energy efficiency and has developed capacity load shape recommendations memos.[13]
  - **Pros:** Well-documented and regionally appropriate.
  - **Cons:** Locating and navigating the actual load profiles can be challenging for users not familiar with the RTF website or CEUS/ELCAP.
- **Electric Power Research Institute (EPRI) Load Shape Library:**[14] EPRI maintains a public repository of both end-use and premise load shapes in an easy-to-navigate web interface. The source data includes regional utility studies such as BPA's Building Stock Assessments.
  - **Pros:** (1) Includes both end-use and premise load shapes. (2) Includes a variety of end-uses by sector as well as premise load shapes for approximately 20 building types.
  - **Cons:** Does not capture diversity across BPA's service territory. For end-use load shapes, practitioners would select the WSCC\NWP region. For premise load shapes, the Medford, Oregon location would be the most regionally appropriate value.
- **Northwest Energy Efficiency Alliance (NEEA)[15]:** The Northwest End Use Load Research (EULR) project is a regional study designed to gather accurate load profiles for electrically-powered equipment in homes and businesses.

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12 *https://rtf.nwcouncil.org/end-use-load-shape-eulr-hourly-data/*

13 *https://rtf.nwcouncil.org/capacity-benefits-efficiency-load-shape-recommendation-memos*

14 *http://loadshape.epri.com/*

15 *https://neea.org/data/nw-end-use-load-research-project/energy-metering-study-data*

4. Overview of Method

4.1. Description

This *Estimating Peak Demand Impacts Protocol* provides guidance for calculating the capacity savings achieved by energy conservation measures (ECMs) implemented in commercial buildings, industrial facilities, or their subsystems. This application guide is intended to be flexible enough to use the procedures in conjunction with multiple BPA energy M&V protocols.

The application guide provides methods to estimate the average energy savings during a specific subset of hours on specific days or weather conditions. BPA defines the peak period for the purposes of this guide as cold winter weekday mornings from 6:00 AM to 10:00 AM (hours ending 7, 8, 9, and 10 local prevailing time). Capacity savings are expressed on a power (kW) as opposed to an energy (kWh) basis. At the hourly level, these two quantities are interchangeable so the average hourly kWh savings during the peak period is equivalent to the expected kW impact.

Working with hourly or sub-hourly data to estimate demand impacts for a specific subset of hours requires careful attention to certain data management procedures to ensure accurate inferences. Examples include:

- ➡ **Handling of time stamps, including daylight savings time.** Whether an analysis relies on interval readings from the facility revenue meter or end-use logging equipment, it is important to determine the convention used in the date/time series. The same attention to detail is needed when merging hourly weather records to granular load data to ensure proper modeling of the weather relationship.
- ➡ **Energy vs. demand.** For sub-hourly data it is essential to determine whether the measurements represent average demand during the interval or energy consumed. For example, a utility meter might measure average kW or kWh in 15-minute intervals. When using 15-minute kWh readings, each value needs to be multiplied by four to convert to demand (kW).
- ➡ **Interval ending vs. interval beginning.** For a given record in a table of trend data, does the timestamp represent the end of the interval or the beginning? Consider the example shown in Table 3-1 of 15-minute interval meter data stamped interval ending. The 15-minute interval ending at 6:00 AM represents the load measurement from 5:45 AM to 6:00 AM.

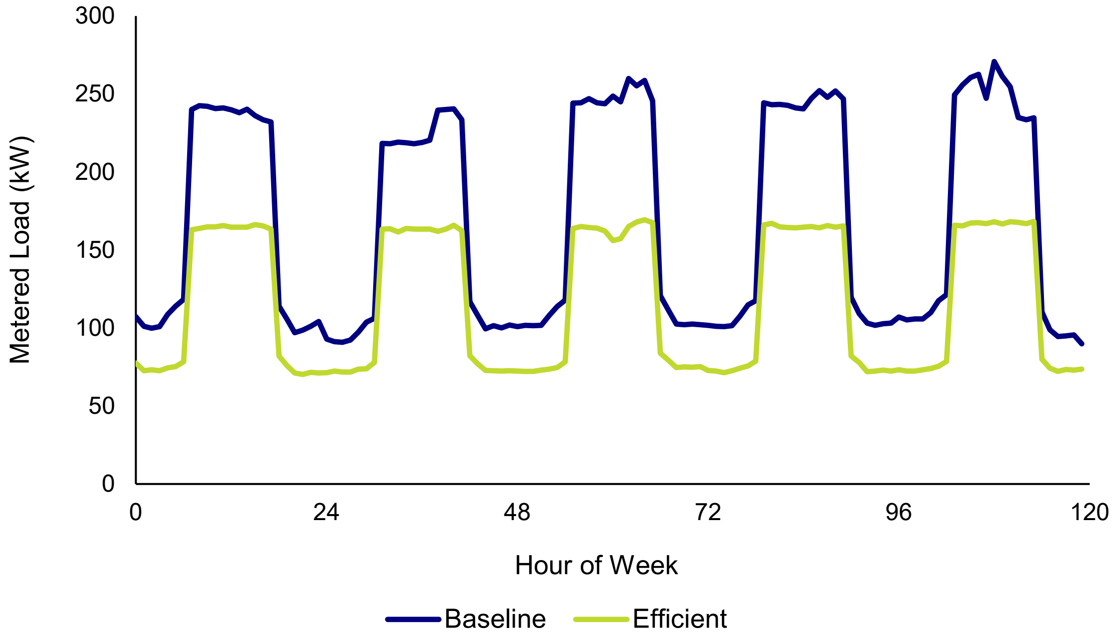
Table 3-1: 15-minute Interval Data Example

Date	Timestamp	Hour Ending	Peak Period?
2/12/2019	05:45:00 AM	6	No
2/12/2019	06:00:00 AM	6	No
2/12/2019	06:15:00 AM	7	Yes
2/12/2019	06:30:00 AM	7	Yes
2/12/2019	06:45:00 AM	7	Yes
2/12/2019	07:00:00 AM	7	Yes
2/12/2019	07:15:00 AM	8	Yes

➡ **Handling of missing data.** Data gaps, spikes, and missing/zero/negative reads happen with high-frequency data. There are entire protocols on validation, estimation, and editing of meter data. Practitioners should review data streams for outliers prior to analysis to avoid spurious results. Charting the raw data is a useful tool for identifying potential data issues. Observations that are clearly bad should be removed from the data set after investigating the root cause of the bad measurements. Short gaps – particularly for weather data - can be interpolated using observations from before and after the missing period.

A Constant Load, Timed Schedule (CLTS) profile from the *Verification by Equipment of End-Use Metering Protocol* provides a simple illustration of peak demand impact estimation. Figure 3-1 shows average hourly loads for a large compressed-air load in a manufacturing facility that was metered for three weeks before and after the addition of a VFD and updated staging. The baseline and efficient period data are each averaged by day of week and hour for easy visual comparison. Because our peak demand definition focuses on weekdays, the figure excludes weekend loads.

Figure 3-1: Average Hourly Load Profile by Day of Week



This process load shows a distinct pattern by time of day, but a discussion with the site contact indicated that the load pattern is uncorrelated with weather conditions. In this case, the estimated capacity savings is equal to the average difference in power draw from 6:00 AM to 10:00 AM on weekdays between the baseline and efficient metering periods (see Table 3-2). For this facility, the peak demand period includes a mixture of the overnight and daytime operating profiles.

Table 3-2: Peak Demand Savings Calculation

Hour Ending	Mean kW Baseline	Mean kW Efficient	kW Savings
7	116.3	78.4	37.9
8	239.3	164.4	74.9
9	240.8	165.0	75.8
10	242.4	164.6	77.8
Average kW Reduction During Peak Demand Window			66.6

4.2. Applicability

This *Estimating Peak Demand Impacts Protocol* is applicable to any of the BPA M&V protocols below the "Prescriptive Boundary" in the protocol selection flowchart shown in the *BPA M&V Protocol Selection Guide*[16] . This includes:

- ➡ Verification by Equipment or End-Use Metering Protocol,
- ➡ Verification by Meter-Based Energy Modeling Protocol, and
- ➡ Engineering Calculations with Verification Protocol (ECw/V).

The tools used to estimate savings for prescriptive measures – Unit Energy Savings (UES) values or approved calculators – will generally include estimates of the capacity savings.

[16] BPA Measurement & Verification (M&V) Protocol Selection Guide and Example M&V Plan, V3.0. *https://www.bpa.gov/energy-and-services/efficiency/measurement-and-verification*

5. Algorithms and Examples

5.1. Basic Procedure

The basic formulation of the capacity impacts (or peak demand savings) algorithm is presented in Equation 1. Two mathematically identical forms are shown. The first equation averages demand measurements (kW) that would often be collected by end-use metering equipment. The second presentation bases the calculation on energy values (kWh) divided by the number of hours considered. In both cases, the aggregation of intervals should include the entirety of the peak demand period.

Equation 1: Generalized Form of the Peak Demand Savings Algorithm

- $\Delta kW_{peak} = \frac{\sum_{i}^{n}(kW\ baseline_i - kW\ efficient_i)}{n}$
- Or

$$\Delta kW_{peak} = \frac{\sum_{i}^{h}(kWh\ baseline_i - kWh\ efficient_i)}{h}$$

Where:

$kW\ baseline_i$ = the estimated demand of the baseline building/system at interval i

$kW\ efficient_i$ = the estimated demand of the efficient building/system at interval i

$kWh\ baseline_i$ = the estimated energy use of the baseline building/system in interval i

$kWh\ efficient_i$ = the estimated energy use of the efficient building/system in interval i

n = the number of data intervals in the peak demand period definition

h = the number of hours in the peak demand period definition

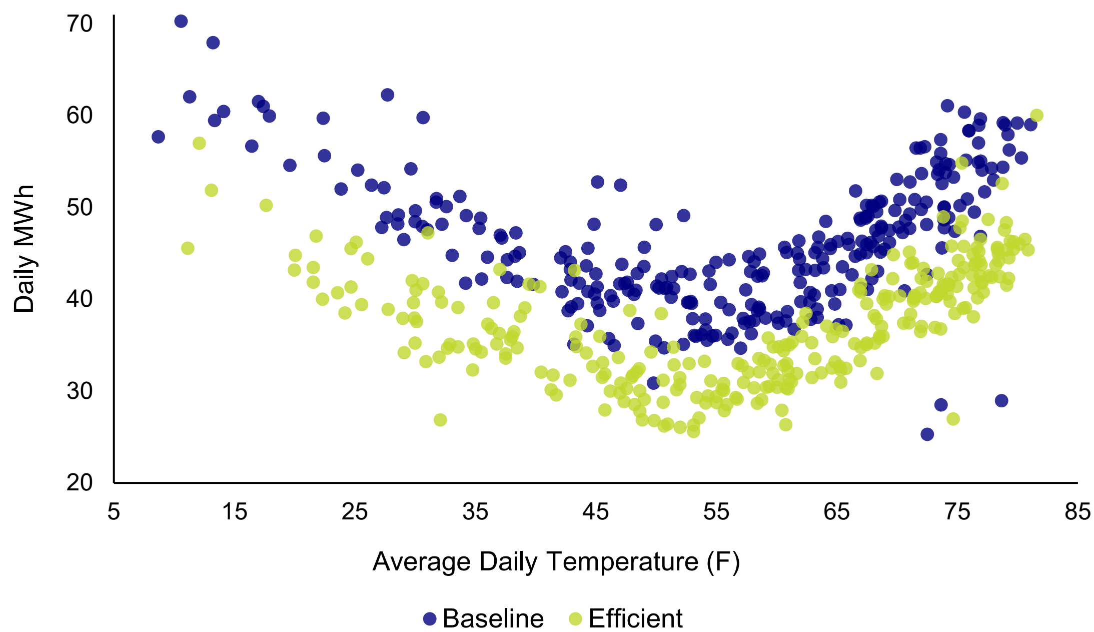
The methods used to estimate the baseline and efficient kW values will vary depending on the M&V protocol used to determine energy savings for the project. Section 3.1 provided an example of estimating capacity savings within the *Verification by Equipment or End-Use Metering Protocol*. The following sections provide an overview of the detailed calculations for several commonly used analysis protocols. Section 4.2 is an example of direct estimation with primary data (hourly data). Sections 4.3 and 4.4 illustrate estimation using secondary sources (daily data and energy calculations, respectively).

5.2. Energy Modeling with Hourly Data

When the expected project savings represent a significant portion of the total consumption of a facility, practitioners will often choose to implement the *Verification by Energy Modeling Protocol*. Even with access to hourly or sub-hourly readings from the utility revenue meter, engineers may choose to model the energy savings using daily records to make the analysis dataset more manageable and avoid the autocorrelation that accompanies high frequency data.

Figure 4-1 is a scatterplot of daily energy consumption (MWh) against average daily temperatures for a large facility that implemented multiple conservation measures over a six-week period. The scatterplot is limited to weekdays as a separate model was developed for weekends when facility loads were considerably lower.

Figure 4-1: Daily Energy Use versus Temperature Before and After Project Implementation



The facility shown in Figure 4-1 is clearly weather dependent, so a 4P model with a change point of 55 degrees (F) was selected to estimate the annual energy savings attributable to the project. (See BPA's *Energy Modeling Protocol* for a discussion on four-parameter (4P) models and modeling in general.) [17]

For a weather-dependent analysis, a simple average of the baseline demand values and of the efficient period demand values (as in the example in Table 3-2) is not appropriate. It is necessary to first identify the expected weather conditions during the peak period and then estimate consumption using the baseline and efficient period regression models at the relevant time of day and ambient weather. This analysis would be accomplished using Typical Meteorological Year (TMY3) data for the relevant weather station.

The practitioner would filter the TMY3 data to hours ending 7, 8, 9, and 10 during the months of December, January and February. It is unnecessary to exclude weekends from this analysis, as weather is unaffected by daytype. Table 4-1 shows what the results of such a calculation might return.

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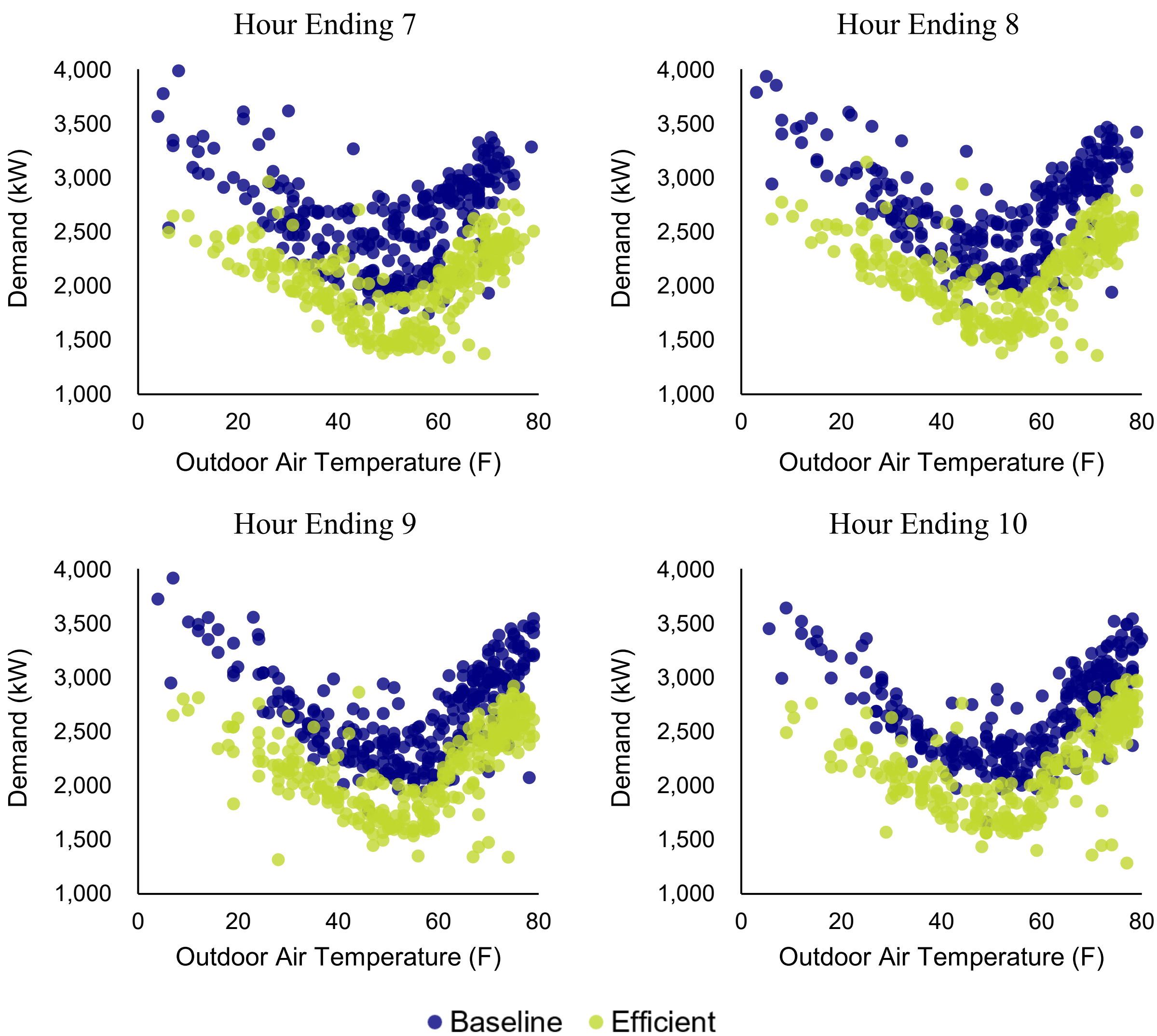
[17] *https://www.bpa.gov/EE/Policy/IManual/Documents/7_BPA_MV_Energy_Modeling_Protocol.pdf*

Table 4-1: TMY3 Conditions During Peak Demand Period

Hour Ending	Average TMY3 Temperature (F)
7	22.1
8	22.8
9	24.1
10	25.3

The peak demand analysis requires the use of hourly data, even if the practitioner had previously aggregated granular data into daily totals. Limiting the peak demand analysis data set to the hours of interest gives data such as shown in Figure 4-2.

Figure 4-2: Load-Temperature Relationship During Hours of Interest



Because the peak demand definition is associated with winter months, the analysis dataset for capacity impacts can be limited to the heating slope side of the spectrum for modeling. Table 4-2 shows the results of eight distinct regression models – one for each peak demand hour in the baseline and efficient periods. These models use outdoor air temperature (OAT) as the measured value, rather than the change point minus OAT. Models with OAT and with change point minus OAT are mathematically identical, differing only in the interpretation of the intercept term. In Table 4-2, the intercept represents the expected load (kW) at 0 degrees (F) and the OAT coefficient represents the expected change in kW for a 1-degree (F) increase in OAT.

Table 4-2: Regression Coefficients by Hour and Period

Period	Hour Ending	Model Intercept	OAT (Slope)	Coefficient
Baseline	7	3,502.8	-25.71	
Baseline	8	3,691.6	-28.96	
Baseline	9	3,660.5	-28.38	
Baseline	10	3,515.7	-25.50	
Efficient	7	2,843.0	-23.98	
Efficient	8	2,930.8	-24.14	
Efficient	9	2,853.6	-22.40	
Efficient	10	2,734.4	-19.63	

In Table 4-3, the regression coefficients from Table 4-2 are combined with the temperature values in Table 4-1 to predict demand for each hour using the baseline and efficient period models. The estimate of capacity impacts for the hour is calculated as the baseline demand minus the efficient period demand. For example, the predicted baseline load (kW) in hour ending 7 is equal to:

$$3{,}502.8 + 22.1 * (-25.71) = 2{,}934.7\ kW$$

And the predicted demand for the efficient case in hour ending 7 is:

$$2{,}843.0 + 22.1 * (-23.98) = 2{,}313.0\ kW$$

Table 4-3: Regression-Based Peak Demand Savings Calculation

Hour Ending	Predicted Baseline (kW)	Predicted Efficient (kW)	Demand Savings (kW)
7	2,934.7	2,313.0	621.7
8	3,031.2	2,380.3	651.0
9	2,976.4	2,313.8	662.6
10	2,870.4	2,237.7	632.7
Peak Demand Period	2,953.2	2,311.2	642.0

For the facility in this example, the relationship between load and weather was stable across the peak demand period. A very similar result could have been obtained by modeling the four hours together in two regression models (one for the baseline period and one for the efficient period) and predicting demand for the average OAT of the four-hour period of 23.575 degrees (F). The analysis could even be done with a single regression by including a binary indicator variable for the post implementation period and an interaction term between the temperature variable and the post indicator term. Figure 4-3 shows the output from such a model.

Figure 4-3: Regression Output for a Pre-Post Demand Savings Model

```
      Source |       SS           df       MS      Number of obs   =     1,084
-------------+----------------------------------   F(3, 1080)      =   1155.27
       Model |   190198605         3  63399534.9   Prob > F        =    0.0000
    Residual |  59268908.1     1,080  54878.6186   R-squared       =    0.7624
-------------+----------------------------------   Adj R-squared   =    0.7618
       Total |   249467513     1,083  230348.581   Root MSE        =    234.26

------------------------------------------------------------------------------
         kwh |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
        temp |   -27.1858    .795072   -34.19   0.000    -28.74586   -25.62574
        post |  -748.7169   47.77764   -15.67   0.000    -842.4644   -654.9693
 post_x_temp |   4.500518   1.186203     3.79   0.000     2.172994    6.828043
       _cons |   3594.111   32.17726   111.70   0.000     3530.974    3657.248
```

The equation to estimate demand impact from the coefficients in Figure 4-3 is as follows. The "post" coefficient represents the change in the intercept ("_cons" or constant) in the efficient period and the interaction term ("post_x_temp") represents the change in the slope during the efficient period.

$$\Delta kW = kW_{baseline} - kW_{efficient}$$

$$\Delta kW = (Cons + Mean\ OAT * temp) - (Cons + post + Mean\ OAT * (temp + post\_x\_temp))$$

$$\Delta kW = (3594.1 + 23.575 * (-27.186)) - (3594.1 - 748.72 + 23.575 * (-27.186 + 4.50))$$

$$\Delta kW = 2953.2 - 2310.6$$

$$\Delta kW = 642.6$$

A shortcut to the calculation above isolates the coefficients representing the change in demand in the efficient period, as shown in the steps below. When using this approach, it is important to remember to flip the sign to convert from impact to savings.

$$\Delta kW = post + Mean\ OAT * post\_x\_temp$$

$$\Delta kW = -748.7169 + 23.575 * 4.500518$$

$$\Delta kW = -642.6$$

In jurisdictions other than BPA, the definition of peak demand incorporates some assumption about extreme weather. For example, perhaps instead of the average winter weekday morning conditions, peak demand is assumed to occur on a winter weekday morning when the temperature is 10 degrees (F). In this case, the weather assumptions from TMY3 data can be replaced with the extreme weather values to estimate demand impacts at the appropriate fixed conditions. Using the single regression model approach shown in Figure 4-3, the calculation would be as follows and result in an estimated demand savings of 703.7 kW.

$$\Delta kW = post + Extreme\ OAT * post\_x\_temp$$

$$\Delta kW = -748.7169 + 10.0 * 4.500518$$

$$\Delta kW = -703.7$$

The *Verification by Energy Modeling Protocol* includes guidance on issues of coverage and extrapolation beyond the range of the independent variable values used to fit the model. These considerations are important to review when estimating savings at extreme conditions.

5.3. Energy Modeling with Daily Billing Data

When the *Verification by Energy Modeling* or *Verification by Energy Use Indexing* protocols are used with daily or monthly meter readings, it is not possible to directly estimate the peak demand impact from the data used in the energy savings analysis. The data are not granular enough. In this case, a secondary load shape is needed to estimate how the energy savings are distributed across the hours of the day or across the hours of a year.

Figure 4-1 showed the daily consumption totals for a facility before and after implementation of a custom energy efficiency project (weekdays only). To model energy savings for this facility, two terms are created using a 55-degree change point. The term CDD55 (cooling degree days relative to 55 degrees) takes on the higher of the values average daily temperature minus 55 degrees (F) and zero. Similarly, the term HDD55 (heating degree days relative to 55 degrees) takes on the higher of the values 55 degrees (F) minus the average daily temperature and zero. Stated in equation form:

- CDD55 = maximum (0, average daily temperature – 55)
- HDD55 = maximum (0, 55 – average daily temperature)

Table 4-4 shows the regression coefficients for the regression models for the baseline and efficient periods.

Table 4-4: Daily Regression Model Coefficients for the Baseline and Efficient Periods

Period	Intercept	CDD55 Coefficient	HDD55 Coefficient
Baseline	37,093.8	746.4	548.2
Efficient	28,405.1	710.4	445.4

For the annual energy savings analysis on weekdays, these weekday regression coefficients would be applied to values from TMY3 weather records for the relevant station (normalized to degree days). Separate models would be created for weekends and used to compute annualized savings on weekends.

For the capacity savings analysis, the first step is to estimate the expected daily savings on winter weekdays. Assume that a review of the average daily temperature values in TMY3 data for December, January, and February revealed that 30 degrees (F) was the normal daily mean temperature for the area. Table 4-5 shows the estimated daily consumption and savings using the model coefficients from Table 4-4 at 25 HDD55 and zero CDD55.

Table 4-5: Calculation of Daily kWh Savings on Winter Weekdays

Period	Modeled Daily kWh at 30 Degrees
Baseline	50,799
Efficient	39,540
Savings	11,258

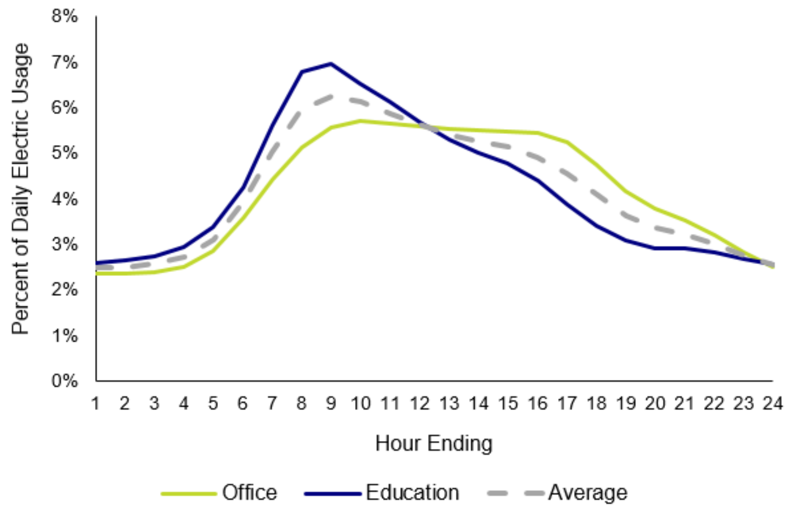
In a situation where daily meter reads are the most granular measurement available, engineers will have to leverage secondary information to estimate the distribution of the 11,258 kWh of daily energy savings across the day and isolate the average impact during the peak demand window. This requires selection of a secondary load shape.

The facility in our example is a university and the project involved multiple ECMs that affected multiple end-uses. Based on this information, a whole premise load shape is a reasonable choice. The implicit assumption in applying a premise load shape to energy efficiency savings is that the savings are distributed proportionately to load (equivalently, that savings are proportionate to consumption). Note that this assumption is not valid for all ECMs.

The EPRI Load Shape Library does not include a "University" building type. The closest building types available are "Education, K12" and "Office, Large." Figure 4-4 shows the daily load shapes for the two similar building types and an average of the two for an Oregon location. The table on the left side of the figure shows the percent of the daily winter weekday electric consumption in each hour of the day for the average profile; it highlights the peak demand hours.

Figure 4-4: Winter Weekday Load Shapes for Relevant Oregon Building Types

Hour	Share	Hour	Share
1	2.48%	13	5.41%
2	2.50%	14	5.25%
3	2.57%	15	5.12%
4	2.72%	16	4.92%
5	3.11%	17	4.56%
6	3.91%	18	4.08%
7	5.02%	19	3.62%
8	5.95%	20	3.35%
9	6.26%	21	3.21%
10	6.12%	22	3.02%
11	5.88%	23	2.76%
12	5.63%	24	2.53%



The average of the four highlighted hours in Figure 4-4 is 5.84%. (Note that these shares are *averaged* across the peak window, not summed.) This value is applied to the daily energy savings estimate of 11,258 kWh to estimate the peak demand savings.

$$\Delta kW = Estimated\ Daily\ kWh\ Savings * Average\ Share\ During\ Peak\ Hours$$

$$\Delta kW = 11{,}258 * 0.0584 = 657.5\ kW$$

The fact that disaggregation of daily savings via a load shape produced a similar peak demand impact to the hourly modeling shown in Section 4.2 suggests that the blended EPRI load shape was a reasonable proxy for this facility and the ECM savings being estimated. In practice, when the practitioner needs to estimate capacity impacts using secondary sources, this check would not have been possible because hourly readings would not be available.

5.4. Engineering Calculations with Verification

The *Engineering Calculations with Verification Protocol* uses project-specific equipment characteristics and sound engineering principles to estimate energy savings from custom energy efficiency projects. A wide range of engineering calculations might be used depending on the type of equipment being considered and the type of facility installing the project.

Bin calculations are a common method for weather dependent projects. A bin calculation separates the hours of the year into different temperature bins, and the practitioner estimates the expected loading conditions for the baseline and efficient cases for each bin.

Table 4-6 illustrates a bin calculation for a hypothetical project in a Spokane hospital where VFDs were added to supply-air fan motors. The baseline controls for the motors were backward inclined airfoil. The "Hours" column is created by binning hourly temperature values from a Spokane TMY3 weather file; it represents the quantity of hours from the TMY weather file that fall into each temperature bin. The energy savings calculation would then incorporate the motor size (HP) and efficiency to estimate annual energy consumption for the baseline and efficient configuration.

Table 4-6: Supply Air Fan Bin Calculation

Temperature Bin	Hours	Part Load Ratio	Flow Fraction Baseline (Backward Inclined Airfoil)	Flow Fraction Efficient (VFD)
Below 10 degrees	10	0.92	1.02	0.81
10-19 degrees	91	0.85	1.02	0.81
20-29 degrees	569	0.71	0.89	0.49
30-39 degrees	1,593	0.63	0.8	0.39
40-49 degrees	2,029	0.55	0.8	0.39
50-59 degrees	1,523	0.48	0.72	0.31
60-69 degrees	1,477	0.60	0.8	0.39
70-79 degrees	781	0.72	0.89	0.49
80-89 degrees	533	0.79	0.96	0.63
90-99 degrees	146	0.84	0.96	0.63
Above 100 degrees	8	0.91	1.02	0.81

The same calculation framework can be used to estimate peak demand savings by focusing on the temperature bin that corresponds to the expected weather during the peak demand definition. The "Hours" column can be ignored if the weather definition for capacity savings is a single bin, because the output of interest is the change in power draw, not energy consumed. If the weather definition spans multiple bins (e.g. all hours below 30 degrees) the "Hours" term would be used to weight the results across the bins of interest. The part load ratio column is also not needed as the flow fraction values are a function of the part load ratio.

If the peak demand period is expected to correspond to the "20-29 degrees" temperature bin, the calculation would take the following form for a 50-horsepower fan of 90% efficiency and assumed load factor of 0.8. The value of 0.746 is an engineering constant to convert horsepower to kW.

$$\Delta kW = kW_{Baseline} - kW_{Efficient}$$

$$\Delta kW = 0.746 * HP * \frac{Load\ Factor}{Efficiency} * (Flow_{Base} - Flow_{EE})$$

$$\Delta kW = 0.746 * 50 * \frac{0.8}{0.9} * (0.89 - 0.49) = 13.26\ kW$$

For this ECM, capacity savings are derived from the same secondary information as the energy savings – engineering assumptions about the relationship between loading/temperature and motor power draw at different loading conditions.

This example illustrates the simplest capacity savings calculation that would accompany use of the *Engineering Calculations and Verification Protocol*. Practitioners will likely encounter ECMs where the peak demand savings analysis requires incorporation of additional secondary information such as a load shape, coincidence factor, or energy-to-demand factor.

6. References and Resources

Electric Power Research Institute Load Shape Library. Available at: *http://loadshape.epri.com*

Northwest Power and Conservation Council Library Load Shapes. Available at: *https://nwcouncil.app.box.com/v/MCandLoadshapev3-0-47-1*

National Renewable Energy Laboratory. 2017. Uniform Methods Project: Methods for Determining Energy Efficiency Savings for Specific Measures – Chapter 10: Peak Demand and Time-Differentiated Energy Savings Cross-Cutting Protocol. Available at: *https://www.nrel.gov/docs/fy17osti/68566.pdf*

Pennsylvania Public Utility Commission. 2019. *Technical Reference Manual, Volume 3: Commercial and Industrial Measures.* Available at: *http://www.puc.pa.gov/pcdocs/1614951.docx*