



Engineering Calculations with Verification Protocol

September 2024



Engineering Calculations with Verification Protocol

Version 3.1

September 2024

Prepared for

Bonneville Power Administration

Prepared by

Facility Energy Solutions

Stillwater Energy

SBW Consulting

Contract Number BPA-2-C-92283

Table of Contents

Table of Contents i

1. Introduction 1

 1.1. Purpose 1

 1.2. Protocols Version 3.0 1

 1.3. How is M&V Defined? 1

 1.4. Background 2

2. Overview of Method 4

 2.1. Description 4

 2.2. Applicability 5

 2.3. Common Requirements Regardless of Approach 6

 2.3.1. A Well Substantiated Baseline 6

 2.3.2. Baseline Planning 7

 2.3.3. Reasonable Characterization of Post Implementation Behavior 8

 2.4. Additional Considerations in Using this Protocol 8

 2.4.1. Safety 8

 2.4.2. Data Collection Techniques and Devices 9

3. Basic Procedure 11

 3.1. Pre-Installation Phase 11

 3.1.1. Step 1: Process/Measure Description 11

 3.1.2. Step 2: Establish Baseline Annual Energy Use 11

 3.1.3. Step 3: Establish Post-Installation Annual Energy Use 12

 3.1.4. Step 4: Calculate Energy Savings 13

 3.2. Post-Installation Phase 13

 3.2.1. Step 5. Measure Verification 13

 3.2.2. Step 6. Adjust Savings Estimation 14

4. Engineering Calculations for Existing Buildings 15

 4.1. Recommended Approach for Reviewing Calculations 15

 4.2. Typical General Calculation Issues 15

 4.3. Bin Calculations 17

 4.4. Establishing a Solid Baseline and Good Energy Calculations 18

 4.4.1. Data Relationships Associated with Loads 19

 4.4.2. Extrapolation 20

 4.4.3. Extrapolation Errors Due to Seasonal Changes 22

4.4.4.	Data Relationships Associated with Control Strategies	22
4.4.5.	Tips on Choosing Data Relationships	22
4.4.6.	Developing Regressions	24
4.5.	General Spreadsheet Calculations Guidance	25
4.6.	Common Specific Issues	25
4.7.	Some Sources of Calculations and Tools for Energy Analysis	27
4.7.1.	General	27
4.7.2.	Weather Data Sources and Binning Tools	27
4.7.3.	Industrial Sector Tools.....	28
5.	Simulation for Existing Buildings	29
5.1.	Practical Considerations and Best Practices.....	29
5.2.	Recommended Approach for Reviewing Calculations	30
5.3.	General Simulation Guidance	31
5.3.1.	Energy Modeler Qualifications	31
5.3.2.	Developing Simulation Models	31
5.3.3.	Evaluating Simulation Models	33
5.4.	Establishing a Solid Baseline	33
5.5.	Common Simulation Issues.....	34
5.5.1.	General Simulation Issues	35
5.5.2.	Enclosure Modeling Issues	36
5.5.3.	Internal Load Modeling Issues	37
5.5.4.	HVAC Modeling Issues	37
5.6.	Public Sources of Simulation Support.....	38
6.	Simulation for New Construction or Major Renovation	40
6.1.	Applicability	40
6.2.	Recommended Approach for Reviewing Calculations	40
6.3.	Baseline Definition.....	41
6.3.1.	ASHRAE 90.1 Appendix G.....	41
6.4.	Overall Procedure	42
7.	Minimum Reporting Requirements.....	44
7.1.	Measurement and Verification Plan	44
7.1.1.	Essential Elements of the Measurement and Verification Plan	44
7.1.2.	M&V Plan Additional Elements.....	45
7.1.3.	Documentation for BPA Database	45
7.2.	Savings Verification Report	46
7.2.1.	General Verification Report Requirements Based on IPMVP.....	46
7.2.2.	Additional Savings Verification Report Requirements	47
7.3.	Unique Requirements for Engineering Calculations with Verification Protocol	49

7.3.1.	Pre-Project Reporting Requirements.....	49
7.3.2.	Preparation of Documentation.....	50
7.3.3.	Specific Requirements for Simulation for Existing Buildings	51
7.3.4.	Specific Requirements for Simulation for New Construction or Major Renovation	52
8.	Examples.....	53
8.1.	Example #1: Engineering Calculations Using a Publicly Available Software	
	Tool	53
8.1.1.	Overview	53
8.1.2.	M&V Approach	53
8.1.3.	Measurement Boundary	54
8.1.4.	Baseline Conditions.....	54
8.1.5.	Post-Installation Conditions.....	55
8.1.6.	Annual Savings Calculation.....	57
8.1.7.	Annual Energy Savings	57
8.2.	Example #2: Simulation Approach for an Existing Building Using eQuest	
	Software	58
8.2.1.	Overview	58
8.2.2.	M&V Approach	58
8.2.3.	Measurement Boundary	59
8.2.4.	Baseline Period	59
8.2.5.	Post-Installation Period	59
8.2.6.	Annual Savings Calculation.....	60
8.2.7.	Annual Energy Savings	60
8.3.	Example #3: Engineering Calculations Using a Vendor Supplied Software	
	Tool	61
8.3.1.	Overview	61
8.3.2.	M&V Approach	62
8.3.3.	Measurement Boundary	62
8.3.4.	Baseline Conditions.....	62
8.3.5.	Post-Installation Conditions.....	63
8.3.6.	Annual Savings Calculation.....	64
8.3.7.	Annual Energy Savings	65
8.4.	Example #4: Engineering Calculations Using a Custom Spreadsheet.....	65
8.4.1.	Overview	65
8.4.2.	M&V Approach	65
8.4.3.	Measurement Boundary	66
8.4.4.	Baseline Conditions.....	66
8.4.5.	Post-Installation Conditions.....	68
8.4.6.	Annual Savings Calculation.....	69
8.4.7.	Annual Energy Savings	69
9.	References and Resources.....	70

1. Introduction

1.1. Purpose

Engineering Calculations with Verification Protocol (ECwV Protocol) is one of the Measurement and Verification (M&V) protocols used by the Bonneville Power Administration (BPA). It provides guidance for assuring energy savings for qualified changes in existing buildings or new construction projects using either engineering calculations or simulations, including calculation review and verification of the measures' potential to perform as calculated.

The *ECwV Protocol* can be used instead of a comprehensive M&V protocol for projects with expected savings under 400,000 kWh or projects for which other criteria dictate that a fully IPMVP¹-adherent protocol is not possible or not appropriate. Such criteria are described in Chapter 2 and in the *Measurement and Verification (M&V) Protocol Selection Guide and Example M&V Plan (Protocol Selection Guide)*. In some cases, this protocol may be applicable to projects with higher expected savings. BPA engineering staff retains discretion as to whether a project with annual energy savings over 400,000 kWh may use this protocol and remain consistent with BPA's *Implementation Plan* requirements. Plainly stated, this protocol is not adherent with IPMVP.

Originally developed in 2012 and updated in 2024, this *ECwV Protocol* is one of ten documents produced by BPA to direct M&V activities; an overview of the ten documents is given in the *M&V Protocol Selection Guide*.

Chapter 8 of this protocol provides full citations (and web locations, where applicable) of documents referenced. The document *Glossary for M&V: Reference Guide* defines terms used in the collection of BPA M&V protocols and guides.

1.2. 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. This document is Version 3.1 since Section 8 Examples were subsequently updated.

1.3. 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

¹ *International Performance Measurement and Verification Protocol.*

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, savings calculators, and custom projects.^{4,5} Custom projects require site-specific Measurement and Verification (M&V) to support reliable estimates of savings. For UES measures and Savings Calculators, measure specification and savings estimates must be RTF approved or BPA-Qualified [...] BPA M&V Protocols⁶ direct M&V activities and are the reference documents for reliable M&V.⁷

The *Selection Guide* includes a flow chart providing a decision tree for selecting the M&V protocol appropriate to a given custom project and addressing prescriptive projects using UES estimates and Savings Calculators.

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 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.

1.4. 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

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 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.

⁷ <https://www.bpa.gov/-/media/Aep/energy-efficiency/document-library/24-25-im-april24-update.pdf>, page 1.

- 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 *ECwV Protocol*.⁸

⁸ William Koran, formerly of QuEST, and Erik Kolderup, of Kolderup Consulting, were the primary authors of Version 1.0 of the ECwV Protocol.

2. Overview of Method

2.1. Description

The *ECwV Protocol* approach may be summarized as one of the “well thought-through engineering estimation approaches linked with on-site examination of technology application and use conditions.”⁹ It is warranted for projects meeting the selection criteria for ECwV outlined in BPA’s *Protocol Selection Guide*.

The reader should recognize that the *ECwV Protocol* does not meet M&V requirements as articulated by the Efficiency Valuation Organization (EVO) in its *International Performance Measurement and Verification Protocol* (IPMVP). Unlike the IPMVP specifications, this *ECwV Protocol* does *not* require pre- and post-project measurements of energy use, but instead relies on engineering models of equipment, systems, or buildings.

For further information on the choosing between this protocol and another custom protocol, refer to the *M&V Protocol Selection Guide*.

Use of the *ECwV Protocol* is not intended to be solely based on a kWh-per-year savings threshold, but rather to recognize that other criteria (such safety issues in accessing metering points and recognition of well understood, small variance key parameters) factor into the appropriate use of this protocol. These considerations should be combined with well-documented energy engineering savings calculations with realistic error boundaries (best- and worst-case conditions) and application of quality assurance methods.

There are two approaches applicable to using engineering models to calculate savings for the *ECwV Protocol*:

- 1) engineering calculations (typically spreadsheet-based, e.g., 8760-hour methods, bin calculations), and
- 2) system-level or whole-building simulation.

A spreadsheet or computer simulation models of physical systems are used to predict facility or process energy consumption for the baseline and post-installation cases, and the savings are the difference between the predicted energy use.

Engineering estimates based on these approaches span a wide range depending on application. Data may include weather data, system design information, manufacturer specifications, and operational data from on-site monitoring. The type and quality of these calculations, as well as the availability of building data, vary from project to project.¹⁰

⁹ California 2002-2003 Portfolio Energy Efficiency Program Effects and Evaluation Summary Report

¹⁰ California Commissioning Collaborative, *Guidelines for Verifying Savings from Existing Buildings*, Method 1: Engineering Calculations with Field Verification

The preferred choice depends upon project application, discussed next.

2.2. Applicability

Both the calculations and simulation approaches have broad applicability to existing buildings and systems. Simulation is generally more appropriate for new construction, although there may be occasional new construction applications for which engineering calculations are appropriate. This document has chapters pertaining to three distinct approaches:

- ➔ Engineering calculations (Chapter 4),
- ➔ Simulations for existing buildings (Chapter 5), and
- ➔ Simulations for new buildings (Chapter 6).

Generally, if there is an existing system or whole building simulation model, then it will often be the correct savings assurance approach. Conversely if there is not an existing whole building simulation model, then engineering calculations should be considered the default approach. However, there are several factors that should be considered in choosing simulation or engineering calculations.

Whole building or system simulation is typically favored when:

- ➔ Correlations to real data cannot be developed
- ➔ Zone-level loads are needed
- ➔ Complex interactions must be simulated – for example, variable loads in zones that are not easily modeled with temperature bins or other simplified methods
- ➔ Transient or dynamic behavior is an important consideration

Conversely, engineering calculations will often be favored when:

- ➔ Baselines can be developed from real data
- ➔ Savings are associated with a single piece of equipment or system
- ➔ A significant fraction of the savings is anticipated to come from changes to controls

Often in many situations expert practitioners can overcome the limitations or improve the deficiencies of whole building simulation programs.

Other considerations in selectin an approach include the practitioner’s experience and capability, the tool’s capabilities, and the type of projects and the variety of measures possible within a given project. With many considerations, a list of questions whose answers can provide guidance toward the most appropriate approach for a project is provided in

Table 2-1.

Table 2-1: Key Questions Toward Selecting an Appropriate Approach

QUESTION	IF YES, FAVORS	IF NO, FAVORS
Are the savings low on an absolute, not percentage, basis?	Engineering Calculations	Neither
Is there an existing simulation?	Simulation	Engineering Calculations
Are most of the estimated savings based on controls changes or improvements and not equipment retrofits?	Engineering Calculations	Neither
For controls changes, are they at the zone or served area?	Simulation	Engineering Calculations
Are zone-level loads, or the loads ultimately served, needed to estimate the savings?	Simulation	Neither
Are the savings from controls changes able to be lumped into one or two zones or served areas?	Engineering Calculations	Neither
Conversely, is load diversity going to constrain the savings at frequent operational conditions?	Simulation	Neither
Are controls changes associated with set points that are not part of the inputs for the simulation program?	Engineering Calculations	Neither
Are there significant savings associated with changes to the building shell?	Simulation	Neither
Are the savings associated with multiple interactive systems and pieces of equipment?	Simulation	Engineering Calculations
Are real building data available to characterize the relevant building or equipment loads associated with systems from which the savings would be derived?	Engineering Calculations	Simulation
Are the savings associated with building or controls dynamics?	Simulation	Neither

2.3. Common Requirements Regardless of Approach

There are two simple requirements for good engineering calculations: these are intuitive, but we wish to expound upon them a bit:

1. A well-substantiated baseline
2. Baseline planning
3. Reasonable characterization of post-implementation behavior

2.3.1. A Well Substantiated Baseline

The appropriate baseline conditions should be selected based on the *M&V Selection Guide*. The appropriate baseline may be based on either: existing conditions or a code baseline (includes standard industry practice baseline).

A well-substantiated baseline is the most important part of an energy calculation because it constrains the estimate of savings: the savings can never be more than the baseline energy use.

With engineering calculations, a well-substantiated baseline usually requires understanding the relationship of important variables to other driving variables. Commonly, this means energy use or load is related to ambient temperature, but it may also indicate a relationship between load and other variables such as a daytype or a production rate. Annual use or load at various conditions can then be extrapolated from a regression describing this relationship.

Engineering calculations should not have any internal inconsistencies. Within a single calculation, we have often seen a number of assumptions that cannot all be true. Each assumption may make sense in isolation, but when combined they don't make sense (for example, they form a set of equations for which there is no possible answer when solved simultaneously).

For both simulations and engineering calculations, the outputs of either should not have any inconsistencies with known data from the project. This does not mean that model calibration is required. The *ECwV Protocol* does not require a particular level of precision to known data; however, outputs should not be markedly different from known data.

Practically, this means that a model should closely match annual energy use, or the energy use or other relevant parameter over the time period for which there is data. In contrast, a calibrated model may also need to match monthly or hourly energy use, and/or the energy use of specific end uses or systems.

One of the features of engineering calculations, as opposed to simulations, is that the actual measured values of parameters can be used as inputs. Put in simulation terms, it's akin to skipping the Loads module and inputting known loads directly into the Systems module or skipping both Loads and Systems and putting the Systems loads directly into the Plant module. (Simulation tools such as *DOE-2* divide the simulation into four parts: Loads, Systems, Plant, and Economics.)

2.3.2. Baseline Planning

Planning for the calculations should start during the earliest phases of a project. Information for the baseline should begin being collected prior to the first site visit. Prior to going on-site, think about what will be needed to establish a baseline. Break the equipment energy usage down into load and schedule components, what parameters the load depends on, and how best to collect operation schedule information. Information needed may include:

- ➔ Equipment specifications, nameplate data, equipment configuration, and operation schedules
- ➔ Measurements: spot or short-term measurements, or data loggers for longer monitoring periods
- ➔ Control system trends and data logs

At this time the analyst should anticipate questions that should be asked of the building or equipment operator. Common questions may include seasonal changes in operation that might not be observed from trend or longer data; and any ongoing, persistent, or pervasive issues that the operator needs to deal with on a frequent basis.

2.3.3. Reasonable Characterization of Post Implementation Behavior

Although not quite as important as the baseline development, the characterization of the energy efficiency measure or measures is also key to a good estimate of the energy savings. A good characterization may require the following:

- ➔ A clear understanding of the measure
- ➔ Knowledge of the system to which the measure applies
- ➔ Knowledge of the physics underpinning how the measure generates savings
- ➔ A strategy or methodology for calculating savings from the measure
- ➔ The simulation tool inputs pertaining to the measure

There are other pieces of information that fit within these top-level requirements and are also critical to a reasonable characterization. There must be a clear understanding of when the measure is applicable:

- ➔ Is measure impact related to equipment status, time of day, season, or weather condition?
- ➔ Are the savings highly dependent upon a particular set-point or set-points?
- ➔ Are the savings highly dependent upon the performance of a particular piece of equipment?

The answers to these questions will guide where the emphasis needs to be placed in the analysis. They may also dictate where the focus should be for verification of installation and the potential to perform.

2.4. Additional Considerations in Using this Protocol

2.4.1. Safety

Application of *ECwV Protocol* might require that some data are collected before and after installation of the energy efficiency project. While most efficiency projects are on systems and equipment that operate in the low voltage range,¹¹ the voltage levels are high enough to cause severe injury or worse if proper safety precautions are not taken before making electric power measurements. It is of primary importance that personnel follow their organization's safety

¹¹ There are multiple classifications of voltage levels. The low voltage range is 0 to 600V for three-phase power distribution circuits according to ANSI C84.1-1989.

procedures and equipment whenever the situation warrants it. Implementers of this protocol will need to make decisions about collecting the necessary data based on several factors including: the type and location of measurements, the ability to safely make measurements, and the resources available to make safe measurements. These factors can ultimately determine whether data may be used in the application of *ECwV Protocol* on the project.

2.4.2. Data Collection Techniques and Devices

This protocol can be followed through the two distinct approaches of engineering calculations or whole-building simulation. Though both approaches can be improved through the measurement of data, the method and necessity of the data collection varies. The plans will describe the data collection techniques to be used, and these techniques will include specification of data collection devices. Generally, data collection devices are either hand-held instruments or data loggers that are left in place to store collected data. BPA and its efficiency program partners maintain inventories of data collection instruments and devices. Please consult your organization's resources for data collection tools. The techniques used to collect data fall into these categories:

Constant OPERATIONS

When operations are constant, a single measurement (often referred to as a 'spot' measurement) may suffice to determine the load, temperature, or other value. For load measurements a hand-held power meter measuring volts, amps, and power factor may be used. Alternately, an ammeter or multi-meter or data logger measuring current (amps) may also be used, and power estimated using the amperage measurement and equipment voltage ratings and power factor estimates. More accurate estimates of the parameter are made from averages of multiple readings taken on the equipment. Alternatively, it may be necessary to confirm the parameter is constant by making multiple measurements over time and analyzing the data to assure its variation is low.

VARIABLE OPERATIONS

Variable operations require that data be collected over the period of the operation variation cycle, and often over multiple cycles and operating conditions to assure enough data is collected to properly characterize equipment operation in analysis. The duration of the cycle and operating conditions are factors in deciding the duration of the monitoring period as well as the data collection interval, which is how often measurements are made. When using commercially available monitoring devices, a limiting factor is the data storage capacity of the device. Often, an automated control system with trending capability is present and has relevant points on the project equipment. Trends may be set up to collect data over time. Use of data from the facility's own control system is often preferable, as it is safer, and avoids costly trips back and forth to project sites.

When schedule data is unknown, it may be obtained by using data loggers, collection of control system trend data, and/or runtime estimates from plant staff or facility owners. If data loggers are needed for measuring loads on variable equipment, this data may also be used to determine schedule information. If data loggers are only required to measure equipment schedules, often

only equipment status sensors are needed, not power or current measurements that require safety equipment be used. Control system trends are also good sources of data that may be used to define schedules. In some cases, spot check values from installed electrical panel ammeters or power meters may be used, especially if direct electrical measurements or data logging are unable to be performed. Examples may be in cases where equipment panels cannot be opened due to medium voltage (>600 VAC) or other safety reasons. BPA staff and program implementers reserve discretion for any safety or other customer requirements or reasons.

3. Basic Procedure

The *ECwV Protocol* is an approach based on models of equipment, systems, or buildings, rather than pre- and post-project measurements of energy use. The process of preparing and documenting your savings estimate can be divided into two phases and six basic steps, as follows.

1. Pre-Installation Phase

Step 1. Process/Measure Description

Step 2. Establish Baseline Annual Energy Use

Step 3. Establish Post-Installation Annual Energy Use

Step 4. Calculate Energy Savings

2. Post-Installation Phase

Step 5. Measure Verification

Step 6. Adjust Savings Estimation

These steps are listed in typical order for existing buildings. However, note that when whole-building simulation is used for new construction, the proposed project is typically simulated first. Then, the efficiency measures are ‘removed’ from the simulation to obtain the baseline model.

3.1. Pre-Installation Phase

3.1.1. Step 1: Process/Measure Description

The importance of providing a detailed description of the process and associated energy-saving measure cannot be overstated, since it provides the reviewer with the necessary background information to understand the calculations that follow. Describe both the existing (pre-retrofit or *base case*) system and the proposed (post-retrofit or *efficient-case*) system. In some cases, it may be helpful to describe the measure separately (in addition to) the proposed system. Include sufficient information on the process and equipment involved so it is clear to the reviewer how the proposed measure will be implemented and how it will achieve the stated savings.

3.1.2. Step 2: Establish Baseline Annual Energy Use

As described in the *M&V Selection Guide*, incentives may be based on equipment/improvements that go beyond existing conditions baseline equipment or beyond current practice baselines, depending on how close the equipment is to the end of its useful life. Current practice baseline refers to local, state, or federal efficiency requirements, or to current industry practices. The

baseline for any given project may be the actual equipment efficiency, or applicable code for an individual measure or piece of equipment.

The simplified equation used for the calculation of baseline energy use is shown below.

- **Baseline Energy Use:** *Baseline Energy Use (kWh or Therms/year) = Σ (Op Hours * Equipment Load (kW or Therms/hr))*

Note that it may be necessary to develop a table of equipment loads and the annual operating hours at each load to arrive at an annual energy use estimate. A typical example of this is to use a table of bin temperatures, the number of hours at each bin temperature, and the equipment load at each bin temperature, to get total energy use.

To obtain the baseline value, it may be necessary to adjust the energy use estimate for the existing equipment to account for *standard industry practice* efficiency. For example, a customer that proposes to replace an end of life 50-hp motor with a nominal full-load efficiency of 90.2%, with a premium efficiency motor having an efficiency of 94.1%, must establish the baseline energy using the accepted standard industry practice motor efficiency. In this case, the *Energy Independence and Security Act of 2007* guideline for a similar 50-hp motor is 93%. The baseline energy use of the existing motor must therefore be calculated based on the higher 93% efficiency value, which reduces the baseline (and associated savings) value.

The baseline energy use and demand calculations are critical to the savings calculations, so it is important that the calculations and associated descriptions provide sufficient information on the process, equipment, and applicable standards to justify the proposed baseline energy use and demand:

- ➔ **Use accepted engineering algorithms and procedures from recognized technical organizations** such as ASHRAE, SMACNA, ANSI, etc.¹²
- ➔ **Annotate all assumptions or constants used in engineering calculations.**
- ➔ **Use rated performance factors tested under accepted procedures** specified by recognized rating agencies, such as ARI, AGA, ANSI, ASTM, etc.¹³
- ➔ **Provide an explanation when equipment performance rating conditions vary from standard conditions.**

3.1.3. Step 3: Establish Post-Installation Annual Energy Use

The simplified equation used for the post-installation energy use calculation is essentially the same as for the baseline calculation.

¹² ASHRAE – American Society of Heating, Refrigerating and Air-Conditioning Engineers; SMACNA – Sheet Metal and Air Conditioning Contractors' National Association; and ANSI – American National Standards Institute.

¹³ ARI – Air-Conditioning and Refrigeration Institute, now the Air-Conditioning, Heating, and Refrigeration Institute (AHRI); AGA – American Gas Association; ANSI – American National Standards Institute; and ASTM – now ASTM International, formerly known as the American Society for Testing and Materials.

- **Post-Installation Energy Use:** $Post\text{-}Install\ Energy\ Use\ (kWh\ or\ Therms/year) = (Op\ Hours * Equip\ Load\ (kW\ or\ Therms/hr))_{post}$

Note that it may be necessary to develop a table of equipment loads and the annual operating hours at each load to arrive at an annual energy use estimate.

While the baseline energy use calculation is based on *current practice or existing conditions baseline* equipment, the post-installation calculation is based on the *projected performance* of the new equipment or process. Inputs and associated assumptions (if any) must be clearly stated and verifiable. Use of a manufacturer-specific simulation product can be acceptable but may require additional information on the underlying principles used by the software. Again, it is important that your description provide sufficient detail so that the reviewer will understand the basis for your projection.

It is important to note that the reviewer may require monitoring to confirm post-installation operation. This is not measurement and verification of energy use, but verification that changes were made that provide the potential for reduced energy use. Actual reduced energy use may or may not be a part of this. If it is part of the verification, it is generally anecdotal for the *ECwV Protocol* – it shows reduced energy use or demand at the time or times of measurement, but there is not an attempt to verify reduced or expected levels of energy use over all operational conditions.

3.1.4. Step 4: Calculate Energy Savings

Once the baseline and post-installation annual energy use and demand estimates are completed, then the savings estimate is simply the difference between the annual baseline and post-installation use and demand estimates.

In some cases, it may be easier to calculate the energy savings directly, rather than calculate the post-installation energy use and subtracting it from the baseline to obtain the savings. In any case, it is always necessary to establish the energy use baseline.

3.2. Post-Installation Phase

3.2.1. Step 5. Measure Verification

The *ECwV Protocol* recommends that a level of savings verification be included as part of the process. The verification level may depend on project requirements. For example, a project may include upgrade of a standard efficiency motor with a premium efficiency motor, and due to the relatively small savings and uncomplicated savings analysis, only a visual inspection that the replaced motor is indeed a premium efficiency motor may suffice.

It may often be the case that the *ECwV Protocol* will be used for larger and more complicated savings projects due to safety concerns or inability to collect the amount of data required. In these cases, engineers may elect to use a more rigorous verification method, such as developing and applying functional performance tests designed to assure the improved equipment is

operating correctly and is able to generate savings as expected. This addresses one key weakness in efficiency projects: that the larger and more complicated projects fail to deliver savings because of improper equipment specification, improper installation, or improper operation and controls. Well-designed functional performance testing can uncover these issues so that they may be corrected. The tests may also be used as part of maintenance programs to periodically re-test and reassure proper equipment operation.

Other forms of measure verification include making additional spot measurements, collecting and analyzing data from data loggers, and analysis of control system data trends. The questions used at the outset of the project concerning building and equipment operations may be repeated during the verification site visits and yield useful information. The engineer should consider and document what level of verification is appropriate for the measure, keeping in mind that the verification activity may serve other useful purposes for the owner throughout the equipment's lifetime.

3.2.2. Step 6. Adjust Savings Estimation

Each level of verification rigor yields useful information. This information may be used to confirm the engineer's assumptions about the efficient equipment and operations. When the assumptions cannot be confirmed by the collected verification data, it should be used to adjust the final savings estimate. These adjustments may range from a complete failure of savings to be realized, to more savings realized than expected.

Cases when no savings are realized include finding that the measure was not installed at all, or not installed correctly. It is not uncommon for mistakes in equipment specification or procurement to occur, as the owner is responsible for buying and installing the efficient equipment, while the engineer is not involved. Adding efforts to commission the systems affected by the project may be warranted in order to ensure proper operations and sometimes capture additional savings.

Cases when saving are less than expected may occur when the efficient equipment is not operated correctly, building operations change, or when the engineer's assumptions of post-installation operations are incorrect. Of course, these differences in operation may result in exceeding the engineer's savings estimates.

All adjustments to the final savings estimate must be clearly documented and supported by verification data collected in the post-installation phase.

4. Engineering Calculations for Existing Buildings

4.1. Recommended Approach for Reviewing Calculations

Review of calculations should be based on the level of savings, the reviewer's confidence in the savings, and the measure cost. For measures that are highly cost-effective but have relatively low savings, a reviewer may choose to just use his or her experience to judge whether the calculated savings are reasonable and not provide any further review. This limited level of review is expected to be rare, and to occur only in circumstances where the reviewer is very familiar with the measure and results from prior applications.

If a measure is highly cost-effective but has low savings, significant review is not warranted, since the investment is clearly worthwhile via the cost-effectiveness criteria and the uncertainty in the savings associated with minimal review will have little impact on overall program, utility, and regional savings estimates.

For common measures that are clearly cost-effective and that have high savings, the review will have greater rigor. The reviewer should not just check that the estimated savings are reasonable but should also verify that the assumptions are appropriate and that the calculation method is sound and appears correct.

Measures that are less common, have high savings, and/or are only marginally cost-effective, should have the most detailed review. The reviewer should check that the baseline and assumptions are clearly justified, that the calculations are appropriate for the measure, detailed, and comprehensive, and that the result is reasonable.

In all cases, checking for reasonable results includes comparing the savings to the baseline energy use and comparing the baseline energy use to what would typically be expected for the relevant end-use system or piece of equipment. The latter check may not be possible in all circumstances, particularly in the industrial sector, but it should be possible for most measures in the residential and commercial sectors.

Persons preparing calculations should consider the review cycle in preparing their calculations and documentation. Reviews may include peer-to-peer and internal quality control reviews as well as program reviews by BPA or program implementation technical staff.

4.2. Typical General Calculation Issues

The rest of this chapter of the document provides guidance on improving the precision of energy savings estimates and how to document those estimates. To begin, there are some broad categories of issues that frequently occur with engineering calculations.

Perhaps foremost is the issue of inadequate documentation. This is not just an issue for the reviewer. To develop a robust calculation, the analyst needs a clear understanding of the system, its operation, and associated equipment. Documentation, therefore, should include a clear system description, a system schematic, and relevant equipment performance data.

Another issue is unclear assumptions or calculations. Review Section 7.3.2 on *Preparation of Documentation* and the remainder of this section.

A third issue is an inadequate definition of the baseline: the available measurements are insufficient, or they don't support the assumptions. Much of this section deals with the establishment of a robust baseline.

A related issue is the inadequate segmentation of data into periods of similar operation. In general, baselines and calculations should segment data according to categories (such as equipment status, occupancy, or daytype).

Finally, there is the issue of improper calculations. These generally take one of two forms: simplifying assumptions aren't justified or physical "laws" are improperly applied.

A 2007 paper, "Myth-Busting Savings Calculations," presented at the *2007 International Energy Program Evaluation Conference (IEPEC)* provides additional specificity on common calculation issues. Some of the findings presented in that paper include:

- ➔ Research suggests a nearly universal tendency to underestimate off-shift equipment operation.
- ➔ Much more interior lighting is used after hours than is typically modeled.
- ➔ Equipment that is understood to be "always on" is still rarely on for 8,760 hours per year. Conversely, almost no equipment is always off, including equipment that is only intended for redundancy.
- ➔ Savings for night setback is often overstated.
- ➔ Motor load factors may often be lower than assumed.
- ➔ While variable frequency drives (VFDs) provide significant savings, calculations should include a limit on how low the power can go.
- ➔ The fan affinity laws are "widely misapplied and misused."

Regarding savings for night setback: it seems little understood how night setback/setup provides savings. Many new analysts or engineers think the savings are fully attributable to the equipment being off overnight. Others have an initial conclusion that there wouldn't be heating or cooling savings from night setback, just fan energy savings. If the building heats up overnight, the saved energy would be lost due to the increased cooling that would be required the following morning.

While there are multiple factors commonly considered – including building mass and thermal dynamics, equipment efficiency, and the effect of duty cycling or part-load operation on the equipment efficiency – there is another core benefit of night setback that is seldom considered, although it is implicitly handled in whole-building simulations. That is, not only would the

cooling equipment be operating more efficiently in the morning due to being more fully and continuously loaded, but the cumulative weather-related cooling load has also been reduced by the night setback. If the weather is warm, as the building heats up, the temperature difference between the conditioned space and the ambient is reduced, so the rate of weather-related heat gain is also reduced, as is the cumulative cooling load. Similarly, the converse is true for the heating operation during cold weather.

This document also includes discussion of the misapplication of fan (and pump) affinity laws, and VFDs, under *Specific and Common Issues*, later in this section.

4.3. Bin Calculations

When using spreadsheet-based engineering calculations it can be impractical to run an 8760-hour calculation for a given system. Instead of predicting the operation at each hour of the year, it is reasonable to summarize the year using binned averages to represent the annual operation. If you know the typical or average operation of the system in each bin, that it can be used to calculate the load. Then if you know the schedule, or number of hours each bin is expected to occur annually you can multiply each bin by the number of hours to come up with the annual operation of the system.

Most commonly energy efficiency engineering calculations are developed with temperature bins, where the annual weather data is summarized into outside air temperature bins. For buildings that do not have a significant relationship to outside air temperature, a load bin (for example, computing load in a data center) would be more appropriate. Industrial or kitchen facilities might have production values which could be binned. Hourly bins can be used for scheduled loads such as lighting, which don't vary widely outside of scheduled operation. While typically the bins should relate to the load on the system, there is sometimes an advantage to binning data which influences the efficiency of the system. This might be the case for wet bulb outside air temperature bins and the operation of a cooling tower, especially if it is serving a load that is not temperature dependent.

Temperature bins are a common way of estimating energy savings for systems whose energy use is a function of ambient temperature or humidity, such as for HVAC or refrigeration systems. While these types of calculations are well known, there are certain precautions that should be taken to ensure the calculations are appropriate.

Bin temperature data provides the number of hours in every bin of temperature interval. Five-degree bins are common but are not always appropriate. For example, two-degree bins are the largest that should be considered for economizer calculations, while one-degree bins would be better.

There are many sources for bin weather data, including that created by the analysts themselves. This is fairly easy to do using the *TMY3* dataset¹⁴ and a variety of spreadsheet functions.

¹⁴ <https://www.nrel.gov/docs/fy08osti/43156.pdf>

Microsoft *Excel* features and functions that can be used to create bin data from *TMY3* include: *PivotTables*, the *COUNTIF* function, various array formulas, and the histogram tool. Depending upon one's needs for specific analyses, the easiest may be to use *PivotTables*. Refer to *Excel* help or other sources for further information on these functions.

Commercial tools with schedule creators can be convenient because they make it easy to create bins by time of day or by daytype. Although it does not automatically create *TMY3* temperature bins, there is a useful and free *Excel*-based tool called *ECAM* that facilitates the creation of pivot tables for energy analyses; it also includes a schedule creator.¹⁵ *ECAM* and *Universal Translator (UT)*¹⁶ also help categorize bin data by schedule category or equipment status.

Properly organizing bin data by schedule or other categories can prevent an issue mentioned above: the inadequate segmentation of data into periods of similar operation. Calculations should often be organized not just by temperature, but also by one or more of the following:

- ➔ Occupancy
- ➔ Season
- ➔ Equipment status

Occupancy and season are obviously schedule-related categories. Note that there won't be savings when equipment is scheduled *off* during the baseline, which can occur both by time-of-day and by season.

The need for proper data categorization is discussed in the next section, *Establishing a Solid Baseline*.

4.4. Establishing a Solid Baseline and Good Energy Calculations

The key to establishing a solid baseline is to relate energy use, or the parameters that most affect energy use, to known measured values. This means the creation of regressions.

¹⁵ From the CCC (California Commissioning Collaborative): *Energy Charting and Metrics (ECAM) Tool*. *ECAM* was originally developed for *Excel 2003*. Version 6R6 was released in 2023 and is now available from <https://sbwconsulting.com/ecam/>.

¹⁶ From UTOnline.org.

4.4.1. Data Relationships Associated with Loads

The relationships needed for energy calculations are typically load-related. Table 4-1 shows some examples:

Table 4-1: Examples of Load-Related Dependent Variables

Independent Variable	Dependent Variable
Outside Air Temperature (OAT)	Load
Outside Air Temperature (OAT)	kW
Load	kW
Load	CFM
Load	GPM
Occupancy or schedule	Load
CFM	kW
GPM	kW

Note that the *independent* variable is typically either load or a parameter that can be used as a proxy for load. The *dependent* variable is either power or a parameter that can be related to power.

The objectives for creating regressions from these relationships are to:

- ➔ Mathematically relate building or equipment loads or energy use as a function of weather, schedules, and/or other driving variables
- ➔ Enable extrapolation of a relatively short period (less than one year) to all time periods and conditions that occur over a year of operation.

For existing buildings, the needed data may come from:

- ➔ Trend logs
- ➔ Data loggers
- ➔ Spot measurements
- ➔ Equipment logs (e.g., chiller, boiler)

Energy calculations for new buildings should use manufacturers' data for equipment and may infer load information from similar existing buildings.

Note that these relationships may be multivariate. For example, chiller power is most significantly a function of load, but it is also a function of entering condenser water temperature and leaving chilled water temperature. Similarly, the power of a packaged unit is a function of load, outside air temperature, and entering wet bulb temperature. When developing a baseline, it is the relationship to load that is most important. However, when estimating savings, the other relationships may be important, especially if controlled independent variables (such as the

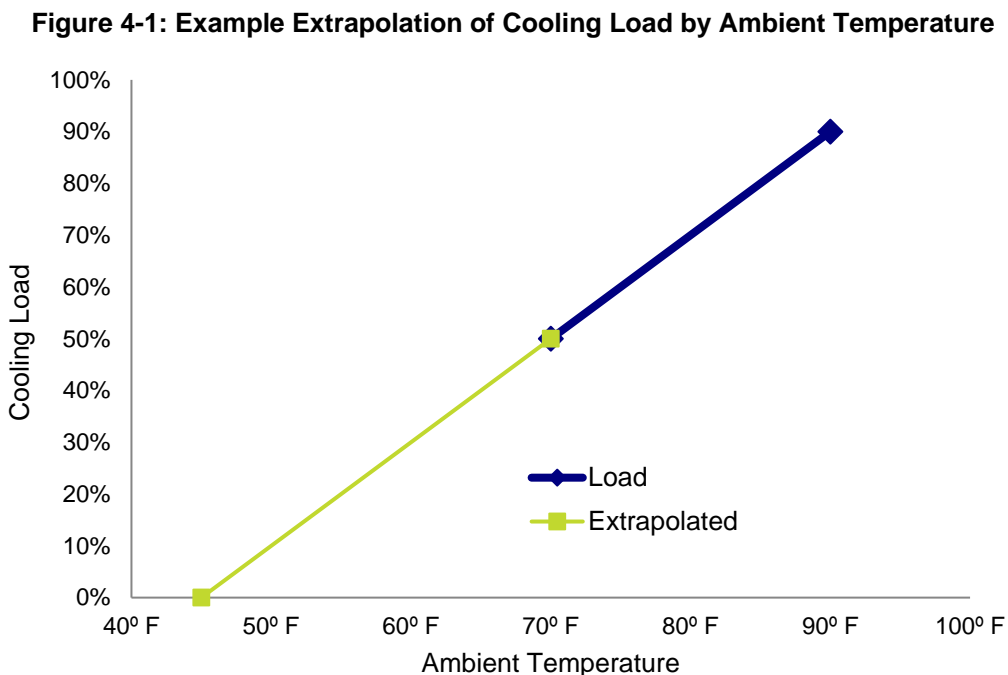
temperatures of entering condenser water and leaving chilled water) will be different in the post case. Sufficient data to fully characterize chiller performance can be difficult to obtain. However, such information may be necessary for measures that change control strategies, such as revising staging or set points.

Information on these relationships can also come from operator interviews. For example, an operator interview can tell you how many chillers are needed at different outside air temperatures. Beware that this does not imply that the chillers are fully loaded when an additional chiller is needed. Issues such as low ΔT can require an additional chiller.

As another example: The building operator may say that the chiller plant is 50% loaded at 70° F ambient temperature and 90% loaded at 90° F. This information can be the basis for load in the engineering calculations.

4.4.2. Extrapolation

The scenario just presented also provides the opportunity to discuss another potential issue with engineering calculations. The regressions developed from known data are only valid over the range of that data and great care should be taken if there is a need to extrapolate outside that range. Figure 4-1 shows the relationship imputed from the data provided by the operator and an extrapolation of that data until the load reaches zero.



If the calculations assume a linear extrapolation they will, in most circumstances, be wrong. If the building has functioning economizers, the load will drop off more rapidly at cooler temperatures and may approach zero at 55° F or higher.

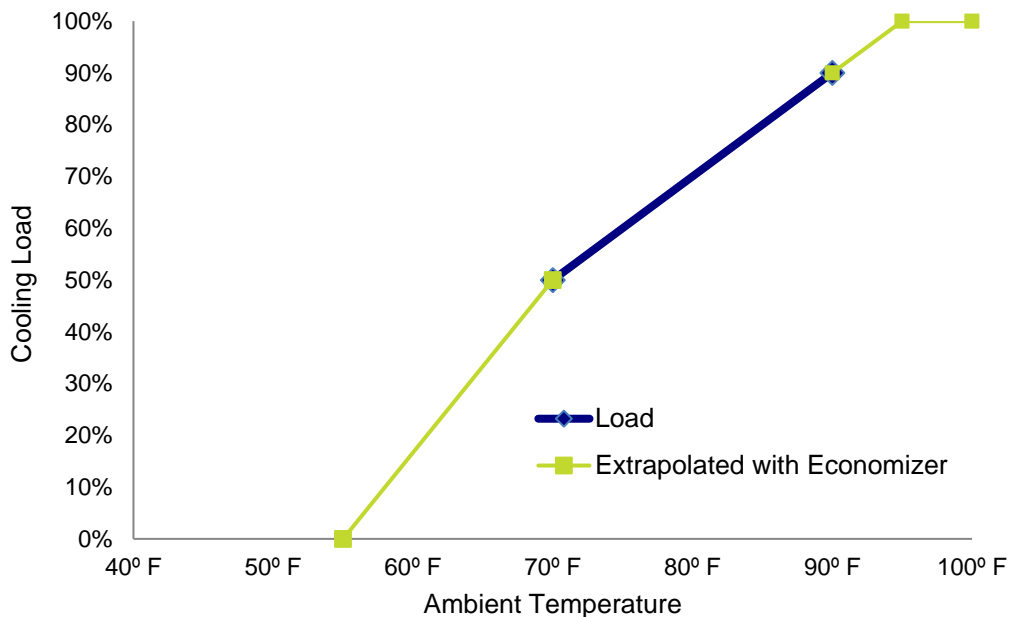
Similarly, but at the other end of the dataset, consider an ambient design condition of 105° F. Note that the cooling plant will be fully loaded at an ambient temperature of 95° F. Therefore, an extrapolation on the high-end could overstate the cooling load. In this example, it is obvious that the cooling load shouldn't be allowed to go over 100%. However, if the relationship were kW as a function of ambient temperature, this limit would not be so apparent.

In general, avoid extrapolation. However, when extrapolation is necessary, errors due to extrapolation can often be minimized by placing limits on the values of variables. It is often better to limit the ends of a regression where the data ends and hold the dependent variable constant beyond that point. This may be especially true for power at low flows in a variable flow system.

But analysts need to consider what the data represents and what it means prior to placing such limits. In the prior example, it is obvious that the cooling load should be limited to 100%. But what should the load be under cool ambient conditions? As stated previously, the analyst should have a thorough understanding of the system being modeled. In this case, if the building was known to have properly functioning economizers, the analyst may choose to supplement the data regression with the expected behavior under conditions outside the monitored range, as shown in Figure 4-2.

If behavior outside the known range is uncertain, make assumptions that will result in conservative savings estimates. This usually means an assumption that leads to reduced baseline energy use.

Figure 4-2: Example Extrapolated Cooling Load with Economizer



4.4.3. Extrapolation Errors Due to Seasonal Changes

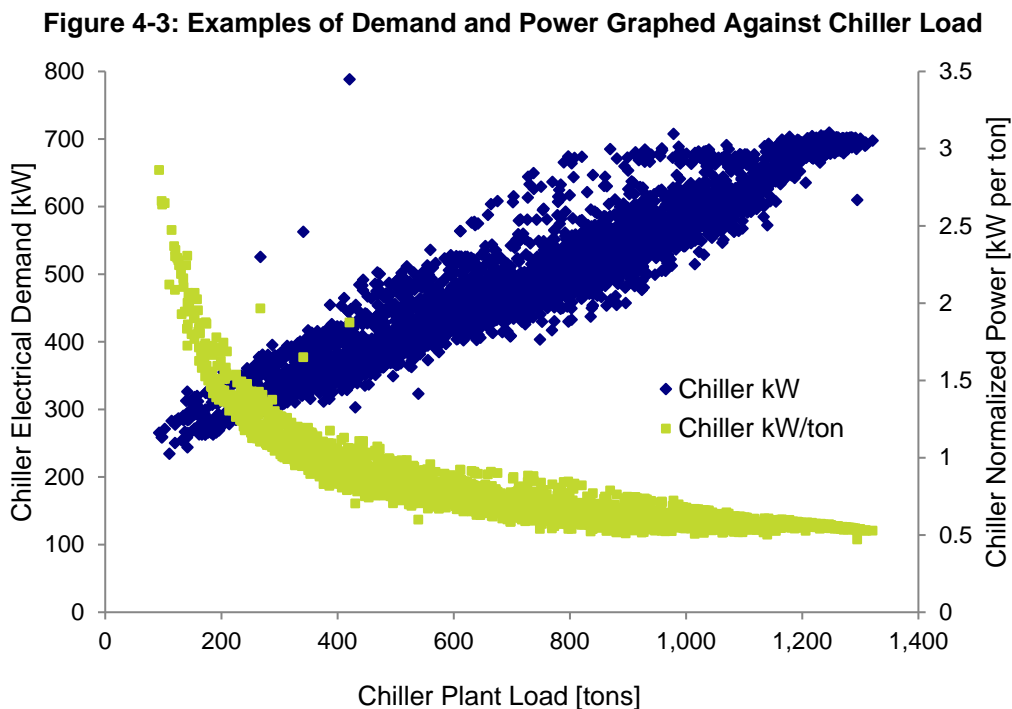
Beware of seasonal changes to operation. These may not be captured in trends or logs, so operator interviews are important. A specific issue to be aware of is seasonal lockouts of equipment, such as winter lockouts of chillers.

4.4.4. Data Relationships Associated with Control Strategies

Relationships used for energy calculations can sometimes be related to control strategy (such as proportional reset), where a set-point is linearly related to another parameter, such as outside air temperature. Be careful with such assumptions, however. Often, proportional plus integral controls make dependent set-points not just a function of offset distance from the set-point, but also duration of the offset from the set-point. This makes the *effective* gain, or slope, of the relationship much greater than would be indicated by the proportional relationship alone.

4.4.5. Tips on Choosing Data Relationships

Whenever possible, choose data relationships that can be represented by a linear or other easy-to-model regression. For example, plot power (kW) versus load, rather than EER or kW-per-ton versus load. It is much easier mathematically to represent kW as a function of load, since it is a linear relationship, whereas kW-per-ton goes asymptotic at low loads (see Figure 4-3).



Note the difference in the shapes of the two scatters. There is no built-in trend line in *Excel* that will fit this kW/ton curve. In contrast, it is easy to fit the kW data with a linear or 2nd order polynomial curve. Since it is trivial to calculate kW per ton if we have both kW and tons, why

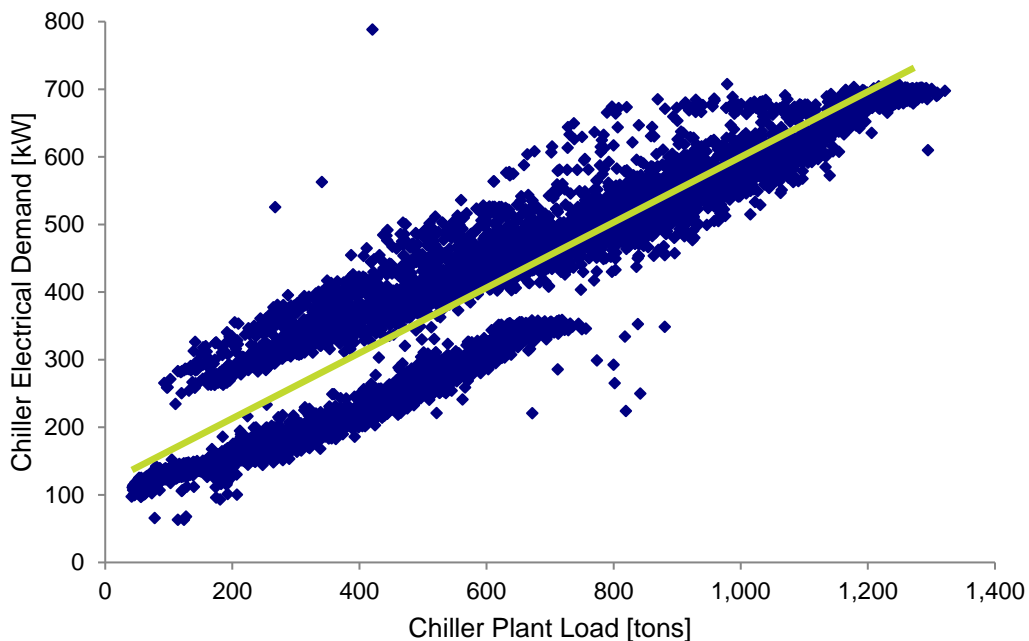
use a difficult fit that is more likely to poorly represent the data, and especially to extrapolate poorly?

As mentioned in the prior section, a common issue in developing baselines is a failure to properly categorize and segment the data. Figure 4-4 shows a common error. A regression is created based on a dataset without sufficient consideration of what the data means. In this figure, the regression is shown as the green line.

The two separate clouds of data points should be an indicator that the data is inadequately categorized. Experience has shown that this issue occurs frequently. Common data categorizations that should be considered include:

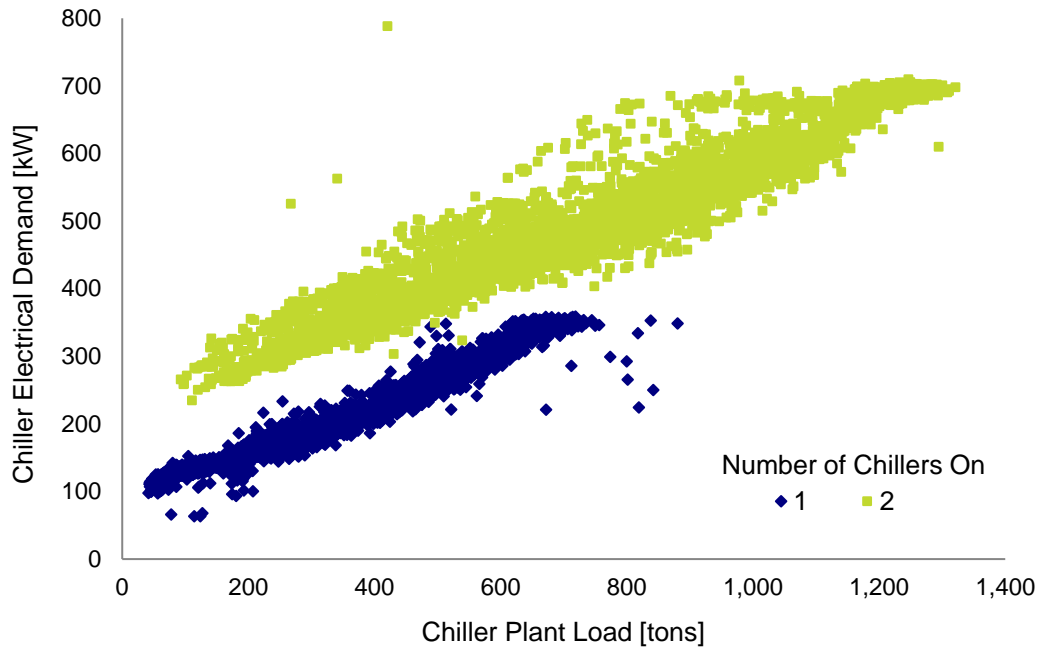
- ➔ Occupancy (or time of day)
- ➔ Daytype
- ➔ Equipment status
- ➔ Combinations of the above

Figure 4-4: Example of Inaccurate Regression Prediction of Chiller Demand



Whenever distinct data clouds are encountered, the analyst should consider the possible reason for the distinction. Figure 4-5 shows the same data, properly categorized.

Figure 4-5: Example of Appropriate Interpretation of Data from Multiple Chillers



The distinct clouds correspond to the number of chillers operating. It is obvious from this understanding of the data that there was an opportunity for an improved chiller staging strategy. To properly characterize the baseline, the analyst should understand the operation of the facility.

Perhaps a broader, more general way of thinking about data categorization is that dissimilar operating conditions must be filtered out of a regression. In the example above, the electrical demand at a given load varied depending upon a number of chillers operating. Therefore, separate regressions should be created. The data for two chillers operating should be filtered out when the regression is created for a single chiller operating, and vice versa.

As another example, consider a regression of load versus outside air temperature. As indicated by the likely categories listed above, the regression may only be appropriate for a specific portion of the day, and only on weekdays. It may only be appropriate when relevant equipment is on.

4.4.6. Developing Regressions

Refer to the *Regression for M&V: Reference Guide* for advice on developing and validating regressions.

4.5. General Spreadsheet Calculations Guidance

Here is a brief list of suggestions for developing spreadsheet calculations. Following this short list of advice will help the reviewer and also help anybody using your spreadsheet in the future – including you, if you haven't looked at it for a long time.

- **Don't bury constants inside formulas; explain any uncommon constants.**
- **List equations, including explanations of variables.**
- **Use names for variables instead of cell references as much as practical.**
- **Consider breaking long calculations into multiple steps where helpful for clarity.**
Where a breakup of a long calculation will increase clutter, thereby reducing clarity, provide an explanation of the calculation in a cell comment or on a separate worksheet.
- **A good organization approach uses the following sections for each savings calculation:**
 - Summary of Results
 - General Fixed Inputs – baseline and post
 - Curve Fits – baseline and expected post
 - Equations – list and explanation
 - Calculations – by category (occupancy, equipment status, daytype, etc.)

4.6. Common Specific Issues

The following are common issues to consider.

- **The detail required in a calculation is often dependent upon the level in the building hierarchy for which the calculations are intended.** For example, a regression of building cooling load to outside air temperature (OAT) may be fine when looking at the chiller plant but may not be correct when looking at an air handling unit (AHU). Interior and perimeter zones will have different relationships of load to OAT.

Similarly, recognize the limitations of single-zone approaches to calculations. In many cases, they will overestimate savings. Often, a single zone will drive the output of an AHU or plant. Therefore, an energy efficiency measure may address this, thereby helping the whole building become more efficient. However, if the measure just addresses one zone, then after implementation or when the measure is active, another zone will become the “critical” zone that drives the AHU or plant output.

This example of the weakness of a single zone calculation is also an example of a case where a whole building simulation may be the superior approach. Whole building

simulations typically lump together zones that are believed to be similar, so care must be taken to ensure that the whole building simulation really is the superior approach.

- ➔ **Fan and pump curves can be very valuable in creating good calculations.** Knowing the relationships between flow, speed, and power can help with the development of regressions. Also, equipment is frequently oversized for the application, less frequently undersized. Retrofits should usually include “right-sizing,” as well as greater efficiency at the design point. Use of the relevant fan or pump curve can help identify any sizing issues. Of course, facility representatives should be involved in any sizing decisions to account for load growth, unique operational requirements, or operation in other seasons.
- ➔ **Use redundant measurements when possible and appropriate.** This is especially true for flows, which are hard to measure. For flows, compare two or all three of the following to verify the measurement:
 - Measured flow
 - Flow from pump or fan curve at measured conditions
 - Flow from differential pressure across another device, such as chiller evaporator bundle or balancing valve
- ➔ **Do not use fixed power or efficiency.** Power may be a function of load, flow, temperature, and/or humidity for different pieces of equipment. Use measured data or equipment curves. Sufficiently complete data is typically available for packaged cooling equipment. Chiller data is typically inadequate, and some effort must be expended to obtain a relatively complete chiller map, where power is a function of load, leaving chilled water temperature and entering condenser water or air temperature. Note that the relationships can be somewhat different for different types of compressors and are very different for variable speed units.
- ➔ **Implement reset strategies for existing systems.** As implied above, the relative benefit of these strategies can be different for different chillers and types of compressors. An example of benefits are provided in *Chiller Controls-related Energy Saving Opportunities in Federal Facilities*, a paper by Tom Webster of the Center for the Built Environment (CBE), University of California, Berkeley.
- ➔ **Note that motor efficiency can drop off significantly at low load.** A great source of motor data is the U.S. Department of Energy’s *MotorMaster+* database. The *MotorMaster+* database can be used to get specific or typical efficiencies at four load levels.
- ➔ **Similarly, VFD efficiency drops off significantly at low speeds.** This is typically very low load and hence not generally as significant an issue as motor efficiency but may be in some cases. Also, note that motor efficiencies when driven by a VFD will have a different, typically more efficient, relationship than for a motor driven off line power.
- ➔ **For most variable flow systems, power is not proportional to the cube of flow.** This may be a satisfactory relationship for cooling tower fans and other fans serving a constant

or open system, and where the speed is directly varied to satisfy the load, but it is not satisfactory for a system where the flow is controlled by a restriction (valve, damper) and the speed is varied to satisfy a pressure set-point. The affinity laws are for a fixed system. A system with variable restriction is not a fixed system. Also, the relationship of power to flow depends upon the starting point (max flow) on the fan or pump curve.

The best approach is to measure actual performance after the change. This can provide data for the proper correlation. Standard Protocols prepared for the Regional Technical Forum (RTF) by may be helpful in some cases.

4.7. Some Sources of Calculations and Tools for Energy Analysis

4.7.1. General

- ➔ BPA has a variety of tools intended for prescriptive UES measures which can be applicable and appropriate for custom projects in certain cases. (See <https://www.bpa.gov/energy-and-services/efficiency/document-library>)
- ➔ A list of tools is available at the U.S. Department of Energy's *Building Energy Software Tools Directory* (see <https://www.energy.gov/eere/buildings/building-energy-modeling>)
- ➔ California Commissioning Collaborative Existing Building Commissioning Toolkit: Spreadsheet Tools – Energy Charting and Metrics (ECAM) Tool (see www.sbwconsulting.com/ecam for version 6r6).
- ➔ UTOonline.org's *Universal Translator* version 3, (www.utoonline.org)

4.7.2. Weather Data Sources and Binning Tools

- ➔ NREL's TMY3 Weather Data. *National Solar Radiation Data Base: 1991- 2005 – Update: Typical Meteorological Year 3 (TMY3)*.
- ➔ InterEnergy Software's *BinMaker 3.0* adds TMY3 data sets with 1020 U.S. locations to TMY2 bin energy analysis available in the previous versions.
- ➔ TMYx¹⁷ Weather Data. Similar to NREL's TMY3, TMYx files are typical meteorological data derived from hourly weather data through 2018. Data includes more extreme improved irradiance data compared to TMY3 data.
- ➔ ASHRAE Weather Data Viewer.
- ➔ Hands Down Software's *HDBinWeather* allows you to easily create your own bin tables, customized for the hours of interest.

¹⁷ <https://climate.onebuilding.org/>

- ➔ HAVCware.net's *TMY2BIN* converts *TMY2* (hourly) weather files to bin weather data for quick energy calculations.
- ➔ NOAA *Engineering Weather Data*, Department of the Air Force Manual AFM-88-29.
- ➔ Historical Weather Data online – Weather Underground.

4.7.3. Industrial Sector Tools

A wide variety of software tools are available at the U.S. DOE *Software Tools* website (at <https://www.energy.gov/eere/iedo/measur>). These include the following:

➔ **Plant-wide**

- *Industrial Facilities Scorecard*
- *Quick Plant Energy Profiler/Integrated Tool Suite*

➔ **Motor-Driven**

- *AirMaster+*
- *Fan System Assessment Tool (FSAT)*
- *MotorMaster+*
- *MotorMaster+ International*
- *Chilled Water System Analysis Tool (CWSAT)*
- *Pumping System Assessment Tool (PSAT)*

➔ **Steam**

- *Mechanical Insulation Assessment and Design Calculators*
- *Steam System Tool Suite (SSTS)*

➔ **Process Heating**

- *Combined Heat and Power (CHP) Application Tool*
- *NOx and Energy Assessment Tool (NxEAT)*
- *Process Heating and Survey Assessment Tool (PHAST)*

➔ **Data Centers**

- *Data Center Profiler Software Tool Suite (DC Pro)*

5. Simulation for Existing Buildings

5.1. Practical Considerations and Best Practices

This chapter of the *ECwV Protocol* covers the use of simulation to estimate savings for existing buildings. Chapter 4 discussed the alternate path of engineering calculations for existing buildings, and Chapter 6 presents the use of simulation for new construction or major renovation projects.

The use of simulation is appropriate for some, but not all, efficiency projects in existing buildings. In many cases, however, engineering calculations will take less effort and can be more accurate. Guidance on the choice of simulation vs. engineering calculations is provided in Chapter 2 of this *ECwV Protocol*. The following are examples of measures in existing buildings that can be good candidates for simulation analysis.

- **Building enclosure upgrades** – such as window replacement, retrofit window films, window shading devices, roof insulation, and wall insulation
- **Installation of skylights and automatic daylighting control in conditioned spaces**
- **Air-side economizers**
- **Demand controlled ventilation**
- **Supply air temperature reset controls**

Other measures can be good candidates for simulation analysis, depending on the specific circumstances. In these cases, it should be considered whether or not engineering calculations are more appropriate.

- **Chiller retrofit** – when measured chilled water load data are not available and sufficient performance data is available from the manufacturer for the development of performance curves for use in the simulation program
- **Packaged HVAC system retrofit** – when the potential savings magnitude justifies the effort to create a whole building simulation model
- **Supply air pressure reset controls** – when the modeler has the knowledge and skill to produce alternate fan power curves to accurately represent alternate control schemes
- **Refrigeration retrofits** – when the simulation program includes appropriate refrigeration capabilities and the modeler is experienced in their use

Some measures are poor candidates for simulation analysis, due either to the fact that the effort to create a simulation model is not justified or that a simulation model would be less accurate than engineering calculations because of limitations in the modeling software. For example:

- **Lighting retrofit** – simulation effort is typically not justified

- ➔ **Motor efficiency** – simulation effort is typically not justified
- ➔ **HVAC retrofits for specific system types that are not accurately represented by the simulation tool**
- ➔ **Process efficiency measures where building envelope loads have little or no impact on energy use** – such as compressed air, well pumps, or manufacturing processes

5.2. Recommended Approach for Reviewing Calculations

The appropriate depth of review for simulation calculations is a judgment call. It is unrealistic to expect a detailed review of input and output files for each project. In general, a calculation review should include careful inspection of end-use results and summaries of simulation inputs. Reviewer experience with the simulation program is not absolutely necessary, but that experience will be valuable to focus the review on critical inputs.

The following is a list of suggested steps in a review process. The reviewer should verify the following items.

- ➔ Required documentation is provided.
- ➔ Appropriate weather data is used for the simulation.
- ➔ The correct baseline definition is applied (for example, local code, existing system performance).
- ➔ Baseline modeling assumptions are documented, well supported, and are reasonable (typically in a table showing side-by-side baseline and proposed inputs).
- ➔ Claimed efficiency measures are documented, and modeling assumptions are correct and reasonable.
- ➔ Differences in simulation input between baseline and proposed cases are correct and reasonable for the proposed efficiency measures (for example, operating hours and thermostat set-points should be identical in the two cases, unless appropriate for a specific efficiency measure).
- ➔ The magnitude of end-use energy and demand savings is appropriate when considering the claimed energy efficiency measures.
- ➔ The total energy consumption and demand in terms of kWh/ft², W/ft², and kBtu/sf are reasonable for the building type and location.
- ➔ System-level and component-level energy and demand are reasonable in terms such as W/cfm, kW/ton, and kWh/ton-hour for important systems.
- ➔ Loads and airflows in terms such as kBtu/h-ft², ft²/ton, and cfm/ft² are reasonable for building type and location.

- ➔ Simulation outputs show that the number of hours for which heating or cooling loads are not satisfied are no greater than 300 and that the difference between baseline and proposed models is no more than 50 hours, unless reasonable explanations are provided. These thresholds are equal to those in *ASHRAE Standard 90.1-2016, Appendix G*.
- ➔ Simulation input and output files match the separately reported output results and input assumptions. Spot checks of input and output files may be appropriate.

5.3. General Simulation Guidance

In the context of this guideline, simulation is hourly (minimum), full-year dynamic simulation. In general, a whole-building simulation model is developed; but, in some cases, a model of a portion of a building or a system within a building may be appropriate. When used to estimate savings for an existing building, simulation models are developed for a baseline condition and one or more proposed alternatives.

5.3.1. Energy Modeler Qualifications

Due to the complexity of simulation programs, it is essential that the person developing the simulation model have significant experience with the specific simulation tool used for the analysis. As a rough guide, that person should have developed at least five models of similar scope. In cases where the primary modeler has less experience, then the model should be reviewed for accuracy by a person who meets the criterion.

Knowledge of the design and operation of the systems being evaluated is also critical. In the ideal case, the modeler possesses that experience. Otherwise, the model and results should be reviewed by a person with design and operation experience to ensure that the efficiency measures are defined properly and that the results are reasonable.

5.3.2. Developing Simulation Models

This section provides recommendations for the process of developing simulation models, with the goal being a high-quality, well-documented savings calculation.

- ➔ **Clearly define the problem before creating a simulation model.** Describe both the proposed efficiency measures and the baseline conditions. If feasible, make preliminary “back-of-the-envelope” savings estimates that will be useful later when evaluating the simulation results.
- ➔ **Think about the required outputs.** Create a list of simulation outputs that will be needed in order to report the savings results, to evaluate the accuracy of the models, and to verify performance. In addition to typical end-use energy and demand results, this list may include specific simulation program output reports and hourly variables. Make sure that the simulation program can provide the desired outputs.
- ➔ **Identify and list primary input assumptions.** Create a list of important simulation inputs for both the baseline case and proposed case. Having this list prepared in advance

will speed up model development. This list will also serve as documentation that is useful to the reviewer. Note that this step in the process can take a significant amount of time.

- ➔ **Select a simulation program that fits the problem.** Ensure that the program can represent the measures to be evaluated. If approximations will be necessary, then write down a description of the method to be used. This description will also be useful to the reviewer.
- ➔ **Identify an appropriate weather data file.** Use typical weather data (such as *TMY3* data) for savings calculations, even if actual year weather data has been used to calibrate a baseline simulation model.
- ➔ **Identify utility rates.** Whenever possible, identify and use the actual utility rates that will apply to the project, including demand and time-of-use rates where applicable.
- ➔ **Develop a thermal zoning plan.** Most models will consist of multiple thermal zones. As discussed in the section *Common Simulation Issues*, the goal should be to include enough zones to accurately represent building loads. Including excessive numbers of zones increases model development time, simulation run time, and the potential for errors.
- ➔ **Develop an HVAC system modeling approach.** Some simplifications can be appropriate and provide sufficient accuracy while reducing model development time. For example, when multiple single-zone HVAC units serve a large space, such as a grocery store, then those units can be modeled as a single unit if they are expected to experience similar loads.
- ➔ **Develop a building enclosure modeling approach.** Simplifications can also be appropriate for the building enclosure geometry and, in some cases, approximations will be necessary to represent configurations that cannot be explicitly represented in a simulation program. Limitations vary between programs, but examples include curved surfaces, multi-story spaces (such as atria), or complex shading devices.
- ➔ **Create a baseline simulation model.** Once all the previous tasks are complete, then enter information into the simulation program. For an existing building, it will usually be appropriate to first create the baseline model. More information on defining a baseline is provided below. It may be necessary to create two baseline models: one calibrated model that represents existing conditions and a second that represents appropriate baseline performance for the savings calculations. The second model might include, for example, code-minimum insulation levels or equipment efficiency.
- ➔ **Add energy savings measures.** Create the simulation model of the proposed case by changing inputs to represent the energy efficiency measures. It is recommended that changes be made one at a time and that results be recorded for each step. While these intermediate results are not necessarily required for submission, they are extremely valuable as a quality assurance measure to ensure that the impact of each change makes sense. This step-by-step process also helps the modeler develop an understanding of the relative impact of simulation inputs. When modeling more than one efficiency measure, it may be appropriate to model individual measures separately to evaluate performance,

then add measures incrementally to create a package of measures. There are no specific rules regarding the order in which measures are added to the baseline model, but a common method is to add them in order of cost effectiveness.

5.3.3. Evaluating Simulation Models

Some simple evaluation steps can help ensure accurate simulation model results. These steps can be grouped in two general categories: confirming inputs and reviewing outputs.

- ➔ **Confirm inputs.** In a typical simulation program, many of the inputs are reported in output files. The following are examples of items that should be checked in the output files to make sure they match expected values.
 - Building enclosure thermal performance – such as U-factors for building walls, roofs and windows, and solar heat gain coefficients for windows and skylights
 - Weather data file
 - HVAC system airflow, cooling capacity, and heating capacity
 - Fan power and pump power
- ➔ **Review outputs.** The following are suggested steps when reviewing simulation model results.
 - Examine end-use energy and demand for the baseline, and demand in side-by-side format; calculate percent savings for each end use. Check that savings are reasonable and be able to explain the reason for the magnitude of savings in each case.
 - Check that heating and cooling loads match expectations, perhaps in terms such as kBtu/hr-ft² or ft²/ton.
 - Check that heating and cooling loads are being met.
 - Compare the results to “back-of-the-envelope” calculations performed before starting the model.
 - Compare results to benchmark data that may be available from sources such as the U.S. Energy Information Administration (EIA) or the ENERGY STAR[®] website.

5.4. Establishing a Solid Baseline

This *ECwV Protocol* does not set specific requirements for calibration of the baseline simulation model, because the time required for a detailed calibration process may be excessive relative to the magnitude of savings. However, some level of effort is appropriate to ensure that the baseline

model represents the actual facility with reasonable accuracy. This section provides guidance on appropriate steps.

- ➔ **Operating hours.** Matching actual hours of operation is a first priority in getting a simulation model to match actual energy consumption. The best option for determining on/off times for HVAC and lighting systems is through monitoring, trend data, or direct observation of control system settings. Interviews with building operators or occupancy can also be acceptable sources, but direct observation is more reliable.
- ➔ **Operating profiles.** In addition to on/off times, the hourly profiles for lighting energy, plug loads, and number of occupants can have a significant impact on model results. However, accurate estimates are difficult without monitoring. If using “typical” schedules, note some sources underestimate the magnitude of nighttime plug loads, which are often 30% to 50% of daytime demand. A single short-term monitoring point on whole-building electric demand will show nighttime electric loads and can be useful for refining lighting and plug load schedules in the simulation model.
- ➔ **Cooling and heating set-points.** Thermostat set-points are best determined from observation of control settings or trend logs.
- ➔ **Component and system efficiency.** Precise inputs for many baseline model inputs will be difficult to determine. Direct measurement is not practical in many cases. Manufacturers’ specifications will be acceptable in most cases. When those specifications are not available, then educated guesses are necessary, based on sources such as codes or standard practice.
- ➔ **Outdoor air ventilation rate.** In some facilities, the outdoor air ventilation rate has a big impact on heating and cooling loads. If direct measurements are not feasible, then seek out a recent test-and-balance report. Mechanical equipment schedules on the original building plans are a less reliable source and assuming that the facility is operating with code-required ventilation airflow is an even less desirable approach. If the system includes air-side economizers, then try to verify whether they have been operating correctly, because a failed economizer can have a big impact on actual heating and cooling loads.
- ➔ **Other monitored data.** Baseline model accuracy can be improved using monitoring and spot measurements of the existing systems. Examples include fan kW and pressure, pump kW and pressure, and air and water flow rates.
- ➔ **Comparison to annual and monthly results.** In most cases, utility bills will be available for the existing facility. While calibration is not required, a comparison of actual monthly consumption to simulation results can be very valuable in improving the accuracy of the model.

5.5. Common Simulation Issues

This section highlights important simulation topics and identifies common errors in the use of simulation.

5.5.1. General Simulation Issues

The following are general issues to be addressed in simulation.

- ➔ **Unknown inputs.** Simulation models require detailed information about the building enclosure and building systems, but for an existing facility some of that information may be difficult or impossible to determine. Examples include wall insulation within enclosed cavities, window solar heat gain coefficient (SHGC) for glazing with low-e coating, and efficiency for HVAC components without manufacturers' literature. In such situations, clear documentation of assumptions is essential, along with a record of the source of information, which will in some cases be an educated guess. If defaults from the simulation program are used, then identify and record those values. Judgment is necessary regarding the level of effort appropriate for identifying performance of the existing facility, and the effort should be focused on inputs that have the biggest impact. A quick sensitivity study can help in prioritizing effort. In some cases, spot measurements or short-term monitoring may be appropriate for important inputs.
- ➔ **Appropriate level of complexity.** For practical reasons, most simulation models include many simplifications compared to the actual facility. In a typical model, the details of the actual enclosure geometry are simplified, and the number of modeled thermal zones may be fewer than in the actual building. Internal loads may include averaged plug loads and lighting loads rather than actual room-by-room values. The goal should be a model that is as simple as possible in order to minimize the potential for errors, but not too simple that it misses important performance issues. For example, a variable air volume (VAV) system model will likely be inaccurate if the model does not include separate thermal zones for each unique orientation and occupancy type. And heating and cooling loads may be misrepresented if small, yet highly conductive, building enclosure elements are ignored, such as metal window frames. For most cases, the rules in *ASHRAE Standard 90.1-2016 Table G3.1*, which cover building enclosure simplifications and thermal zoning, result in an appropriate level of model complexity.
- ➔ **Hourly weather data not available for the project location.** Weather data are available for most simulation programs in *TMY3* format, which covers more than 1,000 locations in North America. Therefore, weather data for a reasonably close location should be available. Note, however, that the most appropriate choice may not be the geographically nearest location. If there is any question, then compare weather statistics for the actual location (such as temperature bins or heating and cooling degree-days) to the same statistics for the nearby *TMY3* locations.
- ➔ **Design values vs. typical values.** In most cases, the plug load and occupant density values used for HVAC design calculations are higher than typical actual values. In some cases, the same is true for lighting loads. Therefore, the values used for HVAC design are usually not appropriate for simulation models, which should represent typical consumption. Where actual values are not available, potential sources include the 2017 *ASHRAE Handbook – Fundamentals, Chapter 18*, the *ASHRAE Standard 90.1 User's Manual*, COMNET (Commercial Energy Services Network), and the U.S. DOE's technical documents supporting the 30% and 50% savings design guides.

- ➔ **Nameplate vs. actual values.** When using a survey of existing equipment to estimate space heat gain, it is important to note that nameplate power data is often much higher than actual consumption. For example, research has shown that a typical desktop computer consumes 10% to 15% of its nameplate value, and a typical laptop consumes 25% of its nameplate rating (*ASHRAE Handbook – Fundamentals, Chapter 18*).
- ➔ **Features not directly supported by a simulation program.** It is common to encounter real-life systems and controls that cannot be directly represented by commonly-used simulation programs. Variable-refrigerant-volume HVAC systems are one example. Static-pressure reset controls are another. Therefore, thermodynamically similar approximations are necessary. Whenever such approximations are made, then clearly document the method used.
- ➔ **Incomplete understanding of the simulation program.** Few individuals have complete understanding of any simulation program. Therefore, inadvertent errors are challenging to avoid. To minimize the chance of errors, it is important to not underestimate the time and skill required to get a good result. Allow time for reading program documentation and studying simulation outputs. Perform sensitivity studies for key inputs.
- ➔ **Incorrect baseline definition.** In some cases, the rules for developing the baseline model are complex and open to interpretation. Allow time for a careful reading of the appropriate energy code or program requirements.
- ➔ **Lack of documentation of assumptions and methods.** Due to the time required to create a simulation model, modelers may not allocate the appropriate amount of time for developing complete and clear documentation of assumptions. However, the total amount of time required for a project can often be reduced through time spent to list important inputs and their values before starting model development. That initial investment of time helps to minimize wasted modeling effort.
- ➔ **Inappropriate use of simulation.** Some efficiency measures may be more accurately or efficiently evaluated using engineering calculations rather than simulation. Simulation is generally not necessary for measures such as lighting or motor efficiency improvements, because the calculations can be performed much more quickly and with good accuracy using engineering calculations. Most process-efficiency measures are not good candidates for typical building simulation programs unless thermal loads from the building enclosure are significant.

5.5.2. Enclosure Modeling Issues

The following enclosure modeling issues should be addressed.

- ➔ **Center of glass U-factors.** Make sure that overall window U-factors are being used in the simulation, including the effect of framing. Glazing manufacturers typically publish center-of-glass values, which are typically around 0.30 for a good double-pane low-e window. When the frame impact is included, the overall U-factor is more likely in the range of 0.35 to 0.55, depending on frame type. Whenever possible, use the NFRC rating for the specific window and frame combination. When a rating is not available, then refer

to tables in *ASHRAE Handbook – Fundamentals* or use the software *Window* from Lawrence Berkeley National Laboratory.

- ➔ **Thermal bridging.** U-factors for walls and roofs must account for thermal bridging, especially in metal-framed constructions. *Appendix A* of *ASHRAE Standard 90.1* has recommended values for a number of different construction types.

5.5.3. Internal Load Modeling Issues

The following internal load modeling issues should be addressed.

- ➔ **Realistic plug loads vs. design values.** As mentioned earlier, actual plug loads are usually lower than values used for design calculations.
- ➔ **Realistic schedules.** Also, as mentioned in the section *Establishing a Solid Baseline*, nighttime and weekend electric demand for lighting and plug loads is often higher than in schedules typically used for simulations. Nighttime plug loads are commonly 30% to 50% of daytime demand.

5.5.4. HVAC Modeling Issues

The following internal load modeling issues should be addressed.

- ➔ **Equipment performance and rating conditions.** Most HVAC component efficiency or capacity ratings apply at specific rating conditions. It is very important to make sure that the efficiency entered in the simulation program is provided at appropriate rating conditions. For example, the EER for a packaged air conditioner with an air-cooled condenser is typically rated at 95° F outdoor temperature and with air entering the cooling coil at 67° F wet bulb. Most simulation programs expect either the entered EER to correspond to those conditions or will allow the user to enter the rating conditions.
- ➔ **Efficiency ratings and fan power for packaged equipment.** Packaged air conditioner EERs usually account for the total electric input to the unit, including supply fan input power, as well as compressor and condenser input power; those EERs also account for heat gain from the supply fan and use net cooling load. However, many simulation programs take separate inputs for supply fan power and compressor cooling capacity and efficiency, and those programs calculate fan heat directly as well. Therefore, an accurate representation requires disaggregation of the supply fan power (often input as W/cfm) and the compressor input power (often input as kW/ton or COP). If the manufacturer reports those values separately, then use that information for input to the simulation model. Otherwise, there is no exact method for disaggregating the two values, but some simulation programs make approximations. The *User's Manual to ASHRAE Standard 90.1-2019* provides some guidance.
- ➔ **VAV box settings.** For models of variable air volume (VAV) systems, the input for minimum airflow fraction in the VAV boxes can be a very sensitive input and have a significant impact on results. Lower values result in lower fan energy, cooling energy,

and reheat energy. When trying to get a model to match the performance of an existing system, it can be helpful to check actual VAV box set-points.

- ➔ **Supply air temperature control.** The method for controlling supply air temperature in a multiple zone system, such as a VAV system, affects fan energy, cooling energy, and reheat energy. Make sure that the simulation program's modeling algorithm is understood and that it is a reasonable representation of the actual control scheme.
- ➔ **Fan curves.** Most simulation programs use a simplified fan power model comprised of a curve relating input power to current-hour airflow. Default curves may be provided for different control schemes, such as variable-speed control or inlet-vane control. In some cases, these curves, especially curves for variable-speed control, are optimistic and under predict actual fan power. A good discussion of fan curves in *DOE2* can be found in the *Advanced Variable Air Volume (VAV) System Design Guide* from Energy Design Resources, which also provides guidance on modeling static pressure reset control via fan curves.
- ➔ **Cooling equipment performance curves.** Most programs also use curves to represent cooling equipment capacity and efficiency, based on temperatures and part-load ratio. The appropriate choice of curves is especially important for measures that improve part-load efficiency, such as variable speed compressor control in chillers. When creating custom curves, make sure that the simulation program operation is clearly understood and that the performance data used to create the curves covers the full range of potential equipment operation. Guidance on creating chiller curves can be found in Energy Design Resources' *Design Guidelines: CoolTools Chilled Water Plant*.
- ➔ **Modeling non-standard systems.** Some HVAC system types are not directly represented by commonly used simulation programs and approximations will be necessary to represent their performance. Or, in some cases, the simulation program outputs, typically in the form of hourly variables, can be used as input to a spreadsheet model for a non-standard system. Examples of these system types include variable-refrigerant-volume systems, radiant heating and cooling, and dedicated outdoor air systems with heat recovery. Whenever non-standard methods are used, provide clear documentation of the methodology.
- ➔ **Heating and cooling loads not satisfied.** The simulation program will typically provide an output indicating the number of hours or the percent of operating hours when either heating or cooling temperature set-points are not met. There can be several reasons for unmet loads and it is not necessarily a case of undersized equipment. In some cases, it may be a control issue rather than a capacity issue. For VAV systems, common problems are the supply air-temperature control method or the minimum flow fraction on the VAV boxes (too low and under heating can occur).

5.6. Public Sources of Simulation Support

The following are sources of support in developing simulation models.

→ **U.S. DOE**

- *Building Energy Software Tools Directory*

→ **Energy Design Resources**

- *Advanced Variable Air Volume (VAV) System Design Guide*
- *Design Guidelines: CoolTools Chilled Water Plant*
- *HVAC Simulation Guidelines*
 - *CoolTools Chiller Bid and Performance Tool*

→ **Open Studio / EnergyPlus**

- *Cross-platform collection of software tools supporting whole-building energy modeling using EnergyPlus (www.openstudio.net)*

→ **ASHRAE**

- *ASHRAE Handbook – Fundamentals*
- *ASHRAE Standard 90.1-2019 – Energy Standard for Buildings Except Low-Rise Residential Buildings*
- *Standard 90.1-2019 User's Manual*
- *Weather Data Viewer*

→ **IBPSA**

- *International Building Performance Simulation Association*
- *Developing online BEMBook - Building Energy Modeling Book of Knowledge*

6. Simulation for New Construction or Major Renovation

This chapter provides guidance for the use of whole-building energy simulation to estimate energy savings for a proposed new construction or major renovation design when compared to a baseline defined by energy code or standard practice.

This method does not require model calibration. Therefore, this protocol is not IPMVP-adherent and is most applicable for smaller projects where the extra accuracy provided by calibrating the simulation model is not justified due to the extra cost of the calibration process.

Larger projects with significant savings should consider including model calibration. Model calibration implies a match to metered energy use within a specified level of precision. When calibrated, the simulation model should reasonably predict the load shapes and energy use of a facility or system. Guidance on calibrating a simulation model is provided in IPMVP.¹⁸

6.1. Applicability

This *ECwV Protocol* is applicable to the following situations:

- ➔ New building design and construction that incorporates high-performance features
- ➔ A major addition to an existing building that incorporates high-performance features
- ➔ Major renovation, refurbishment, or change of use that render historic energy use information irrelevant

This whole-building simulation approach will be most appropriate for projects with interactive energy efficiency features that are not easily or accurately represented through engineering calculations.

This method will be most convenient for projects where a simulation model has been developed for other purposes, such as energy code compliance or green building rating system points.

6.2. Recommended Approach for Reviewing Calculations

The recommendations provided earlier in *Chapter 5, Simulation for Existing Buildings* also generally apply to simulations for new construction projects. The following are a few additional considerations related to reviewing simulation calculations for new construction.

¹⁸ IPMVP Core Concepts, 2022 Section 9.4 provides details on model calibration.

- **Some simulation programs automatically create a baseline model from the description of the proposed design.** When reviewing these calculations, check that the appropriate baseline standard has been applied.
- **Savings calculations for projects seeking green building certification may also be reviewed by the green building rating authority.** That review provides an “extra set of eyes” on the project, but at least a quick review is still appropriate to check that the correct baseline has been applied and that the savings are reasonable for the specified efficiency measures.

6.3. Baseline Definition

The baseline for savings calculations is the applicable code standard, based on the local or state-level code in effect *at the start of the project*. The efficiency level of the baseline equipment must be consistent with any state or local mandates for new equipment, which may vary from city to city and state to state. The *M&V Selection Guide* includes regional resources for local codes.¹⁹ If a local code is more stringent than the applicable state code, the local code establishes the baseline. The guiding principle when establishing a baseline is that the applicable code defines “what would have been built” in the absence of energy-efficient design.

Energy efficiency measures not covered by energy codes may be eligible for savings if an industry-standard baseline performance level can be documented and an accurate calculation method is established. Efficient refrigeration, efficient elevators, and efficient data center servers are examples of new-construction efficiency measures that are typically not addressed by energy codes. These non-regulated end uses should be reviewed on case-by-case basis.

6.3.1. ASHRAE 90.1 Appendix G

Appendix G to define the baseline. Appendix G defines baseline HVAC system types based on the size of the building. For example, the baseline system type for a large (>150,000 square feet) nonresidential building is a variable air volume fan system with reheat at the terminal boxes (VAVRH). The baseline system type may be a different type than the system installed in the building. If a high efficiency heat pump system was installed, and the baseline was defined as a VAVRH system, then the savings cannot be easily determined by the methods in the End-Use Metering Protocol. A simulation modeling approach is generally required for a case where the entire system type is changed.

¹⁹ Resources include:

Oregon Department of Energy, <https://www.oregon.gov/energy/energy-oregon/Pages/Energy-Code.aspx>

Washington State Building Code Council, <https://sbcc.wa.gov/state-codes-regulations-guidelines/state-building-code/energy-code>

Washington State University’s Energy Program, <http://www.energy.wsu.edu/BuildingEfficiency/EnergyCode.aspx>

Northwest Energy Efficiency Alliance (NEEA), <http://neea.org/initiativesour-work/codes-standards/codes>

Appendix G also defines baseline characteristics for some parameters for which no minimum efficiency is specified in the main code. For example, the 2022 version specifies baseline pump power for systems with condenser water pumps as 19 watts per GPM. Such values may provide a defensible baseline for a highly efficient hot water pumping and distribution system.

6.4. Overall Procedure

Energy savings are based on two simulation models: the building *as-constructed* and the *baseline* building. Since these calculations must represent the building as-constructed, calculations performed during the design phase will need to be updated at the end of construction if substitutions were made during construction that affect energy performance. Measurement or monitoring of actual performance can be useful but is not required.

In the absence of specific simulation guidelines established by the local authority, use the procedures in *ASHRAE Standard 90.1-2022, Appendix G Performance Rating Method*. That document sets rules for creating simulation models representing the proposed design and the baseline design, described below. Simulation models shall assume 80% occupancy, unless another occupancy rate is supported by documentation.

The overall savings verification process begins with the design model and estimated savings based on the code-minimum baseline. During construction and commissioning, design and operational changes are expected to occur. The design model should be modified to reflect these changes. A simple example is that the building may have an occupancy or schedule different from that originally assumed during the design phase. Although this protocol does not require model calibration, the *as-built* model should reasonably reflect current occupancy, weather, and operations. The verified savings are the differences between the baseline and as-built models.

The following are the steps that should be taken:

1. **Estimate the energy use of the proposed and baseline building designs under expected operating and occupancy conditions.** The baseline design is set by the applicable energy code. The difference in electrical energy consumption between the two models represents the expected savings and forms the basis of potential incentives.
2. **Based on the proposed energy-efficiency features and expected savings, develop a Measurement & Verification Plan adhering to IPMVP.** The M&V plan should report $Savings = Calibrated\ Baseline\ Model - Calibrated\ As-Built\ Model$. Except for this protocol, calibration is not required and hence not relevant. Verified savings are to be normalized to Typical Meteorological Year (TMY) weather. Additionally, savings may be normalized to 80% occupancy if actual occupancy is between 50% and 80%.
3. **Build, commission, and occupy building.** During the construction and commissioning process, document design and operational changes for inclusion into the as-built and revised baseline models.
4. **Following building occupancy, collect twelve months of utility bills, plus other significant building information** (such as occupancy rate, actual operating schedule, and heating and cooling set-points). Optionally, collect actual site weather data and system-

level operating information from the energy management and control system and/or data loggers that can be used to improve the model.

5. **Update the as-designed simulation model** by incorporating the design modifications and replacing occupancy, schedule, and plug load assumptions with actual values to form the as-built model. Incorporate system-level metered information from building automation system (BAS) or data logger if available.
6. **When the as-designed model has been modified so that it reflects the as-built / as-operated conditions, map all relevant assumptions back to the baseline model** (that is, everything but the envelope and systems). If actual occupancy is between 50% and 80%, the models may be adjusted to emulate 80% occupancy. Using TMY weather, run the baseline model to establish the baseline energy use under typical weather conditions.
7. **BPA recommends using EPA's *Portfolio Manager* to track actual utility bills to ensure long-term performance persistence.** Designate the first performance year as the *baseline* in Portfolio Manager; annual deviations exceeding 10% energy use should trigger investigation and corrective actions.

7. Minimum Reporting Requirements

7.1. Measurement and Verification Plan

7.1.1. Essential Elements of the Measurement and Verification Plan

Proper savings verification requires planning and preparation. The IPMVP lists several requirements for a fully-adherent M&V plan.²⁰ The *ECwV Protocol* describes methods for verifying savings in equipment and end uses. This protocol describes planning requirements as well as specific measurement and analysis activities in the baseline and in the post-installation periods. Documenting in an M&V Plan how these requirements will be met is important so that others who subsequently become involved in the project can obtain a full understanding of the project's history and progress. The following are the essential items in documenting a savings verification plan.

- ➔ **Measurement Boundary:** Define the boundary around the equipment or end use within which the savings will be verified. This boundary can be around a specific piece of equipment, such as a pump and its motor, or a combination of equipment comprising a building subsystem, such as an air-handling system or chilled-water system.
- ➔ **Baseline Equipment and Conditions:** Document the end-use baseline systems affected by the ECMs. Document equipment configurations, operational characteristics (operating practices or operation schedules that characterize its hours-of-use), and equipment inventories, sizes, types, and conditions.
- ➔ **Energy and Other Usage-Related Data:** Include all energy data from spot measurements and short- or long-term monitoring from each source. Describe:
 - The parameters needed to characterize equipment load,
 - The sources of the energy and independent variable data and the time interval at which they are monitored,
 - The start and duration of monitoring for both the baseline and post-installation periods, and
 - Any needed corrections to the data
- ➔ **Reporting Period:** Describe the length of the reporting period and the activities that will be conducted, including data collection and sources.
- ➔ **Analysis Procedure:** Describe how the baseline and post-installation energy use or demand will be adjusted to a common set of conditions. Describe the procedures used to

²⁰ Chapter 6, *IPMVP Core Concept*, 2022.

prepare the data. Describe the procedures used for analyzing the data and determining savings. Describe any extrapolations of energy use or savings beyond the reporting period. Describe how savings uncertainty (if required) will be estimated. Document all assumptions.

- ➔ **Savings Verification Reports:** Describe what results will be included in the savings reports. Describe what data and calculations will be provided. Describe when savings will be reported for the project. Indicate the reporting format to be used. See the section below regarding the *Savings Verification Report* for the minimum requirements.

7.1.2. M&V Plan Additional Elements

The IPMVP describes several other elements of a good M&V plan. These items are good practice in general, but not necessary for every project. Many of them are provided here for reference and consideration for inclusion in M&V Plans written under this protocol.

- ➔ **Energy Prices:** Document the relevant energy prices to be used to value the savings. This can be a blended electric rate, or a schedule of rates based on time-of-use. Note that the latter will add significant complexity to the calculations.
- ➔ **Measurement Instrument Specifications:** Document the instruments used to obtain the data used in the calculations, including their rated accuracy and range. Identify the last instrument calibration date.
- ➔ **Budget:** Estimate the budget required for the savings verification activity. Estimate labor and material (such as meters and instruments, and associated safety equipment) costs and provide an approximate schedule for when activities will occur.
- ➔ **Quality Assurance:** Describe any quality assurance activities that will be conducted as part of this M&V project. This may include how data is validated, how assumptions or estimates are checked, identifying other parties who will review the work, and so on.

7.1.3. Documentation for BPA Database

The documentation should also include the following information to support review and inclusion of the project and measure in the *BPA Energy Efficiency Tracking System*²¹:

- ➔ Utility name
- ➔ Utility program
- ➔ Sector (commercial/industrial/residential)
- ➔ Existing building or new construction
- ➔ Site address (this will be used to establish the climate zone)

²¹ <https://www.bpa.gov/energy-and-services/efficiency/bpa-energy-efficiency-tracking-system>

- ➔ Building type (examples: office, school, hospital)
- ➔ Building size, square feet
- ➔ Affected end uses (examples: HVAC, interior lights, exterior lights, receptacle plugs, DHW)
- ➔ Affected system (examples under HVAC: cooling plant, heating plant, HVAC fans, terminal units, controls)
- ➔ Affected equipment type (examples under cooling plant: chiller, packaged unit, cooling tower, pumps)
- ➔ Measure type (broad category)
- ➔ Measure name (specific category)

In addition, BPA requires the costs incurred to implement measures are reported. These eligible costs determine incentives and are defined in BPA's *Custom Cost Documentation Guide*.²²

7.2. Savings Verification Report

7.2.1. General Verification Report Requirements Based on IPMVP

After the M&V calculations have been completed, the savings and actual M&V process used need to be documented.

Per the IPMVP, the *Savings Verification Report* should follow the savings verification report requirements described in the project's M&V Plan. Any deviations from the M&V Plan must be clearly described. If the M&V method followed the M&V Plan, then the information in the M&V Plan does not need to be repeated but can just reference the Plan. However, deviations from the planned method, measurement boundary, baseline characteristics, etc. necessitate new descriptions.

IPMVP Chapter 13, M&V Plan and Reporting, generally requires the following:

- ➔ Report both energy and cost savings.
- ➔ Report the data relevant to the reporting period, including the measurement period and the associated energy data and independent variables. Any changes to the observed data must be described and justified.
- ➔ Detail M&V data collection and analysis activities and [savings calculations](#).
- ➔ Describe any non-routine baseline adjustments, including the details of how the adjustments were calculated.

²² https://www.bpa.gov/-/media/Aep/energy-efficiency/custom-project-protocols/bpa_cost_project_documentation_guide_v1.pdf

- ➔ Report the energy prices or rates used in the cost-savings calculations.

In addition, actual data for baseline and post-period energy use should both be reported.

7.2.2. Additional Savings Verification Report Requirements

SAVINGS VERIFICATION REPORT INFORMATION

The report should include the following information in most cases. It may be organized in this order with a separate section for each of these items, or in another order or organization that makes sense for that program or project.

1. The data for the baseline period, including the time period, monitoring intervals, and data points should be described.
2. The data for the reporting period, including the time period, monitoring intervals, and data points should be described.
3. Report consumption (and where relevant, demand), as well as savings, since this facilitates review and reasonableness checks.
4. As required by IPMVP, report the energy prices or rates used in the cost savings calculations.
5. Also, as required by IPMVP, report both energy and cost savings.
6. Provide verification of potential to generate savings.

POST INSTALLATION VERIFICATION OF POTENTIAL TO GENERATE SAVINGS

IPMVP Section 7.6 requires that, “Confirmation that EEMs are installed and operating per the design intent and have the potential to perform and generate savings is required.” Therefore, an IPMVP-adherent process requires evidence that the efficiency measures have the potential to generate savings. BPA may require short-term monitoring, spot measurements, production data, or other forms of verification to confirm potential.

Verification includes notation of any changes to the project subsequent to the M&V plan. If the project changed, the energy and demand savings should be recalculated based on as-installed conditions. Data and analysis from metering performed before or after installation should be included with the calculations.

In general, verification of potential to generate savings can take either of two forms:

- ➔ Installation verification
- ➔ Operational verification

Installation Verification

Installation verification is the less rigorous of the two verification methods. It demonstrates the measures were installed as planned. This demonstration may vary by measure. Project developers are required to describe the evidence and documentation they plan to provide to demonstrate that the measures were installed, and this evidence and documentation belongs in the savings verification report.

Examples of installation verification include:

- ➔ Photographs of new equipment
- ➔ Photographs of new control set-points
- ➔ Screen captures from energy management control systems (EMCS)
- ➔ Invoices from service contractors (invoices should not be the sole form of evidence, but may supplement other verification documentation).

Operational Verification

Operational verification demonstrates that in the post-installation period, the system is operating (or not operating) as modeled in the calculations. It is based on visualization of *operational* data (as opposed to *energy* data) collected during one or more site visits after the measures have been installed.

Operational verification is in addition to installation verification and documentation should include the same types of evidence as for installation verification. In addition, the data logging, control system trending, or functional tests used to establish baseline should be repeated to demonstrate that operations have been improved. Documentation of the commissioning of the new systems or equipment can be used for operational verification.

If the collected post-installation data, test results, and/or commissioning indicate less than predicted performance, or that the measures were not installed as assumed in the savings calculations (for example, due to incorrect or partial installation, or other circumstance), either:

- ➔ Act to help the customer fully install the measure properly and then re-verify it using these procedures; or
- ➔ Use the same calculation methodology with the post-installation data to calculate a revised measure savings estimate.

Choice of Verification Method

Common, well-known measures, or measures with certain savings, need only *installation verification*. Measures with less certain savings, or whose savings can vary greatly dependent upon application, may also require *operational verification*.

This viewpoint should be coupled with the savings expectation: if the savings are low, operational verification is not warranted, but if the savings are high, then it may be.

Thus, there is no hard-and-fast rule for this choice. The analyst should recommend a verification method and the evidence expected to be presented for verification when submitting calculations or simulations. The final choice of verification method and evidence will be made by the reviewer.

7.3. Unique Requirements for Engineering Calculations with Verification Protocol

Because the BPA *ECwV Protocol* is not based on pre- and post-measurements of energy use, but just on calculations, the documentation needs are greater. Reviewers need to understand more completely the project and the efficiency measures. Documentation may include a wide variety of items such as pictures, field notes, equipment specifications, vendor quotes, calculation files, and written reports.

7.3.1. Pre-Project Reporting Requirements

Review of project applications will typically require examination of:

- ➔ Building information, including submitted equipment lists and systems diagrams
- ➔ Measure baselines
- ➔ Implementation cost estimates
- ➔ Energy and demand savings calculations, including inputs based on measured data, assumptions, and equations

And determination that:

- ➔ Each measure is reasonable for the types of systems in the building.
- ➔ Measure savings estimates are a believable fraction of the typical use for the equipment, system, or end use.
- ➔ The suggested evidence (that will be available after implementation) shows that the measure is implemented as intended for the savings estimate and has the potential to generate savings.
- ➔ Potential interactions with other measures and systems are considered in the analyses.

To facilitate review, the following should be provided:

- ➔ A detailed description of the methodology used, including assumptions and variables
- ➔ Electronic files of calculations
- ➔ Logged data, measurements, or data sources used to validate equipment efficiency or baseline operation
- ➔ Results of your analyses

7.3.2. Preparation of Documentation

[NOTE: Significant portions of the following details on submittal requirements were excerpted and adapted from the following sources:

- ➔ *DTE Energy's Your Energy SavingsSM Commercial & Industrial Program 2011 Policies and Procedures Manual*
- ➔ *The 2011 California Statewide Customized Offering Procedures Manual for Business, Section 2: Estimating Energy Savings, August 18, 2010, Version 1.3]*

In preparing your documentation, assume that the reviewer, while having a technical background, *will not have direct knowledge of your specific project*. Therefore, the description(s) that you provide should contain sufficient detail to clearly understand the processes involved, the proposed savings measure, and how the measure will achieve the stated savings. To facilitate the review process, please consider the following:

- ➔ Break up your calculations and associated descriptions into steps that are sufficiently small to make them easy to follow
- ➔ Fully describe how you obtained any data used in the calculations (such as equipment load, operating hours)
- ➔ Fully describe any simulations/software used
- ➔ Attach (and be able to electronically submit) printouts/reports summarizing both the inputs and results of simulations or other software used in preparing the calculation(s)
- ➔ Attach any manufacturer's data, production data, and/or other documentation that supports the inputs and assumptions used in your calculations or descriptions
Note that spot measurements of load, whether in kW or amps, under realistic operating conditions are preferred over assumed loads and or use of manufacturer's design values.

Here is some guidance to help you be clear in the description:

- ➔ **Be as precise, yet concise, as possible in the descriptions** – include specific quantities and equipment descriptions.
- ➔ **Identify equipment with the terminology or numbering system used by the customer** (such as “Replace compressor #3 with a new variable speed compressor” or “install a VFD on VAV AHU #3, 5, 7, 8, 9”). This helps ensure consistent nomenclature with specifications and scopes of work, but make sure that the reviewer can easily understand what is meant by “compressor #3.”
- ➔ **Provide copies of sketches, drawings, equipment lists, or inventories that help to clarify the scope.**
- ➔ **Describe both the facility operating hours and the equipment operating schedule for each day of the week.** Where equipment operation varies with days of the week or

seasons, be sure to provide a description of the operation for all days of the week and all seasons.

- **Describe equipment load conditions for the hours the equipment typically operates.**
- **Provide the quantity, make, model number, and rated capacity of both the existing and the new equipment that is being installed.** Also provide other nameplate information like operating voltage and rated full load amps where appropriate. The scope of work from the proposal to the customer is often helpful to describe the new equipment.
- **Describe the locations where the equipment is installed.**
- **Provide copies of the manufacturer's specification sheets and/or performance rating sheets** and the website address where further technical information about the equipment performance might be found.
- **Provide the name and contact information of the person(s) conducting the savings calculations.**

7.3.3. Specific Requirements for Simulation for Existing Buildings

Retrofit projects using whole-building simulation for energy savings calculations should include the following additional documentation.

- **Narrative description of energy efficiency measures**
- **Input assumptions** – side-by-side table of input assumptions for baseline and post-installation cases
- **Source of baseline assumptions** – such as energy code section number
- **Results tables** – with side-by-side energy and demand results by end use including percent savings for each end use
- **Hours loads not satisfied** – number of hours that the simulation model indicates that systems do not meet heating or cooling loads in the baseline and post-installation models, if any
- **Software version** – identification of simulation program and version
- **Weather file** – specific weather data file
- **Non-standard methods** – description of any non-standard modeling methods, such as for system types not directly supported by the simulation tool
- **Simulation input and output files** – baseline and proposed cases (in electronic form)
- **Contact information** – for person performing simulation
- **Schedule** – for project completion and site inspection

- **Verification checklist** – a list of primary energy saving features for which installation can be verified by site inspection

7.3.4. Specific Requirements for Simulation for New Construction or Major Renovation

In addition to documentation requirements described above in the section *Simulation for Retrofit Project*, additional information is required for new construction and major renovations projects.

- **Baseline standard used in the calculations** – including documentation supporting the baseline definition for any non-regulated end-use savings
- **Rules used in developing simulation models** – such as *Standard 90.1-2016 Appendix G*, including a description of any exceptions taken
- **Method for developing the baseline simulation model** – automatic or manual

8. Examples

8.1. Example #1: Engineering Calculations Using a Publicly Available Software Tool

The following whole-building example was chosen for the following reasons:

- ➔ It illustrates the general approach.
- ➔ It demonstrates the use of measured data in the calculations.
- ➔ It demonstrates clarity of calculations.
- ➔ It demonstrates the use of baseline adjustments to allow for comparable pre and post conditions.

8.1.1. Overview

The facility manufactures wood products. The system affected by the measure is the compressed air system. The issue being addressed by the project is the need to expand operations and improve energy efficiency.

The primary measure is to replace the three existing compressors (total of 95 HP) with a 100-hp variable frequency drive (VFD) compressor. Additional new equipment includes a cooling fan VFD, a cycling refrigerated dryer, a mist eliminator low pressure-drop filter, and a zero-loss drain. These save energy by reducing operating pressure and minimizing air loss compared to baseline conditions with variable speed rather than fixed drives.

The loads on the compressed air system are expected to increase in the future, but are not well understood. The loads on the compressed air system will be monitored after installation and used to calculate savings.

8.1.2. M&V Approach

The BPA protocol selected is *Engineering Calculations with Verification Protocol*. The approach chosen is spreadsheet calculations enabled by the Excel based Northwest Regional Compressed Air Savings Calculator (NWRCAT) available through BPA²³. This tool is used to calculate energy savings for compressed air systems and auxiliary compressed air equipment. Typical inputs include compressed air flow rates, operating hours, nameplate efficiency, and gauge pressure setpoints.

²³ NWRCAT is an analysis tool for compressed air system that is available through BPA (<https://www.bpa.gov/-/media/Aep/energy-efficiency/document-library/small-ca-v51.xlsm>).

This calculator is used to determine the energy use of the baseline compressed air system. The use of the new compressor will be monitored after installation (kW, SCFM).

8.1.3. Measurement Boundary

The measurement boundary includes the electrical energy used directly by the compressed air equipment. Interactive impacts on other systems should be negligible due to the specific focus on the compressed air system.

8.1.4. Baseline Conditions

Baseline conditions at this site will not be replicated in the post period, due to a known plan to expand operations. The existing equipment and conditions in the baseline include:

1. Three existing air compressors - 25 HP, 30 HP, and 40 HP (all fixed speed)
2. A non-cycling refrigerated air dryer,
3. A standard coalescing filter, and
4. A standard drain valve.

The data collected in the baseline is derived from nameplate values and gauge pressure readings are summarized in Table 8-1.

Table 8-1. Baseline compressor performance

Existing Air Compressors @ 100 PSI	Rated Flow (ACFM)	Rated Power (HP)	Type
25 HP	113	20	Reciprocating
30 HP	144	30	Screw
40 HP	202	40	Screw
Total Capacity:	469	90	

The baseline equipment did not have data monitoring capabilities. The existing system was modeled using NWRCAT. The baseline equipment used in the calculation model included one 20 HP reciprocating compressor with on/off control at 113 SCFM and one 30 and one 40 HP screw compressor rated at 144 and 202 SCFM respectively. The total power used by these units was estimated as shown in Table 8-2. In addition, the cooling fans for the compressor added 2.6 kW.

Table 8-2. Total (90 hp) fixed speed compressed air baseline kW

% Load	Power Use (kW)
100	87.2
75	77.4
50	68.0
25	56.8

The non-cycling air dryer was modeled in the calculations as a 500 SCFM air-cooled, non-cycling unit. The average power draw was estimated at 3.0 kW under all operating conditions. The air-dryer runs at all times the plant is operating.

8.1.5. Post-Installation Conditions

The relevant equipment and conditions in the post-installation period include:

1. A 100-hp VFD screw compressor with cooling fan.
 - 508 ACFM rated flow capacity
 - 100 PSIG at rated flow
 - 1870 Gallon receiver
2. The air flow demand profile (scfm) and the energy demand (kW) of the installed 100 hp VFD compressor was collected from the compressed air control center and used to create a load profile for the post-installation conditions. The new system was used to monitor the system’s air flow rates for 2 weeks. These results were used to estimate annual run times and loads, summarized in Table 8-3. This air flow demand load profile is also used to calculate the energy consumption of the old compressors.

Table 8-3: Measured air use and energy demand profile of new 100-hp compressor

Air Flow (scfm)	% of Max Flow	Demand (kW)	% Time
235	47%	44.2	20%
166	33%	35.1	38%
116	23%	28.7	38%
53	10%	20.3	5%
0	0%	0	-
-	-		100%

3. A cycling refrigerated dryer with a mist eliminator low pressure-drop filter. The mist eliminator savings were modeled as a 4 psi reduction in operating pressure and the zero-loss drain savings were modeled as a 1 scfm reduction in demand-side air flow as compared to the baseline equipment.



Figure 8-1: New 100 hp VFD compressor

Table 8-4. summarizes the annual energy use of the new compressor calculated using the monitored load profile and power data shown above.

Table 8-4: Annual Energy Use of New Compressor

% Load	Annual hours (hrs/yr)	Demand (kW)	Energy use (kWh/yr)
47%	1,282	44.2	56,664
33%	2,434	35.1	85,433
23%	2,460	28.7	70,602
10%	298	20.3	6,049
0%	0	0.0	0
Total:	6,474		218,749

Energy use of the new dryer was also verified with spot power readings, and shows a demand of 1.3 kW which represents a demand savings of 1.7 kW over the baseline. The dryer is estimated to run at least as many hours as the compressor. Both cases are summarized in Table 5.

Table 8-5: Upgrade Energy Use of New Air Dryer

Air Dryer	Baseline case	Efficient Case
Demand (kW)	3.0	1.3
Operating Hours	6,474	6,474
Annual Energy Use (kWh)	19,422	8,416

Post-installation verification activities included reviewing the M&V plan and collecting and assessing invoices that detailed all the equipment, as well as conducting a site visit to confirm installation, collect data, and verify the new compressor discharge setpoint was the same as during the baseline site visit (i.e., 103 psi). The summarized energy use for the pre and post install conditions are shown in Table 8-6.

8.1.6. Annual Savings Calculation

Assumptions include:

- ➔ A 4 psi reduction in operating pressure
- ➔ A 1 scfm reduction in demand-side air flow

The calculations followed these general steps:

1. **Compare baseline and post-installation energy usage:** The savings calculations were made in Excel and used the NWRCASC tool to estimate baseline energy consumption and monitored data from the new compressor. This tool displayed separate pages for compressor analysis and the air dryer analysis. All specifications for compressors, dryer, and data logging were provided to the implementer via email.
2. **Adjust for changes in operating conditions:** Loads (scfm) for the baseline were updated in the calculator to be the same as measured in post-installation period.
3. **Calculate the difference to determine energy savings.** Calculations are based on the measured data, described above, and manufacturer’s nameplate data. Engineering assumptions are documented in the calculations.

8.1.7. Annual Energy Savings

Annual energy savings were determined to be 45,872 kWh/year. The savings for each component of the project and the total are shown in Table 8-6

Table 8-6: Annual Energy Savings by Measure

Item	Equipment Description	Baseline Energy Use (kWh)	Upgrade Energy Use (kWh)	Energy Savings (kWh)
1	Air Compressor	308,122	281,749	26,373
2	Cooling Fan	10,878	2,385	8,493
3	Refrigerated Dryer	19,422	8,416	11,006
Total		338,422	292,550	45,872

8.2. Example #2: Simulation Approach for an Existing Building Using eQuest Software

The following is an example of how this *ECwV Protocol* may be implemented for a common type of retrofit project using whole building simulation. The example is for window and HVAC replacement in an elementary school.

8.2.1. Overview

Existing single-pane clear windows in a 1960s vintage elementary school classroom building are replaced with double-pane low-e windows with thermal-break aluminum frames. Existing packaged heat pumps are also being replaced with new high-efficiency units. A whole-building simulation model was developed during the project planning phase to evaluate these and other potential retrofits. That simulation model is used to calculate savings.

8.2.2. M&V Approach

The BPA *ECwV Protocol* is used to calculate and verify the savings from this window and HVAC retrofit project.

M&V OPTION

The whole-building simulation option is used for this project (Figure 8-2). Using this approach, two simulation models are developed, one representing the baseline condition and another representing the post-installation condition. This approach is an alternative to the engineering calculations approach within the BPA *ECwV Protocol*. The whole-building simulation approach is a good choice for this project because the impact of building envelope retrofits (the windows in this case) is difficult to capture accurately through engineering calculations.

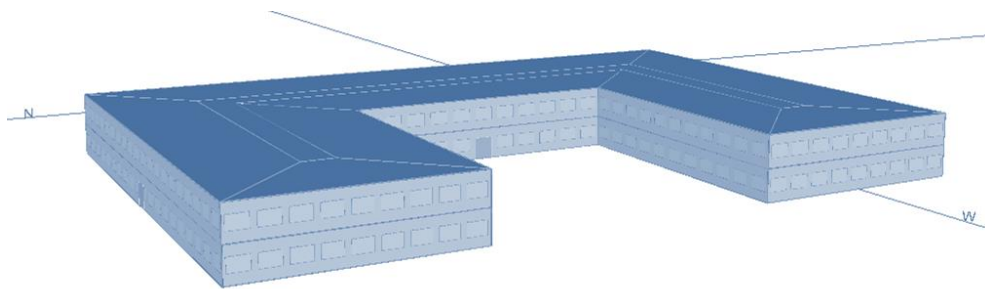


Figure 8-2: Rendering of Whole-Building Simulation Model Geometry

8.2.3. Measurement Boundary

Whole building energy consumption is calculated for this project. However, no measurements are required in this case. Actual building consumption is not known because it is one of several on a campus and is not separately metered. Short-term metering would be useful for calibrating the simulation model, but it is not required by the BPA *ECwV Protocol* because the cost of data collection is not warranted due to the relatively small energy savings.

8.2.4. Baseline Period

The baseline simulation model represents the actual pre-installation building with two important exceptions: the windows and the heat pumps. The baseline performance for the new windows and heat pumps is equal to current energy code requirements.

The actual pre-retrofit windows are single-pane clear glass. However, the windows in the baseline model must meet minimum code prescriptive requirements. In this case, the code requires a U-factor of 0.46 and SHGC of 0.40 per *Table 502.3* of the *2010 Oregon Energy Efficiency Specialty Code*.

Baseline heat pump efficiency must also meet minimum code requirements. In this case, the requirements for a 4-ton heat pump are 13.0 SEER cooling efficiency and 7.7 HSPF heating efficiency.

Other inputs for the baseline building model reflect the actual performance and operation as accurately as possible. For example, lighting power inputs are based on a survey of the existing lighting system. Operating schedules are based on interviews with the school administration. Actual wall and roof insulations are also modeled, even though they do not necessarily meet current code requirements. Baseline model calibration is not required under this protocol, as noted earlier.

8.2.5. Post-Installation Period

The simulation model representing the post-installation case is identical to the pre-installation model, with the exception of the elements affected by the retrofit; in this case, those elements are the windows and the heat pumps. Otherwise, all other inputs, including operating schedules, remain the same.

The new windows are double-pane low-e windows with thermal-break aluminum frames. The rated performance is U-factor of 0.38 and the SHGC is 0.30. The new heat pumps have rated efficiency of 16.0 SEER and 8.2 HSPF.

The post-installation model may be completed prior to project implementation. However, revisions to the model will be necessary if measures are not installed as anticipated. In this case, the post-installation model would need to be updated if the specifications of the actual installed windows or heat pumps varied from the original specifications used in the model.

8.2.6. Annual Savings Calculation

The simulation program used for the savings calculations is *eQUEST (DOE2.2)*. This is one of several hourly simulation programs that are appropriate for this type of analysis. *eQUEST* includes wizards to aid development of the building geometry and provides forms for describing inputs (including envelope constructions, internal loads, and HVAC systems). For this example, development of the baseline model was the first step. A second model, representing the post-installation case, used the baseline model as a starting point, then inputs were changed for window U-factor, window SHGC, cooling EER, and HSPF.

Typical-year weather data are used in the simulation. In this case the TMY3 (Typical Meteorological Year) weather file for Salem, Oregon, is used.

8.2.7. Annual Energy Savings

Savings are simply the difference in annual whole-building electricity consumption between the baseline and post-installation energy models. Results for this example are shown in Table 8-7, which includes a breakdown by end-use. Presentation of the end-use results is very important because it allows a quick check to make sure that the savings in each end use is of reasonable magnitude. The end-use results also allow the reviewer to check that savings are not being claimed in end uses that are not related to the proposed efficiency measures. In this case, for example, there should be no savings for lighting or miscellaneous equipment.

Table 8-7: Savings Results

End Use	Baseline Model (kWh/yr)	Post-Installation Model (kWh/yr)	Savings (kWh/yr)	Savings (Percent)
Space Cooler	23,570	14,810	8,760	37%
Space Heater	33,710	28,090	5,620	17%
HP Supply	10,370	8,607	1,763	17%
Ventilation Fans	57,540	53,590	3,950	7%
Pumps & Auxiliary	3,240	3,200	40	1%
Misc. Equipment	50,780	50,780	—	0%
Area Lights	133,140	133,140	—	0%
Total	312,350	292,217	20,133	6%

In addition to the savings table shown above, documentation for this savings calculation should include the following:

- ➔ Narrative description of measures, including the quantity and location of equipment
- ➔ Table listing the model input assumptions, with baseline and post-retrofit model inputs shown side-by-side
- ➔ Electronic copies of the input and output files for the simulation program used

- ➔ Name and Version number of simulation software used (such as *eQUEST*, version 3.6)

The recommended approach to reviewing the calculations is discussed earlier in this protocol. In this case, the relatively small magnitude of savings suggests that a deep review is not appropriate. However, the following items should be checked:

- ➔ Review the end-use savings to see that they are reasonable and consistent with the narrative descriptions of the efficiency measures.
- ➔ Check that appropriate code-complying baseline assumptions are used, based on a review of the narratives and table of inputs assumptions. In this example, the baseline windows and heat pumps must meet minimum energy code performance.

Installation verification is the appropriate verification approach in this case. A site inspection should verify that the quantity and specification of heat pumps matches assumptions in the simulation model. Heat pump operation schedules should also match assumptions used in the simulation, and presence of dual-pane windows and their approximate area should be verified. If possible, a manufacturer's certificate showing rated U-factor and SHGC should be obtained.

8.3. Example #3: Engineering Calculations Using a Vendor Supplied Software Tool

The following whole-building example was chosen for the following reasons:

- ➔ It illustrates the general approach.
- ➔ It demonstrates the use of a calculation tool that already exists instead creating a calculation from scratch.
- ➔ It provides concise project information and details of assumptions used in the calculations.

8.3.1. Overview

The facility is large cold storage facility located in Salem, OR. The project installed a high-speed door separating the refrigerated (-5F space) from ambient warehouse space, replacing a hard door with strip curtains. The new high speed door has automatic controls to keep the doors closed more often and keep cool air inside the cold space, which reduces the overall load on the refrigeration system. The old doors were manually operated, very slow to open and close, and the sensors were performing poorly and causing delays in the flow of goods through the warehouse.

The new doors operate significantly faster than the old ones and reduce heat loss and loads on the refrigeration system. The annual energy savings from this project are from reduced loads on the existing refrigeration system. The door into the freezer operates while the warehouse is staffed: 18 hours/day, 6 days/week, for a total of 6,451 annual operating hours.

8.3.2. M&V Approach

The BPA protocol selected is *Engineering Calculations with Verification Protocol*. This project is in an existing building and equipment is being replaced as an early replacement project.

8.3.3. Measurement Boundary

The measurement boundary includes the refrigerated warehouse and related equipment. This includes the electrical energy used directly by the refrigeration equipment. Interactive impacts on other systems should be negligible. The energy consumption of the door heaters was negligible and not included in the analysis.

8.3.4. Baseline Conditions

The relevant equipment includes the old hard door with strip curtains and the facility’s ammonia-based refrigeration system. The refrigerated warehouse is maintained at -5°F and 50% RH.

The doors were 8’ x 12’ standard hard paneled motorized doors with manual controls. Operating data on the door was collected during the baseline. The cycle time for the existing door is specified by the manufacturer at 15 seconds / cycle. However, because the door had manual controls it was being left open frequently.

Through ongoing observations by the staff the door was left open every day most of the time (10 to 12 hours of 18). The door was estimated to be open 50% of warehouse hours, a conservative estimate based on observations. The ambient side of the door opens into the unrefrigerated warehouse area. The temperatures in this area largely follow outdoor temperatures and range from 40-85 F.

Describe Baseline Door: Hard door with strip curtains		Describe the Space the Door Opens to: Inside to a refrigerated or air conditioned space		# of Identical Doors 1
Room Temperature Setpoint: -15 °F		Average Temp. of Adjoining Space: 60 °F	RH of cold space 85%	RH of adjoining space 76%
Door Width: 8 ft	Door Height: 12 ft	Strip Curtain % Covered 80%	Hard Door Gap Dimensions: 0.8 in wide by 10.0 ft high	
Door Heater Upgrade? No		Fast Acting Door Cycle Time: 8 s	Infiltration Mode: Convection	
State WA	Nearest Weather Station: WA - Seattle Seattle-Tacoma Intl A		Elevation: 50 ft	

Figure 8-3: Key Inputs in Calculation Workbook

The existing refrigeration system consists of R717 (ammonia) Frick screw compressors using slide valve for capacity control. The evaporators at this facility run continuously and the condensers run as needed, as summarized in Figure 8-4.

COLD SIDE			
Compressor Type: Packaged Condensing Unit	Refrigerant: R717	Compressor Suction: -10 °F	
Describe evaporator fan control in refrigerated space: Evaporator fans always run			
WARM SIDE			
Compressor type: Packaged Condensing Unit	Refrigerant: R717	Compressor Suction: 50 °F	
Describe evaporator fan control: Evaporator fans always run			

Figure 8-4: Refrigeration System Summary

8.3.5. Post-Installation Conditions

The data collected in the post-installation period included verifying the conditions at the site were otherwise unchanged and the specified door was installed as planned and operates as intended. An on/off data logger was installed for two-weeks to verify number of cycles and time open. The door was also inspected and functionally tested to ensure the automatic controls (occupancy sensors) were installed and working, and the cycle time measured using a stopwatch. Invoices from the contractors were collected and site staff were interviewed.



Figure 8-5: New Fast-Acting Door

The equipment and operations of the refrigeration system were confirmed to be unchanged by site staff, and the setpoints of the refrigerated warehouse were the same as the baseline

conditions (-5 F and 50% RH). The data logger indicated there were an average of 78 door cycles per day (range of 68 – 102).

An occupancy schedule for the facility and an annual usage schedule for the door were developed (Figure 8-6). The door cycles were estimated at 70 per day, 6 days per week which total 420 cycles/week.

BUSINESS HOURS PER DAY

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Start Time	18	18	18	18	18	18	18	18	18	18	18	18
Sunday	18	18	18	18	18	18	18	18	18	18	18	18
Monday	18	18	18	18	18	18	18	18	18	18	18	18
Tuesday	18	18	18	18	18	18	18	18	18	18	18	18
Wednesday	18	18	18	18	18	18	18	18	18	18	18	18
Thursday	18	18	18	18	18	18	18	18	18	18	18	18
Friday	18	18	18	18	18	18	18	18	18	18	18	18
Saturday	18	18	18	18	18	18	18	18	18	18	18	18
annual business hours: 6,570												

PREDICTED AVERAGE DOOR CYCLES PER DAY

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sunday	0	0	0	0	0	0	0	0	0	0	0	0
Monday	70	70	70	70	70	70	70	70	70	70	70	70
Tuesday	70	70	70	70	70	70	70	70	70	70	70	70
Wednesday	70	70	70	70	70	70	70	70	70	70	70	70
Thursday	70	70	70	70	70	70	70	70	70	70	70	70
Friday	70	70	70	70	70	70	70	70	70	70	70	70
Saturday	70	70	70	70	70	70	70	70	70	70	70	70

Figure 8-6: Post-Installation Operating Hours for New Door

8.3.6. Annual Savings Calculation

The savings calculations made in an Excel workbook. This workbook is a software tool provided by the project’s implementer that models the refrigeration system’s energy use and the infiltration through the roll-up doors before and after the retrofit to estimate the impacts of the new doors.

Inputs to the software included the type of refrigeration equipment used, the door size, temperature and humidity conditions of the warehouse and adjacent space, the speed of the doors, and the annual schedule for door openings.

The ambient conditions in the unrefrigerated warehouse were based on typical annual weather for the project site. Weather data used was average annual data from Seattle-Tacoma International Airport. This data was also used to model the performance of the condenser as well as the refrigeration loads in the warehouse. The Excel workbook is was submitted as supporting documentation for the custom project completion report.

8.3.7. Annual Energy Savings

Annual energy consumption for the baseline and post-installation scenarios were determined. Average annual savings of 165,115 kWh/year were estimated.

Table 8-8: Average Annual Energy Savings

Baseline Energy Use (kWh/yr)	229,451
Upgrade Energy Use (kWh/yr)	64,336
Energy Savings (kWh/yr)	165,115

8.4. Example #4: Engineering Calculations Using a Custom Spreadsheet

The following whole-building example was chosen for the following reasons:

- ➔ It illustrates the general approach.
- ➔ It demonstrates the use of measured data in the calculations.

8.4.1. Overview

The facility is a sawmill that has a cogeneration boiler that runs on waste wood. The boiler runs constantly throughout the year 24 hours a day every day. The sawmill typically operates the majority of the time throughout the year but is down occasionally due to seasonal maintenance shutdowns and market-driven shutdowns. The boiler will often run when sawmill does not. Until this project, finding an efficient way to keep the boiler operating when the sawmill is not has been an issue since cogeneration started in 2012. The process used to provide fuel to the boiler when the sawmill was inactive included several pieces of equipment and was energy intensive.

The measure installed was a new “repurposed” conveyor to provide fuel for the boiler when the sawmill is off and under low load. This change enables the fuel to be pulled directly from the wood yard when the sawmill is not running and enables eleven pieces of equipment to be shutdown during those periods saving a substantial amount of power.

8.4.2. M&V Approach

The expected electrical energy savings is less than 400,000 kWh and the operations of the impacted equipment are well known so BPA protocol selected is *Engineering Calculations with Verification Protocol* was selected. Spreadsheet calculations based on equipment specifications, spot measurements, and known operations are used to estimate savings.

8.4.3. Measurement Boundary

The measurement boundary includes the equipment used in the primary and auxiliary fuel transportation processes and is represented by the dashed line in **Error! Reference source not found.** This analysis only considers the electrical energy used directly by the equipment.

Interactive impacts on other systems should be negligible as the fuel transportation systems are outdoors and is an isolated process.

8.4.4. Baseline Conditions

The relevant equipment and conditions in the baseline include the equipment used as part of the fuel transportation process used when the sawmill is off. This is a multiple step process necessary to provide fuel to the boiler.

To get wood chip fuel to the boiler, hog fuel is scooped from the excess stockpile on the ground and placed into the plant's truck dumps. Then it is conveyed through the entire process of conveyors in order to get to the boiler. It is unnecessarily reprocessed through the 300 HP wood hog of "hogger", which pre-processes the fuel feeding into the boiler. See **Error! Reference source not found.** below and note the blue arrows that indicate the steps the hog fuel must travel to reach the boiler.

This fuel delivery process normally operates in the off-hours includes several electric dumpers (truck dump #1 – 4), a hopper, a spiked roller, several conveyors, and a 300 HP "hogger" which unnecessarily re-pulverizes the wood.

When the sawmill is running, a series of conveyors transport sawmill wood waste through the hogger and on to the boiler. Additionally, wood waste is moved using front loaders (typically during the day) that is fed into the same system by dumping on the truck dumps.

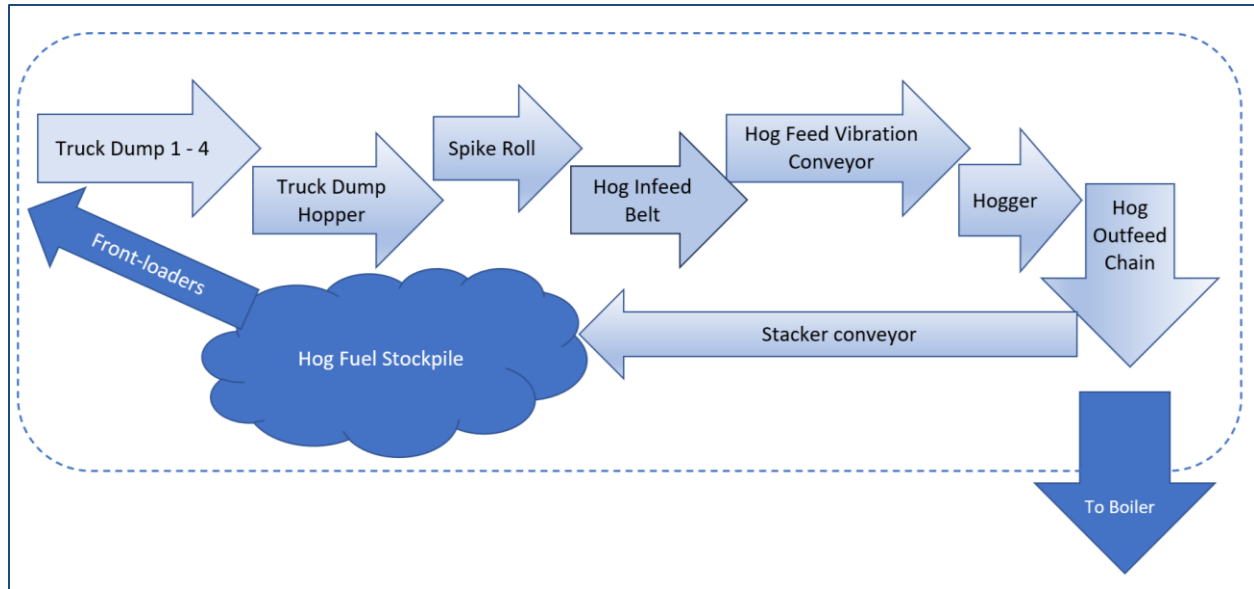


Figure 8-7: Delivery Process Used

The measured data collected in the baseline includes nameplate data on motors, electrical spot measurements, and trend data. This data is detailed in the calculations and summarized below in **Error! Reference source not found.**

Table 8-9: Estimated Power of Existing Equipment

Equipment	Calculated Power (kW)	Source
Truck Dump 1	1.9	Spot measured amps, PF 0.5
Truck Dump 2	4.6	Average of other truck dump measurements
Truck Dump 3	6.9	Spot measured amps, PF 0.5
Truck Dump 4	5.1	Spot measured amps, PF 0.5
Hopper	7.7	Spot measured amps, PF 0.5
Spike Rolls	10.4	Spot measured amps, PF 0.5
Infeed Vibrating Conveyor	2.8	Spot measured amps, PF 0.5
Hog Infeed Belt Conveyor	5.8	Spot measured amps, PF 0.5
Hogger	131.9	3-phase power logger
Hog outfeed chain	2.2	Nameplate HP, motor eff. 85%, belt eff. 90%
Stacker conveyor	3.4	Nameplate HP, motor eff. 85%, belt eff. 90%

Equipment	Calculated Power (kW)	Source
Total	182.8	

8.4.5. Post-Installation Conditions

This project includes the installation of a new conveyor that allows the truck dump system and the hogger to remain down when the sawmill is down. When the plant is down, a loader simply places pre-processed hog fuel on the new conveyor and the material is transported to the boiler conveyor directly downstream of the hogger. This is a chain conveyor of approximately 50' in length.

This bypass saves the power required to run the hogger and the associated equipment during down times. The only increased power consumption is by the new conveyor which has a 10 HP motor, which is shown in Figure 8-8 as a green arrow.

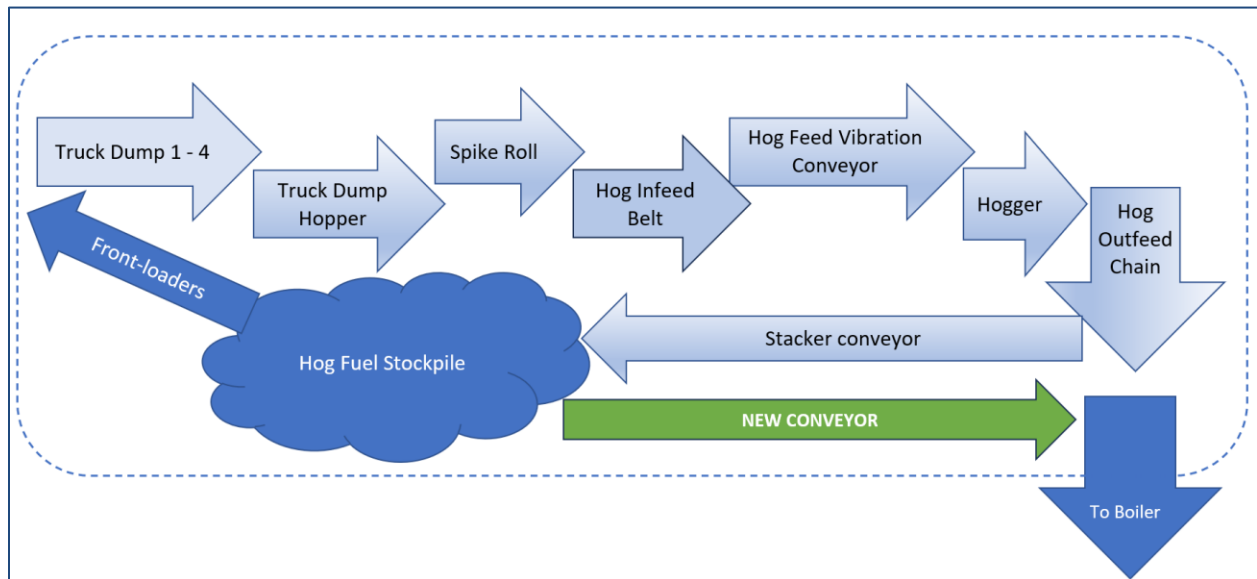


Figure 8-8: Diagram of Fuel Transport System with New Conveyor for Afterhours Operations

Verification of the changes were made through inspection of the new conveyor system. The new conveyor's amp draw was metered using a data logger for 4 weeks. The data is included in the calculations and summarized below.

Table 8-10: Summary of data for new Convey System

Bypass Operating Time Percentage	16.6 %	Measured
New Conveyor Average Current	1.3 amps	Measured
Annual Hours	1454 hours	Calculated

Power use (kW)	0.7 kW	Calculated
kWh used	954 kWh/yr	Calculated

8.4.6. Annual Savings Calculation

The savings calculations were made in Excel. Calculations are based on the assumptions and measured data described above. All the engineering assumptions are detailed in the calculations.

The calculations first determine the energy use of the baseline system. The estimated total power of the equipment included in the baseline shown in **Error! Reference source not found.**

Annual energy use was estimated using the baseline power and the run time measured on the new conveyor. The post-installation energy use was calculated from the measured amp data and hours from the new conveyor.

8.4.7. Annual Energy Savings

Annual energy savings were determined to be 93,847 kWh/year, summarized in Table 8-11.

Table 8-11: Annual Energy Savings Summary

Item	Power (kW)	Energy (kWh)
Baseline power	65.2	94,811
New system power	0.7	954
Energy Savings		93,858

9. References and Resources

AGA [American Gas Association]. Washington D.C.

See: <http://www.aga.org/>.

ANSI [American National Standards Institute]. Washington, D.C.

See: <http://www.ansi.org/>.

ARI [Air-Conditioning and Refrigeration Institute]. Now the Air-Conditioning, Heating, and Refrigeration Institute (AHRI).

See: <http://www.ahrinet.org/>.

ASHRAE. American Society of Heating, Refrigerating and Air-Conditioning Engineers.

See: <http://www.ashrae.org/>.

ASHRAE. 2021. *ASHRAE Handbook – Fundamentals*. Atlanta, Ga.: American Society of Heating, Refrigerating and Air-Conditioning Engineers.

Information at: <https://www.ashrae.org/technical-resources/ashrae-handbook>

Purchase at: <https://www.ashrae.org/technical-resources/ashrae-handbook>

ASHRAE. 2017. *Standard 90.1-2019 User's Manual*. Atlanta, Ga.: American Society of Heating, Refrigerating and Air-Conditioning Engineers.

Purchase at: <https://store.accuristech.com/standards/>

ASHRAE. 2021. *Weather Data Viewer*. Atlanta, Ga.: American Society of Heating, Refrigerating and Air-Conditioning Engineers.

Purchase at: <https://store.accuristech.com/ashrae/searches/34097213>

ASHRAE. 2022. *ASHRAE Standard 90.1-2022 – Energy Standard for Buildings Except Low-Rise Residential Buildings*. Atlanta, Ga.: American Society of Heating, Refrigerating and Air-Conditioning Engineers.

Purchase at: <https://www.ashrae.org/technical-resources/bookstore/standard-90-1>

ASTM [ASTM International (formerly known as the American Society for Testing and Materials)].

See: <http://www.astm.org/>.

Barbieri, D., and E. Swan. 2007. *Myth-Busting Savings Calculations*. Chicago, Ill.: International Energy Program Evaluation Conference (IEPEC), August 14-16.

Available at: https://www.iepec.org/wp-content/uploads/2018/02/7_1007_ab_491.pdf.

- CCC [California Commissioning Collaborative]. 2008. *Existing Building Commissioning Toolkit: Spreadsheet Tools – Energy Charting and Metrics (ECAM) Tool*. Available at: http://www.cacx.org/resources/rcxtools/spreadsheet_tools.html.
- City of Seattle. 2015. *2015 Seattle Building Code*. Seattle, Washington. View at: <http://www.seattle.gov/DPD/codesrules/codes/energy/overview/>
- COMNET [Commercial Energy Services Network]. Oceanside, Calif.: Residential Energy Services Network (RESNET). Available at: <http://www.comnet.org/>.
- Energy Design Resources. 2009. *Design Guidelines: CoolTools Chilled Water Plant*. San Francisco, Calif.: California Public Utilities Commission. Available at: https://datacenters.lbl.gov/sites/default/files/EDR_DesignGuidelines_CoolToolsChilledWater.pdf
- ENERGY STAR®. Washington, D.C.: U.S. Environmental Protection Agency and U.S. Department of Energy. See: <http://www.energystar.gov/>.
- FEMP [Federal Energy Management Program]. November 2015. *M&V Guidelines: Measurement and Verification for Performance-Based Contracts*. Version 4.0. Washington, D.C.: U.S. Department of Energy, Energy, Efficiency, and Renewable Energy. Available at: <https://www.energy.gov/femp/articles/mv-guidelines-measurement-and-verification-performance-based-contracts-version-40>
- Hands Down Software. 2010. *HDBinWeather*. Edmond, Okla.: Hands Down Software. Purchase at: <http://www.handsdownsoftware.com/Products.htm>.
- Havcware.net. 2010. *TMY2BIN*. Purchase at: <http://www.hvacware.net/tmy2bin.html>.
- IBPSA [International Building Performance Simulation Association]. See: <http://www.ibpsa.org/>.
- IBPSA-USA [International Building Performance Simulation Association – USA]. See: <http://www.ibpsa.us/>.
- IBPSA-USA [International Building Performance Simulation Association – USA]. 2011. *BEMBook - Building Energy Modeling Book of Knowledge*. See: <https://energy-models.com/forum/ibpsa-bembook-building-energy-modeling-book-knowledge>.
- InterEnergy Software. 2018. *BinMaker PRO*. Version 4.0. Des Plaines, Ill.: Gas Technology Institute (GTI).

- Purchase at: <https://sales.gastechnology.org/100013.html> Available at: <https://evo-world.org/en/products-services-mainmenu-en/protocols/ipmvp>
- IPMVP. 2022. *Core Concepts International Performance Measurement and Verification Protocol*. EVO 10000 – 1:2022. Washington, D.C.: Efficiency Valuation Organization. Available at: <https://evo-world.org/en/products-services-mainmenu-en/protocols/ipmvp>
- James J. Hirsch & Associates. 2010. *eQUEST, the QUick Energy Simulation Tool*. Camarillo, Calif.: James J. Hirsch. Available at: <http://doe2.com/equest/>
- McRae, M., M. Spahic, J. Van Clock, and W. Koran. 2011. *Findings Pertinent to the Establishment of a Threshold for Light M&V*. Unpublished. Available on request from Bonneville Power Administration.
- NFRC [National Fenestration Ratings Council]. Greenbelt, Md. See: <http://www.nfrc.org/>
- NOAA Satellites and Information. 1996. *Engineering Weather Data*. Asheville, N.C.: National Climatic Data Center, Climate Services Division, Purchase at: <https://www.ncei.noaa.gov/nespls/olstore.prodspecific?prodnum=5005>
- NREL [National Renewable Energy Laboratory]. 2008. *National Solar Radiation Data Base: 1991- 2005 – Update: Typical Meteorological Year 3 (TMY3)*. Washington, D.C.: U.S. Department of Energy, Energy, Efficiency, and Renewable Energy. Available at: <https://nsrdb.nrel.gov/>.
- Oregon Building Codes Division. 2021. *2021 Oregon Energy Efficiency Specialty Code*. Salem, Ore.: Oregon Department of Consumer & Business Services, Building Codes Division. Available at: <https://www.oregon.gov/energy/energy-oregon/Pages/Energy-Code.aspx>
- Regional Technical Forum. 2020. *Guidelines for the Assessment of Energy Efficiency Measures*. Portland, Ore.: Northwest Power & Conservation Council. Available at: <https://rtf.nwcouncil.org/rtf-operative-guidelines/>
- Research Into Action, Inc. and The Cadmus Group, Inc. 2009. *Impact and Process Evaluation of the 2006-2007 Building Efficiency Program*. Portland, Ore.: Energy Trust of Oregon. Available at: https://www.energytrust.org/wp-content/uploads/2016/11/Evaluation_2006-2007_EB_Prog.pdf.
- SBW Consulting, Inc. 2018. *ECAM*. Bellevue, Wash.: SBW Consulting, Inc. Available at: <https://www.sbwconsulting.com/ecam/>
- SEED [State Energy Efficient Design] Program. 2010. *Appendix L Building Modeling Guidelines*, Revised October 1, 2010. Salem, Ore.: Oregon Department of Energy. Available at: <https://www.oregon.gov/energy/energy-oregon/Documents/SEED%20Guidelines%20Appendix%20L.pdf>.

SMACNA [Sheet Metal and Air Conditioning Contractors National Association]. Washington, D.C.

See: <http://www.smacna.org/>.

TecMarket Works, Megdal & Associates, and Architectural Engineering Corporation. 2005.

California 2002-2003 Portfolio Energy Efficiency Program Effects and Evaluation Summary Report. San Francisco, Calif.: California Public Utilities Commission.

Available at: <https://www.cpuc.ca.gov/-/media/cpuc-website/files/legacyfiles/m/8461-mect0203finalreport.pdf>

U.S. DOE [U.S. Department of Energy]. 2018. *Building Energy Software Tools Directory*.

Washington, D.C.: U.S. Department of Energy, Energy Efficiency & Renewable Energy, Building Technologies Office.

Available at: <https://www.buildingenergysoftwaretools.com/>

U.S. DOE [U.S. Department of Energy]. 2018. *Software Tools*. Washington, D.C.: U.S.

Department of Energy, Office of Energy Efficiency & Renewable Energy, Advanced Manufacturing Office.

Available at: <https://www.energy.gov/eere/amo/software-tools>

U.S. EPA and U.S. DOE [U.S. Environmental Protection Agency and U.S. Department of

Energy]. 2018. *ENERGY STAR Portfolio Manager*. Washington, D.C.: U.S.

Environmental Protection Agency and U.S. Department of Energy.

Available at: <https://www.energystar.gov/buildings>

UTOnline.org. 2017. *UT (Universal Translator)*. San Francisco, Calif.: Pacific Energy Center.

Available at: <http://utonline.org/cms/>.

Washington State Building Code Council. 2021. *Washington State Energy Code, 2021 Edition*.

2nd Edition.. Available at: <https://sbcc.wa.gov/state-codes-regulations-guidelines/state-building-code/energy-code/>.

Weather Underground, Inc. 2018. *WunderSearch*[®]. Brookhaven GA.: The Weather Company, an IBM business.

Available at: <http://www.wunderground.com/>.

Webster, T. 2003. *Chiller Controls-related Energy Saving Opportunities*. Berkeley, Calif.:

Lawrence Berkeley National Laboratory.

Available at: <https://www.osti.gov/servlets/purl/860769>.

