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Guide for Determining Energy Savings from Changes in Operations, Behavior, and Maintenance Procedures

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Disclaimer

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Introduction

Purpose

This Guide is intended to provide energy savings estimation methodologies for energy performance improvement actions resulting from changes in operations, behavior and maintenance procedures. These improvements are often referred to as “non-capital measures” because such improvements are typically achievable with little or no capital expenditures. This Guide is designed to assist industrial facilities in quantifying and documenting the energy savings resulting from these types of improvements, including the collection of essential data.

This Guide was developed for use by facilities that are participating in a Strategic Energy Management (SEM) program that use a well-defined whole facility approach to measurement and verification, such as the *Superior Energy Performance Measurement and Verification Protocol* (*SEP M&V Protocol*) to determine their “top down” energy performance improvement level (e.g., 6.3% over three years), using energy consumption data from metered sources. The Guide is designed to assist these facilities in calculating a “bottom-up” comparison to support their top-down claims.

Three categories of improvements are addressed in this Guide, operational, behavior, and maintenance procedures. The focus of the Guide is to assist users in recognizing the nature of the improvement and to select an appropriate method for determining the energy savings. Examples are provided to demonstrate the general principles, which are supplemented with selected detailed examples and additional resources. The principles outlined in this Guide may also be applicable for certain types of capital projects.

Users should be aware that the general methods provided here are for guidance purposes only. SEM program participants should check on the specific requirements of the SEM program in which they are participating to ensure that the required M&V rigor is being met. Use of this Guide should not be construed as either approval of the methodology chosen or the determined energy savings for purposes of SEP certification. Each unique application will be subject to engineering judgement of the SEM audit team or SEP performance verifier on the SEP audit team.

Improvements in Operations, Behavior, and Maintenance Procedures

Non-capital energy performance improvement actions can be divided into three following categories.

Operational

Operational energy performance improvement actions involve the modification of equipment operating parameters (such as pressure, temperature, flow rate or speed) to reduce energy consumption without negatively affecting the production rate or the quality of service or product. Some common examples are reducing the operating pressure of a compressed air or steam system, adjusting chiller temperature settings, and, optimizing chillers and pump sequences and loads.

Behavior

Behavioral energy improvement actions involve routine human behavioral adjustments, typically made by building occupants, manufacturing workers or equipment operators. Some frequent examples include turning off lights when occupants leave the room, shutting off equipment when not in use, and refraining from using compressed air for personal cooling purposes.

Maintenance Procedures

Maintenance-related energy performance improvement actions involve adopting maintenance procedures or practices for equipment or systems which take energy performance into consideration. These types of actions vary significantly by end-use application. Common examples include establishing a compressed air leak detection program, repairing leaking steam traps regularly, periodic equipment vibration testing, and scheduling heat exchanger surface cleaning or equipment filters replacement based on hours of use.

An important common trait of the three categories of improvements is that the resulting energy savings often requires continuous effort in order to persist. This is particularly true for the last two categories – behavior and maintenance procedure improvements. For organizations seeking conformity to ISO 50001- Energy management system standard (required for SEP certification), these types of improvement actions achieve persistence of energy savings through incorporation into the organization or facility's "operational control". Please refer to the standard of *ISO 50001: 2011 Energy management systems -- Requirements with guidance for use* as well as the 50001 Navigator for requirements and guidance on the concept of operational control.

General Guidelines

General Approach

There are multiple established guidelines and best practices on the topic of measurements and verifications for energy conservation measures published by DOE or other sources. These include but are not limited to International Performance Measurement and Verification Protocol (IPMVP), ASHRAE Guideline 14, M&V Guidelines: Measurement and Verification for Performance-Based Contracts and Uniform Methods Project. The general principles outlined in these guidelines are largely applicable to the verification, or estimation when verification is not practical, of energy savings from improvements in operation, behavior and maintenance procedures. This document does not intend to replace or repeat these well-established guidelines wherever applicable to non-capital measures. Rather, it provides a condensed and quick approach to concepts, general principles, common methods, examples and references to assist users in choosing an appropriate method to quantify energy savings from the non-capital improvement actions at hand.

Following a general M&V approach, the annual energy consumption of the affected equipment or system prior to the implementation of the energy performance improvement action (the "Pre-") is determined first. In the next step, the annual energy consumption after implementation of the evaluated action (the "Post-") is determined. The difference between the Pre- and the Post- is attributable to the improvement action, adjusted to similar conditions.

In some cases, the before-and-after- difference in energy consumption (i.e. the energy savings) can be easily determined, but the base-case equipment/system energy consumption can be complex to determine. In those cases, the Pre- energy consumption may need to be a rough estimate for the purpose of reasonability check. Insulating a piece of pipe in a large steam system is an example of this case.

It should be noted that the evaluation of certain types of actions may also require taking pre- and post-weather conditions and/or production rates or mix into account, to normalize for weather or production. The approach and techniques are similar to those used for normalization for capital-investment actions. Typically, either the baseline energy consumption is adjusted to align with the Post-condition or both the Pre- and Post- energy consumption is adjusted to a "standard" or "common" condition using regression analysis approach. An example in the context of retro-commissioning is found in the section of "Combined Changes". The SEP M&V protocol is good references for performing production related normalizations.

Types of Improvements

Due to the range and variety of energy performance improvement actions, this Guide cannot include specifics concerning how to determine energy savings for every possible improvement action. Rather, this Guide attempts to define a few common types of improvements and provide some general principles to assist users in categorizing the improvement under evaluation and finding a method suitable for their unique situations.

To identify a few categories of improvement actions that are generally applicable to common operational, behavioral, and maintenance actions, a closer look at how energy is consumed is needed. From a generic perspective, energy is typically consumed at a certain rate, steady or varying, for a specified period of time, for the purpose of generating an output or result, which can be an input to another energy-using process, a product, a service, or another form of energy. The required energy consumption rate, which is also the energy input, relative to the quantified output defines the efficiency of that energy use. For example, the efficiency can be expressed as CFM/kW for compressed air systems, Btu/Wh (Energy Efficiency Ratio, or EER) for air conditioners, or, ton/Btu for a certain manufacturing process step.

Many systems and equipment operate with distinct modes or operating conditions. For instance, air compressors with load/unload controls have two distinct modes during operation with dramatically different levels of power draw. For many manufacturing processes, equipment may be operating at different conditions depending on day types, shifts, and product types. The energy consumption rate of comfort cooling and heating systems are typically highly dependent on weather. Unlike the two previous examples with discrete modes or conditions, weather is described with continuous variables. “Bin analysis” is a popular and industry-accepted way of handling continuous variables such as weather. By totaling the energy consumption in all operating modes and conditions, we can obtain the annual energy consumption of a system or piece of equipment. Equation 1 below illustrates this approach.

$$AEC = \sum (Demand \times Hours)_{mode/condition} = \sum (\frac{Output}{Eff} \times Hours)_{mode/condition}$$

Equation 1

Where
AEC = Annual Energy Consumption (kWh/yr or Btu/yr)
Demand = Energy Demand (kW or Btu/hr)
Hours = Annual Operating Hours (hrs/yr)
Output = Output (rate of energy or work e.g. kW, Btu/hr, or, products e.g. lbs/hr)
Eff = Efficiency (can be dimensional or dimensionless, e.g. CFM/kW)

Equation 1 provides insights to how the annual energy consumption, or AEC, of a system or piece of equipment may be changed as the result of an energy performance improvement action. There are five basic possibilities, which we call “types of changes”.

1) Change of Annual Operating Hours, or Hours. No other parameter changes.
2) Change of Output. No other parameter changes.
3) Change of Efficiency, or Eff. No other parameter changes.
4) Change of Energy Demand, or Demand, describing simultaneous change in Output and Eff. No change in Hours.
5) Change of the Energy Consumption of a certain mode or condition, or (Demand x Hours). It indicates simultaneous change in Output, Efficiency and Hours.

Note that for a given improvement action, the type of change it makes in each mode or condition can potentially be different. For example, it is possible that an action changes the Output (Type 2) during shift 1 and changes Hours (Type 1) during shift 2. However, those more complex changes can still be broken down into the five basic types of changes for further analysis.

Table 1 provides common examples of operational, behavioral, or maintenance procedure improvements associated with each type of change. Be advised that the categorization of the examples provided below is subject to certain assumptions, which may or may not be true for a specific improvement under evaluation. Later in this document, some of the examples below will be examined in detail to guide users in approaching energy savings estimation for each type of change.

Table 1 Five Basic Types of Changes with Examples

Type of Change	Examples
Type 1: Annual Operating Hours	Shut off air compressor when not needed
	Install occupancy sensor on HVAC fan controls
Type 2: Output	Repair compressed air leaks
	Reduce air compressor discharge pressure
	Repair steam traps or steam leaks
Type 3: Efficiency	Lower chiller condenser water temperature
	Tune-up boiler to reduce excess air
	Clean boiler tubes or heat exchanger surfaces
	Maintenance measures (e.g. fans and pumps, chillers)
Type 4: Energy Demand	Reduce steam system pressure
	Repair failed check valve in distribution piping
Type 5: Energy Demand & Hours	Adjust thermostat settings
	Repair rooftop air conditioner economizer
	Conduct HVAC system tuning measures (retro-commissioning)

General Principles

There are four broad methods that are commonly used for estimating the Pre- and Post-equipment/system energy consumption, as well as energy savings associated with an action under evaluation. They are:

- Utility meter and sub-meter analysis,
- Data logging and spot measurements,
- Engineering calculations, and,
- Estimates and Rule-of-Thumb.

Each of the four methods will be explained in detail in the following chapter. Here, we want to first discuss a few general principles to keep in mind when choosing the method or combination of methods for a specific application.

First of all, for the purpose of performing bottom-up savings analysis for a given energy performance improvement action, the following factors should be considered: magnitude of the energy savings relative to the total top-down energy savings, accuracy (method and device), cost of measurement (hardware and labor) and timeliness. Generally:

1. Improvement actions with greater energy savings impact should be measured with more rigor;
2. When energy savings compared to baseline energy consumption is greater than measurement error and other loads are relatively stable, utility meter and sub-meter analysis or logged consumption/demand data are usually the most accurate. They should be considered first if available or practical to obtain;
3. When energy savings is significant but not practical or cost-effective to measure directly, engineering calculation using well-established models is a popular option to consider. Logged or spot measured values of the key parameters in the model should be used if practical to obtain;
4. When engineering calculation is used and measured values are not available for a certain key parameter, its uncertainty and impact on the overall accuracy of the results should be considered;
5. When energy savings is very small and impractical to measure or calculate (e.g. maintenance related actions), industry-accepted rule-of-thumb should be considered, if one exists. Otherwise, best possible estimate may be used.

It should be noted that the general principles stated above are intended for the determination of energy savings once an energy performance improvement action is made (i.e. post-). The appropriate method for predicting the energy savings associated with a planned or considered action can be significantly different, which is outside the scope of this Guide. For example, to determine how much the pressure can be reduced in a steam system may require complex modeling, which is not required for estimating the energy savings once an action has been taken.

Methods for Determining Energy Consumption

This section builds on the general principles by providing additional details on each of the four common methods.

Utility Meter and Sub-Meter Analysis

In the US, utility meters are often attached to an individual or group of buildings/facilities or one or more section(s) of a larger building/facility. Sub-metering of processes, systems, and equipment may not present. If meters or sub-maters are available and have a scope appropriate to the action taken, analyzing these data is often a preferred method for evaluating pre- and post- improvement energy consumption, due its accuracy. If the process, system, or equipment associated with the evaluated action is the only load tied to a utility meter or sub-meter, or if it is the predominant load and the other loads can be readily estimated, then the energy consumption of the action of interest can be easily characterized by subtracting the other loads from the metered data. The energy savings attributable to the action is then the difference between the pre- and post- energy consumption, after any necessary adjustment for weather or production if necessary. If utility interval data (or also called “interactive data”, with 15-minute or hourly intervals) is available, analysis with greater resolution may be possible and more accuracy may be gained with much shorter pre- and post- data periods.

For example, several weeks' worth of interval data could replace several months' of utility bills in a weather dependent analysis because of increased number of data points with smaller intervals. The required data interval depends on the nature of the change under evaluation.

In many instances, the process, system, or equipment of interest is tied to a meter or sub-meter with many other variable loads. In this case, analyzing the effects of an energy performance improvement action using this method can be challenging and would require knowledge of all the other loads on the meter, as well as their energy consumption levels. Under these circumstances, this method may not be a good choice due to the complexity of the analysis and the inaccuracies resulting from estimating and subtracting multiple loads. This method is not recommended unless the estimated energy savings is 5% or more of the total metered energy consumption and the remaining loads are not variable.

Despite the limitations discussed above, this method can be valuable for a reality check or secondary verification purposes for many improvement actions, even when the measured savings is small compared to the metered total load. It is important to note that any changes to the other loads on the meter will produce a difference in the meter readings. The meter reading may change due to any number of situations, including: a load is added or removed, the operating hours of a load change, a system's operating parameters change, or the production rate/mix change. Any utility meter analysis needs to consider appropriate adjustments to account for these kinds of changes, if present.

Data Logging and Spot Measurements

In addition to utility meters and sub-meters, there are other devices and associated methods that can provide energy consumption data or values of parameters which directly impact energy consumption of the improvement being analyzed. Methods include continuous measurements (also often referred to as "data logging" or "trended measurements") and spot measurements. Continuous measurements are usually done using devices or systems (e.g. SCADA) which can automatically record sensor readings at predefined intervals. Spot measurements are often done with portable tools or manual reading of a meter or gauge. For both categories of measurements, the measured target can be energy demand (rate) or consumption or related influential parameters.

When energy demand or consumption of the evaluated equipment/system is directly logged with a power recording device or fuel consumption meter (e.g. boiler in-line gas meter), the logged data can be used to determine the energy consumption of the equipment both before and after the implementation of improvement actions. Common examples of power recording devices include both equipment-integrated (e.g. VFD, chiller) and user-configured single-phase current transducer (to approximate power with post- calculation) and data logger pairs, see Figure 1, and 3-phase true RMS (root mean square) power meters, see Figure 2. The logged power or fuel consumption often comes in daily, hourly or more frequent intervals as defined by the user or device default. Using a 3-phase true RMS power meter is more expensive, but can be advantageous when input power frequently drops to very low values where power factor is significantly lower, or in an unbalanced configuration among the three phases which makes single-phase measurement potentially misleading. When energy demand is stable enough, spot measurements can be performed instead of logging. For example, handheld multi-meters can be used to get amperage and voltage spot readings for power estimation.

Figure 1 Examples of Portable Single-Phase Current Transducer and Data Recorder ([Online Source](#))

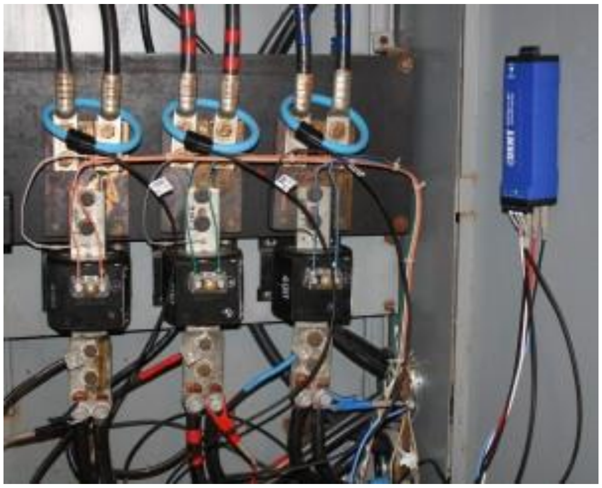


Figure 2 Example of Portable 3-Phase Power Meter ([Online Source](#))

The use of logged data, however, is not limited to power or fuel consumption. They can be anything detected by a sensor and recorded by either individual data loggers or an automation/supervisory system. Examples of such data include temperatures, pressures, flow rates or on/off status. They can be hand logged by operators/crew reading gauges and equipment displays as well. Unlike power or fuel consumption data, these types of logged data often need to be used in conjunction with engineering calculations to determine the pre- and post- energy consumption. For example, if a boiler system does not have a dedicated gas meter, calculations could use data logs of steam pressure, flow rate exiting the boilers, flue gas temperature and oxygen content. It is possible to determine boiler fuel consumption from these parameters using engineering calculations.

In addition to logged data, spot measurements also play a big role in energy savings estimation and verification in general, including for non-capital improvement actions. Similar to logged data, spot measurements cover power and other operating parameters. Generally speaking, data logging is more expensive as compared to spot measurements because it often requires simultaneous sensor allocation for each point of interest as well as investment in a recording mechanism, whereas spot measurements can often be done with handheld tools which can be reused to make readings on multiple points. In many cases, when the parameter or point of interest is relatively stable or operates at a few limited levels, spot measurements are sufficient. The measured readings are then used in conjunction with engineering calculation to determine equipment/system energy consumption.

Engineering Calculations

Engineering calculations for energy consumption and savings fall into two broad types, calculations based on observed energy demand patterns and calculations based on mathematical models of equipment or systems. Both types of calculations require input parameters. As discussed earlier, metered and logged/measured data should be considered for those input parameters for better confidence whenever they are available or practical to obtain.

The following examples are designed to assist the user in determining which type of calculation is most appropriate?

Demand Pattern Based Calculations

Equation 2 below is a common example of an engineering calculation that applies to equipment which operate in duty cycles, such as refrigeration compressors and boilers/furnaces. For these types of equipment, the on/off intervals are referred to as a duty cycle, which is represented as a percentage. Their energy consumption is based on average demand during active duty cycles. It is a special form of Equation 1.

$$AEC = [Demand_{load} \times DC + Demand_{unload} \times (1 - DC)] \times Hours$$

Equation 2

Where AEC = Annual Energy Consumption (kWh/yr or Btu/yr)
$Demand_{load}$ = Energy Demand when loaded (kW or Btu/hr)
$Demand_{unload}$ = Energy Demand when unloaded (kW or Btu/hr)
DC = Duty Cycle (%, 0-100%)
Hours = Annual Operating Hours (hrs/yr)

Some tips for the operating parameters required for this calculation include:

- **Demand**. The average demand during active cycles typically require measured values. If the demand is stable enough, spot measurements can be satisfactory. Otherwise, continuous measurements may be necessary. It can be misleading to use manufacturer's rated demand without knowledge of the true load, which is often determined by the actual operating conditions versus the rated.
- **Annual operating hours**. Off-shift operations and seasonal variations should be taken into considerations. When the equipment operation is driven by demand rather than schedule, data logging is recommended in order to accurately determine the actual operating hours.
- **Duty cycle**. Duty cycle is the total time when the equipment performed active work during a selected operation period (i.e. when the equipment is on). It is expressed as a percentage. If the refrigeration compressor operates 8 hours per day and was actively loaded for a total of 3 hours during that operating period, then its duty cycle is 3/8 = 37.5%. Duty cycle primarily

depends on the system demand. For example, the higher the cooling demand, the more frequently the refrigeration compressor will cycle on. As such, one should be careful about extrapolating measured duty cycle across different demand conditions. Data logging is recommended to determine irregular duty cycles. Using a stopwatch can be a simple alternative for timing regular duty cycles. For variations in demand across time (shift, day type, season), developing a series of demand profiles is highly recommended.

The above model is generally appropriate for motor-driven equipment such as chillers, air compressors, pumps and fans. It can be used on other types of equipment as well, such as boilers and furnaces. It is important to note that appropriate time intervals need to be selected during data logging in order to obtain good-quality duty cycle for a successful use of this method. Ideally, it should provide sufficient resolution to reveal the true operation of the equipment without using excessive logging memories. For example, 15 minutes is often sufficient for HVAC fans, pumps and chillers because they don't typically cycle off frequently during normal operation. However, for compressors in a packaged air conditioner, smaller interval such as 1-5 minute should be used in order to capture on/off cycles. For load/unload controlled air compressors, 6-10 seconds are often recommended if the compressor is not base-loaded.

Mathematical Model Based Calculations

There are many mathematical models available which can be useful in describing the energy demand of a piece of equipment. The pump power equation (Equation 3) below is an example. The numerator in this equation represents "Output" in Equation 1 and the denominator in this equation represents "Eff" in Equation 1.

$$kW_{pump} = \frac{Head \times Flow \times SG \times 0.746}{3960 \times Eff_{pump} \times Eff_{drive} \times Eff_{motor}}$$

Equation 3

Where kW_{pump} = Pump motor power (kW)
Head = Total pump head (ft)
Flow = Pump flow rate (gpm)
SG = Specific gravity of the fluid (dimensionless)
Eff_{pump} = Pump efficiency (dimensionless)
Eff_{drive} = Drive efficiency (dimensionless)
Eff_{motor} = Motor efficiency (dimensionlep

Mathematical models hold great potential for applications where measured demand/consumption is not practical or too costly. However, users should be aware of the limitations of each unique model. Take Equation 3 as an example. If a constant-speed pump is known to be operating at design conditions and design parameters are available (e.g. pump curve available), this equation can provide reasonably good estimates. However, if the pump is driven by a variable frequency drive (VFD), knowing at least two out of the following three parameters in addition to the pump curve is required to use this equation for pump power at a given condition: pump speed, flow rate and pump head. Furthermore, if the pump flow modulates, this requirement has to be met for each condition in order to get a full picture, which essentially make this approach impractical in most cases.

There are also mathematical models which do not describe the energy demand or consumption of equipment or systems, but they are useful in quantifying energy saved because they describe the pre- and post- difference in energy loss directly. Examples include calculating energy savings by adding insulation, eliminating condensate loss and reducing boiler blow-down. The calculated energy savings typically needs to be multiplied by an equipment or system efficiency. This type of calculations is not appropriate if the equipment or system efficiency was also affected by the improvement action.

Estimates, Correlations and Rule-of-Thumb

Some operations, behavior and maintenance related improvement actions are impractical to measure, complicated to model and result in relatively small incremental energy savings. Estimates made based on established rule-of-thumbs, correlations and good engineering judgement are often acceptable for this type of applications.

For example, chiller lift reduces, and hence chiller power, when chilled water discharge temperature is set higher or condenser inlet temperature is set lower. If either is changed by a couple of degrees, the resulted chiller power reduction will be too small to measure but can be easily estimated with industry-accepted rule-of-thumb below.

- **Raise chilled water temperature**. For a centrifugal chiller, if the chilled water temperature is raised by 2°F to 3°F, the system efficiency can increase by as much as 3% to 5%. Refer to Chapter 9.4 of the DOE's O&M Best Practices Guide (page 50) for more information.
- **Lower condenser water temperature**. For a centrifugal chiller, if the condenser water temperature is decreased by 2°F to 3°F, the system efficiency can increase by as much as 2% to 3%. Refer to Chapter 9.4 of the DOE's O&M Best Practices Guide (page 50).

Estimates using indirect measurement

Another type of estimates is based on indirect measurements and correlations. Sometimes key parameters which determine the energy savings of a change are not practical to measure directly but can be estimated by measurement of a correlated parameter. Measuring compressed air leaks is a good example. Two common methods used for estimating the amount of compressed air leaked out of an opening are (1) observing/measuring the size of the opening; and (2) measuring the decibel level of the noise created by the leak. Both methods are based on established correlations with different advantages and disadvantages. The first method works better for larger openings when they are accessible and the second method is very useful when the leak is hidden or the opening is too small to measure. A third method, a leak-load test, can be used to determine the overall fraction of compressed air demand due to leaks if the facility has periods without production demands.

There are other circumstances where estimation could be most appropriate although we cannot exhaust all of them here. Sometimes good engineering judgement is the only practical thing to do to get the energy savings of a particular improvement action.

Choosing an Appropriate Method

The selection of an appropriate method for determining energy consumption and energy savings for a given energy performance improvement action is ultimately based on the availability of data. A combination of methods may be required to obtain an acceptable level of accuracy with available data. Even when the results of data logging or installed metering is readily available, engineering calculations can be useful in determining whether the collected data is within expected ranges (reality check). Table 2 provides a crosswalk between the "type of change", examples, and the four potential methods. It will become clear that, in many cases, there is a level 1 method and a level 2 method, often associated with each key parameter. Several examples in this table will be explained with greater detail in the next section. It should be noted that the examples provided are intended as guidance and are not necessarily the best or only method for a given. A case-by-case evaluation is needed for determining the energy savings of a specific improvement at a given facility using the data/resources available to the facility.

Table 2 Suggested Energy Savings Estimation Methods for the Example Changes in Each Types of Changes

Type of Change	Examples	Potential Methods
Type 1: Operating Hours	*Shut off air compressor when not needed	Calculated with key parameter(s): • Compressor Power – measured; • Operating Hours (pre- and post-) – estimated.
Type 2: Output	*Repair compressed air leaks	Calculated with key parameter(s): • CFM (reduced output) – directly or indirectly measured; • Compressor Efficiency – measured or estimated based on performance rating; • Operating Hours – estimated.
	*Reduce air compressor discharge pressure	Calculated with key parameter(s): • Savings% – estimated with rule-of-thumb; • Compressor Power – measured; • Operating Hours – estimated.
	*Repair steam traps or steam leaks	*Option 1: If boiler(s) have a dedicated gas meter,* Calculated with key parameter(s): • Steam flow rate (pre- and post-) – directly or indirectly measured; • Boiler gas consumption – measured. *Option 2: Otherwise,* Calculated with key parameter(s): • Steam flow rate – same as Option 1; • Combustion Efficiency – measured or estimated based on rule-of-thumb; • Operating Hours – estimated.
Type 3: Efficiency	Lower chiller condenser water temperature, or, raise chilled water temperature	Calculated with key parameter(s): • Savings% – estimated with rule-of-thumb; • Chiller Power – measured; • Operating Hours – estimated.

Type of Change	Examples	Potential Methods
	*Tune-up boiler to reduce excess air	*Option 1: If boiler(s) have a dedicated gas meter and load is stable,* Meter boiler gas consumption before and after; *Option 2: Otherwise,* Calculated with key parameter(s): • Heat Output – calculated with steam properties and measured flow rate; • Combustion Efficiency (pre- and post-) – measured or estimated with measured excess air ratio and flue gas temperature; • Operating Hours – estimated.
	*Clean boiler tubes or heat exchange surfaces	Calculated with key parameter(s): • Savings% – estimated with rule-of-thumb; • Boiler gas consumption – see two options in the example of "Repair steam traps or steam leaks" in this table.
Type 4: Energy Demand	*Reduce steam pressure (significant enough to impact both output and efficiency)	Similar to the example of "Boiler excess air tune up" in this table.
Type 5: Energy Demand & Hours	* Repair economizer and/or adjust thermostat settings for rooftop units (RTU)	Calculated using regression models with key parameter(s): • RTU power – measured with BAS or logging; • Outdoor temperature – measured with BAS or from historical weather data source. Another option: industry-accepted calculators.
	*Conduct HVAC system tuning measures (retro-commissioning)	Calculated using regression models with key parameter(s): • HVAC equipment energy consumption – metered whole-building consumption (as appropriate) or measured with BAS or data logging; • Outdoor temperature – measured with BAS or from historical weather data source.

* Example changes which will be discussed in greater detail in the next chapter.

Detailed Guide and Examples by Type of Change

Change in Operating Hours

This section includes a detailed example on estimating energy savings from a change in equipment operating hours using both direct and indirect measurement.

Example #1

A proposed behavioral action involves adding a sign to remind operators to shut off the single air compressor in a facility at the end of the second shift. If the facility operates on a 5-day, 2-shift (8 hours per shift) schedule, the production hours are 4,016 hours per year (allowing for 10 holidays). Prior to any improvement action, the compressor is been left on 24/7, with 8,760 annual operating hours, well beyond production hours. During off-production periods, the only load demand is from air leaks. After implementing the improvement, the compressor, which has load/unload controls, will be shut off on weekends, holidays, and weekday nights. The resulting reduction in compressor operating hours is estimated at 4,744 (8,760 – 4,016 = 4,744) hours per year.

Following the general principles stated earlier in this document, the thought process for analyzing this example can be described as following. Considering that there are other large and intermittent loads on the same utility electric meter serving a very large section of the factory, utility meter analysis will not be the best option. Given that the expected energy savings is large, a rough estimate will not be satisfactory. Therefore, we have two options for an appropriate method in quantifying the energy savings from this improvement – data logging and engineering calculation. The key of this analysis is determining the air compressor's energy consumption during off-production periods prior to the improvement because the improvement did not impact the production periods. Let's review how each option work.

Option #1: Data Logging is used to determine the average power demand of the air compressor during off-production periods directly. If the factory has access to a 3-phase power logger and installs it on the compressor for 2 weeks, the logged power data can be averaged over the off-production period and multiplied by the 4,744 hours per year saved to determine the annual energy savings of this improvement. A time period of a week would be sufficient to capture off-productions, but the additional week provides two sets of data to better ensure that the period is representative of typical operation. Care should also be given to properly account for any off-production periods, such as holidays, when scheduled maintenance activities may impact compressor savings. It will be a valid alternative to use a single-phase current transducer paired with a data recorder to log compressor power for two weeks. However, the readings during unloaded periods will need adjustment for low power factor, which is explained in detail in Option#2. The remaining steps will be the same as the 3-phase logging.

Option #2: Engineering Calculation, uses Equation 2 and measure key parameters "Demand" and "Duty Cycle" in the equation because of the significance of the savings. The factory can use a stopwatch to time compressor load/unload cycles during a non-production period (time at least a few cycles to obtain average). Then it also involves using a handheld multi-meter to read compressor amperage draw both when it is loaded and unloaded during non-production. Option#2 is less robust than Option#1 and need more calculation steps, but it only requires tools that are commonly available at industrial facilities. And, since there is only leak load during off-production period, this option should provide acceptable accuracy. Such an analysis requires the following steps:

Determine power draw of the compressor. Inspection of the name plate reveals the compressor is rated as 125-hp and draws 90 kW at rated condition. Use clamp-on multi-meter to read operating amperage at both loaded (121 A) and unloaded (55 A) conditions during off-production period. Averaging a few readings across three phases is recommended. Spot check voltage with multi-meter to be 480 V. Use the facility's recent power factor reading if available, otherwise assume 0.85-0.88 for full load condition and use correction curves for partial load conditions.

In the above example, loaded power is calculated as 1.73 x 480V x 121A x 0.88/1000 = 88.4 kW; unloaded power is calculated as 1.73 x 480V x 55A x 0.60/1000 = 27.4 kW. It reveals that unloaded power is more than 30% of loaded power, a non-negligible load.

1. **Determine the conserved annual operating hours**. The compressor operating hours will be reduced by 4,744 hours per year, as discussed earlier.
2. **Determine the duty cycle.** The duty cycle during off-production periods can be determined by measuring the amount of time when the compressor is loaded versus unloaded over a few cycles. In this example, the compressor was timed before implementation during a third shift for four cycles, which lasted 32 minutes in total. A stopwatch was used to determine that the compressor was loaded for 7.5 minutes in total. This determines the duty cycle to be 7.5 min/32 min = 23.4%.
3. **Estimate the savings**. Using the inputs determined above, the annual energy savings can be estimated based on Equation 2 as following:

$$Savings = [88.4\ kW \times 23.4\% + 27.4\ kW \times (1 - 23.4\%)] \times 4{,}744\ hours = 197{,}701\ kWh/yr$$

Changes in Output

The key parameter "Output" used as reference for energy consumption in Equation 1 can either be the rate of energy or work (i.e. power), or, the rate of product throughput. Transformation of energy is very common among industrial and building systems and equipment – electric energy transformed to compressed air, pumped water or chilled water; energy from natural gas combustion transformed into steam. A frequent example among energy consuming equipment is fluid power as the output, which can be expressed as "head or pressure" multiplied by "flow rate". There are many established energy performance improvements which tackle either or both of them to conserve energy.

In the first example, energy savings are determined for a compressed air system leak program that results in a lowered demand for compressed air.

One common strategy to reduce compressed air demand is by establishing an air leak detection and repair program as part of maintenance procedures. Compressed air leaks develop over time in every plant and can be huge waste if not addressed regularly. It is not uncommon in a poorly maintained compressed air system to have leaks that represent more than 20% of total compressed air production. Establishing a proactive leak detection and repair program can keep leaks to under 10%. An ongoing compressed air leak management program is needed in order for the resulting energy savings to persist. It is important to note that the energy savings from fixing compressed air leaks are only fully realized if the compressor controls are properly adjusted to support the reduced demand. Additionally, oversized compressors lacking the ability to operate efficiently at low loads (including centrifugals that blow off) may not yield the expected energy savings.

Energy savings from repairing air leaks is often estimated by multiplying total CFM saved and compressor system efficiency, usually measured in kW per 100 CFM, and compressor operating hours. It should be noted that this approach is limited to its assumption of linear compressor efficiency, which can over-estimate the savings when the compressor power does not turn down adequately or efficiently. There are different options in obtaining leak CFM sizes, including estimates based on ultrasonic leak detector decibel reading, difference in pre- and post- compressed air flow meter readings (make sure the flow meter is reading accurately), pre- and post- leak load tests, and estimates from opening dimension and pressure (see Compressed Air Tip Sheet #3 for an example). As a rule of thumb, 16-20 kW of motor consumption is typically required per 100 CFM of compressor air produced at 100 psig (DOE, see Resources).

Site-specific compressor system efficiency should be used for analysis whenever possible. It can be obtained by logging compressor kW data and CFM data (if available). Alternatively, it can be calculated, see Example 2.

Example #2

A plant decided to implement a regular air leak detection and repair program. The compressed air system includes three lubricated rotary screw air compressors. One of the two 150-hp (600 CFM capacity at 100 psig) compressors normally operates as the baseload compressor while the other serves as backup; there is also a smaller 100-hp (400 CFM capacity at 100 psig) compressor that serves as the trim compressor. Compressors are manually turned on and off, and the two operating compressors are controlled by pressure switches. The facility has a 1000-gallon receiver. During their first compressed air leak detection, the facility found 80 air leaks totaling 200 CFM, as estimated by the ultrasonic leak detector's decibel-to-CFM table, which is over 20% of their normal compressed air produced.

Considering that compressed air demand can be varying even when production is relatively stable, the engineering calculation method was chosen for savings estimation combined with measurements on key parameters. In order to estimate the energy savings transferred to compressor power, the Compressed Air Challenge (CAC) performance curve for load/unload capacity controls (Figure 3) is used. Similarly, the performance curve of other types of compressor capacity controls are also found in DOE/CAC's Industry Sourcebook: Improving Compressed Air System Performance). First, the storage-to-capacity ratio of the compressed air system is determined as 1000 GAL/(600 CFM + 400 CFM) = 1 GAL/CFM. As revealed by the performance chart, when the storage-to-capacity ratio is 1 GAL/CFM, the compressor input power does not scale down as much as it would with higher GAL/CFM ratios. Therefore, using manufacturer rated kW/100 CFM efficiency is not recommended in this case because it will over-estimate energy savings.

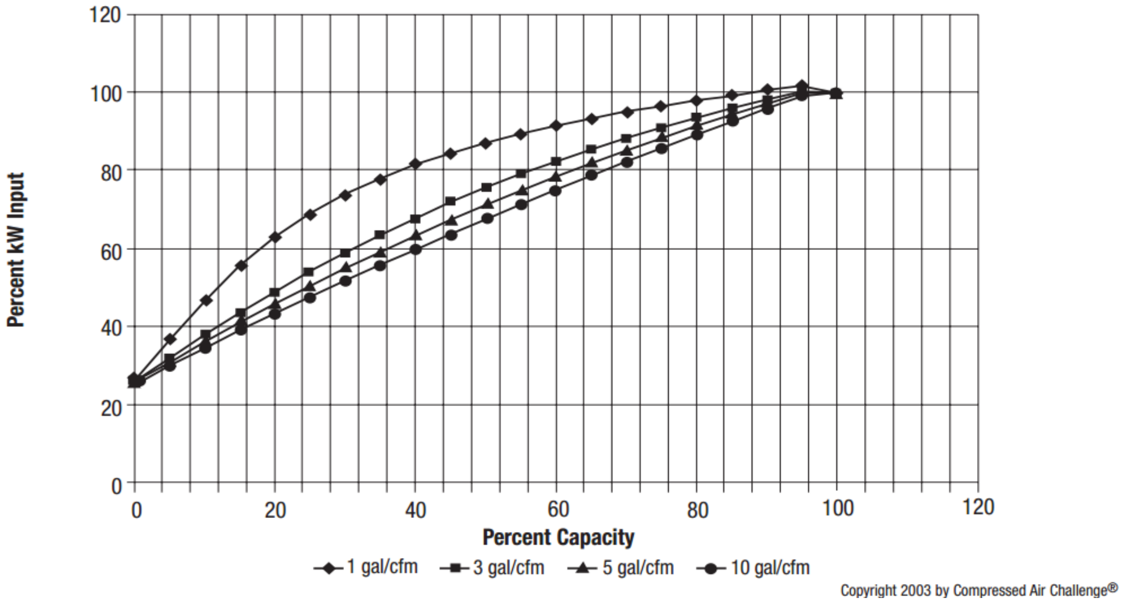


Figure 3 Performance Curve of Lubricant-Injected, Rotary Compressor with Load/Unload Capacity Control

(Source: DOE/CAC's Industry Sourcebook: Improving Compressed Air System Performance, page 43)

Since the 200 CFM of conserved leaking air will affect operation of the 100-hp trim compressor, the next step is to determine the before and after operating points on the performance chart. The average CFM produced as a percentage of the compressor's capacity before and after repair air leaks needs to be determined. Because this facility does not have compressed air flow meters, the average air flow on the trim compressor can be estimated by timing several compressor load/unload cycles with a stopwatch. If the air demand varies significantly, a better alternative would be installing a single-phase current transducer paired with a data recorder or a 3-phase power logger. For example, four load/unload cycles were timed and the trim compressor was loaded for a total of 55 minutes out of a total 75 minutes, then the before-implementation operating point was at 73% (55min/75min = 73%) of capacity and 96% of full-load power by reading the performance curve above. The after-implementation operating point can be determined as 23% [(73% x 400 CFM - 200 CFM)/400 CFM = 23%] of capacity and 68% of full-load power correspondingly.

Handheld multi-meter and back-of-envelope calculation was used to estimate the input power (see Example #1, Option #2 for details about this method) of the trim compressor to be 70 kW when it was loaded and that of the baseload compressor to be 95 kW.

The facility operates its compressed air systems 5,000 hours per year. Therefore, the baseline energy consumption of the air compressor system was 825,000 kWh/yr [(70 + 95) kW x 5000 hrs = 825,000 kWh/yr]. And, the energy savings from repairing 200 CFM leaks was estimated to be 98,000 kWh/yr [70 kW x (96% - 68%) x 5000 hrs = 98,000 kWh/yr]. This savings represents 11.9% of the baseline consumption.

Example #3

Fixing steam leaks is an example of reducing steam flow rate. Similar to compressed air leaks, steam leaks are also difficult to measure directly but can be estimated by the size of the opening and steam pressure using Napier's Equation below. There are other methods for estimating steam leak sizes such as the plume length based method.

$$W = 24.24 \times Pa \times D^2$$

Equation 4

Where W = Leakage rate (lbs/hr)
Pa = Absolute pressure drop across the orifice (psia)
D = Diameter of leaking orifice (inch)

Another similar example is including steam traps inspection and repair in maintenance procedures. In a period of 3 to 5 years, between 15% and 30% of installed steam traps have likely failed. In regularly maintained systems, leaking traps should account for less than 5% of the trap population. DOE's Steam Tip Sheet #1 provides a table for estimating steam loss based on trap orifice size and steam pressure.

Example #4

A facility operates a boiler which provides process heating 24/7. The boiler delivers 4,500 lbs/hr of saturated steam at 215 psig. According to data recorded daily by the boiler operator, last year the boiler used 51,470 MMBtu of natural gas. During a recent maintenance, seven observed steam leaks were repaired, each about 1/16 inch in diameter. In addition to fixing the steam leaks, a new steam line was added to the boiler to meet additional process heating requirements. After using a loaner portable ultrasonic flow meter to measure for a few days, it was determined that the additional line utilizes about 500 lbs/hr of steam stably.

Because of the added load of the new steam line, the energy savings from fixing the steam leaks will not be visible on the boiler natural gas meter. However, an existing steam flow meter can be leveraged in this analysis. The meter monitors the total steam production delivered to the plant and records readings in the supervisory system. The flow meter previously read 4,500 lbs/hr as the baseline. After the leaks were repaired and the added line was operational, the total steam flow rate delivered by the boiler was collected for 30 days and it was found to be relatively stable and averaged 4,820 lbs/hr. Although this figure is higher than before, after accounting for the additional load of 500 lbs/hr, analysis shows that repairing leaks has reduced the steam demand by 180 lbs/hr (4,500 + 500 - 4,820 = 180).

The Napier's equation (Equation 4) was also used for a sanity check:

$$W = 7\ leaks \times [24.24 \times 229.7\ psia \times (0.0625)^2] = 152\ lbs/hr$$

The calculations of saved steam came close using the two different approaches above. The boiler fuel consumption over the 30-day Post-period was determined to be 4,588 MMBtu, which was extrapolated to annual consumption (365 days) of 55,820 MMBtu. The baseline annual fuel consumption is adjusted for the 500 lbs/hr additional load to represent the consumption that would have occurred with the new steam line before the leaks are fixed. Therefore, it was calculated as 57,188 MMBtu [51,470 MMBtu x (4,500 + 500) lbs/hr / 4,500 lbs/hr = 57,188 MMBtu]. If the boiler efficiency has changed significantly before and after, measured efficiency data should also be taken into account in the baseline adjustment. It is not the case with this example. Finally, the annual fuel savings was estimated to be 57,188 - 55,820, or 1,368 MMBtu.

Changes in Efficiency

Changing efficiency is another popular type of energy performance improvements. It's not only achievable with capital improvements such as high-efficiency unit retrofits but also with many operational, behavioral and maintenance improvements. A behavior example may be running less redundant units if supported by the result of a careful risk and response time analysis. This applies to a wide range of equipment and systems. Raising chilled water supply temperature (section *Estimates, Correlations and Rule-of-Thumb*) is an operational change example. There are also numerous examples in maintenance activities, such as those pertaining to lubricating moving parts, cleaning heat transfer surfaces, replacing worn parts and repairing leaks.

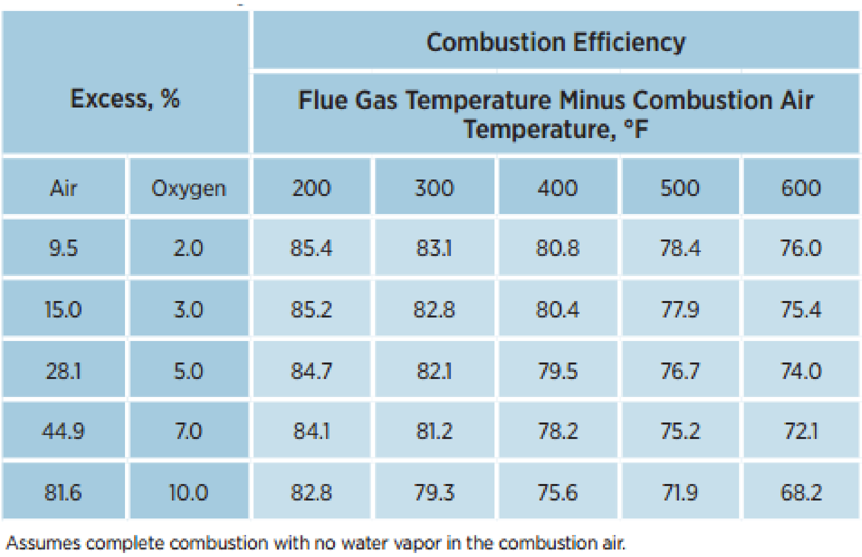
In choosing the appropriate method to estimate energy savings from this type of improvements, the general principles also apply. Generally, the efficiency increase from enhanced maintenance procedures is small and rule-of-thumb or good engineering judgement based estimations are acceptable. For savings greater than a few percent, especially if the baseline consumption is large, it should be supported by before and after spot measurements and/or engineering calculations. Below are two examples with boiler maintenance. There are also exceptions – improvement actions like the first example in this section, which reduces the number of operating redundancy units typically yield very large energy savings, and hence, will require data logging or other rigorous methods as appropriate.

Example #5

Cleaning boiler waterside tubes and adopting maintenance practices to prevent formation of scale on the tubes will increase heat transfer rate and hence the boiler efficiency. Energy savings from this maintenance related improvement can be estimated from measuring the thickness of deposit before the cleaning. For example, removal of a 1/16 inch scale can reduce boiler fuel usage by 4%. Rule-of-thumb values for different thickness of scale and a calculation example can be found in the DOE's Steam Tip Sheet #7.

Example #6

Too much excess air is known to harm boiler and furnace combustion efficiency. Including boiler/furnace excess air tune-up at desirable intervals in maintenance procedures can generate significant energy savings. 10% excess air is attainable on well-designed natural gas fired systems. A common rule-of-thumb is that boiler/furnace efficiency can increase by 1% for each 15% reduction in excess air or 40°F reduction in stack gas temperature. In order to use this rule-of-thumb, before and after spot measurements of stack gas temperature and excess air (or Oxygen) percentage are necessary to support claimed efficiency improvement. Before and after measurements can also be read on Figure 4, which is taken from DOE's Steam Tip Sheet #4, to obtain combustion efficiencies. A savings calculation example is also found in the same source tip sheet. In addition, the DOE's Advanced Manufacturing Office also provides a tool to estimate the savings associated with optimizing a boiler's amount of excess air.



Excess, %		Combustion Efficiency Flue Gas Temperature Minus Combustion Air Temperature, °F				
Air	Oxygen	200	300	400	500	600
9.5	2.0	85.4	83.1	80.8	78.4	76.0
15.0	3.0	85.2	82.8	80.4	77.9	75.4
28.1	5.0	84.7	82.1	79.5	76.7	74.0
44.9	7.0	84.1	81.2	78.2	75.2	72.1
81.6	10.0	82.8	79.3	75.6	71.9	68.2

Assumes complete combustion with no water vapor in the combustion air.

Figure 4 Combustion Efficiency for Natural Gas (Source: DOE's Steam Tip Sheet #4)

Combined Changes

Earlier in this chapter, examples are provided for changing one of the three key parameters (operating hours, output and efficiency) at a time. There are other improvement actions which change two or all of the three key parameters simultaneously. Let's look at a few different scenarios.

First, if the overall change can be broken down and isolated into singular changes discussed in the previous three sections in this chapter, then the corresponding methods discussed earlier may still be able to apply. For example, this might be the case when an improvement changes both output and operating hours or both efficiency and operating hours of equipment.

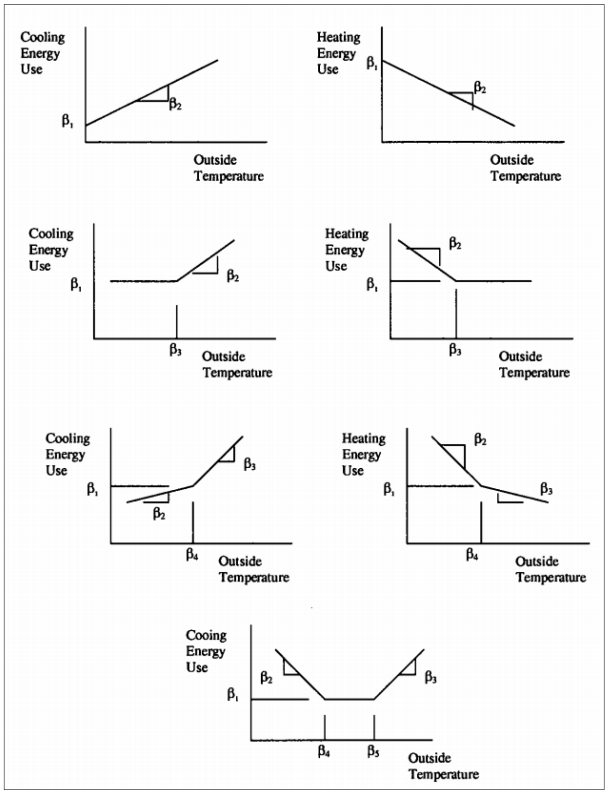
If an improvement changes output and efficiency simultaneously, i.e. changes "Demand" in Equation 1 (Type 4), it will often be difficult to isolate these changes and will likely to require data logging of power or fuel consumption for before and after comparison analysis. For example, reducing steam pressure can potentially be a very good opportunity for plants with oversized boilers and steam systems. If the steam system pressure is reduced significantly, boiler output will be reduced and boiler efficiency may change as well depending on the boiler control. The better option for determining the associated energy savings will involve obtaining boiler fuel consumption data before and after the change. If that is not possible, an indirect alternative may be engineering calculation which can determine the before and after boiler output and efficiency with measured parameters. The DOE's Steam Pressure Reduction, Opportunities and Issues is a good resource, as is DOE's Steam System Modeler.

Another complicated scenario is that output, efficiency and operating hours all change under one improvement or, in some cases, one improvement bundle. In fact, many heating, ventilation and air conditioning (HVAC) related improvements, whether operational, behavioral or maintenance in nature, fall in this category of changing everything altogether. Let's use the improvement of increasing building or factory thermostat setting from 67°F to 72°F during cooling season as an example. In this case, rooftop units (RTUs) provides space cooling. The RTUs will need to operate less hours in a year as a result of this improvement. Meanwhile, on a given cooling day, the cooling load (i.e. output) is also smaller than before. This is because part of the space cooling load is determined by the indoor-and-outdoor temperature difference. RTU efficiency is also known to be dependent on load, and therefore, has also changed as a result of this improvement.

Energy savings estimation for HVAC system improvements are often not straightforward for back-of-the-envelope calculations. Furthermore, multiple such improvements often come in a “bundle”. A frequently seen approach among the building sector but spilled to the industry is called “retro-commissioning”. Retro-commissioning (RCx) originally refers to the action of restoring the HVAC system’s (among other building systems) performance back to the design conditions, although the industry use of the term has expanded and is now inclusive of most low-cost changes that leads to energy savings. Many of the changes under RCx are operational or maintenance-related changes in nature, such as equipment scheduling, repairing/optimizing economizers, supply air temperature reset, static pressure reset, unoccupied room temperature setback, optimize VFDs on supply fans, pumps and cooling towers, repairing pneumatic control components and more. The energy savings associated with HVAC changes can be complex in analysis and very significant in aggregation.

RCx tends to be implemented as a bundle project which covers all HVAC systems and equipment in a building or multiple buildings. It is usually labor-intensive and happens during non-cooling season. The individual changes are often highly interactive on the result of overall energy savings. Therefore, it often makes sense to perform energy savings analysis for the bundle of changes or its subsets. This often involves regression modeling of energy consumption data of affected energy-consuming equipment (e.g. chillers, fans, pumps, RTUs) before and after RCx implementation with respect to weather parameters. Outdoor dry bulb temperature is the most popular parameter for this type of regression analysis although wet bulb temperature is also sometimes used mainly for water-cooled systems. The weather parameter is often captured by building automation systems (BAS) if exists. Otherwise, they can be obtained from historical local weather data available at public sources such as National Climate Data Center (NCDC) and Weather Underground.

In commercial buildings or the like, it’s most common to use building-level utility metered consumption for this regression analysis because HVAC consumption drives its shape with respect to weather. For industrial facilities, this approach might work for light-manufacturing facilities but may be found unviable for many facilities where industrial process loads are dominant and varying. If facility loads (like lighting and HVAC) are on a separate meter from the industrial loads, this approach may still apply. Otherwise, logged or trended data is required for equipment input power and/or fuel demand over a period of time before and after RCx. Today, automatic data trending capabilities for HVAC equipment are common in buildings where BAS exists. Compared to the logging techniques introduced earlier in “Data Logging and Spot Measurements”, this is an easier option for logging multiple pieces of equipment simultaneously. Another aspect for obtaining this energy consumption data is the HVAC system type. For example, it is easier to capture the energy consumption of chiller and boiler systems than that of distributed RTUs or room heat pumps. This is especially true when BAS trending capability is absent and logging is necessary. In the absence of BAS trending capabilities, a sampling approach should be considered for distributed HVAC systems. Hourly time interval is commonly used for collecting data and daily interval is common for regression analysis of the collected data. This is because building physics dictates a delayed load and system response to weather change. The period necessary for BAS trending or data logging can be between several weeks and a few months depending on weather conditions and, sometimes, other factors. Generally, the more outdoor temperature varies during logging, the shorter a period will be needed because capturing readings cover a wide range of temperatures is necessary to develop valid regression models. If shorter logging period is stressed, one technique available for trying is to use 8-hour or 12-hour intervals instead of daily in order to get more data points out of the same logging period.



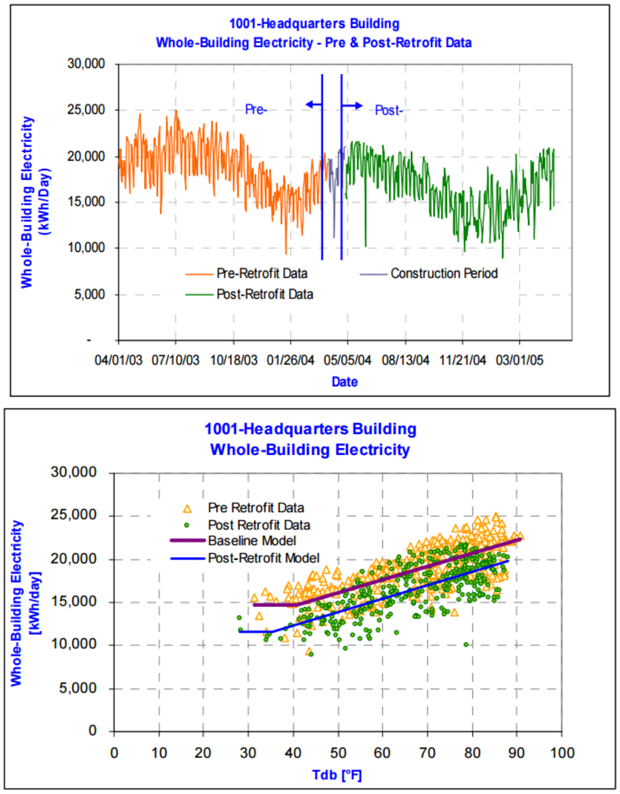


Figure 5 Types of Linear and Change-point Linear Regression Models Frequently Used for HVAC Energy Consumption (Left)

Figure 6 Example of Regression Models of Facility Energy Consumption vs. Weather before and after EE Improvement (Right)

(Source: Figure 6 from A Conference Paper and Figure 5 from ASHRAE Research Project 1050-RP)

Once the necessary energy consumption and weather data are collected, the analysis steps work as following. First, the hourly trended/logged data is processed to daily average values. Then daily average kW or fuel consumption rate is scatter-plotted against daily average temperature on a spreadsheet. A regression model can be fit to the scatter plot. Linear, change-point linear (Figure 5) and polynomial regression models are often used for this purpose. This same process repeats for both Pre- and Post-data (see Figure 6 for an example). Lastly, both Pre- and Post- models will be applied to the local typical meteorological year (TMY) ambient temperature (usually comes in hourly interval) so that Pre- and Post-annual energy consumption is calculated, the difference of which will be the annual energy savings. For additional guidance on regression modeling, Bonneville Power Administration has a Verification by Energy Modeling Protocol for assistance among other resources such as ASHRAE Handbook Fundamentals.

When trending and logging are not possible, simulation models with software tools (such as eQuest, EnergyPlus) is another option to evaluate the dynamic impact of multiple measures although the use of such tools typically require deep HVAC system simulation expertise. It should be noted that such simulation tools are typically less suitable for evaluating changes of maintenance in nature because they are built upon mathematical models representing normal performance characteristics of systems and equipment. When used for operational changes, actual pre- and post- operating parameters should be used instead of assumptions.

There are other industry-accepted estimation tools that are developed at local level for reference when climate zone is applicable or climate characteristics are similar. The C-BOA tool offered by the California Commissioning Collaborative is an example of such. Those type of tools are sometimes good options for evaluating single changes that they are developed for.

Additional Resources

Resources

Air Compressors

DOE, among others, has numerous resources to assist facilities in maximizing compressed air efficiency. These resources can be found at the Office of Energy Efficiency and Renewable Energy's (EERE) Compressed Air Systems overview. For maintenance-related tips and best practices, Chapter 9.11 of the O&M Best Practices Guide offers assistance.

The resources mentioned in maintenance improvement actions for compressed air systems are also applicable to operational improvement. They are listed on the DOE Office of Energy Efficiency and Renewable Energy's (EERE) Compressed Air Systems overview. The most common opportunities for compressed air systems are to reduce either pressure or flow requirements:

- **Replace filters as per manufacturer's recommendation**. For an example of energy savings estimation for improved filter replacement practices, refer to the DOE's Compressed Air Tip Sheet #6. In general, there is a significantly higher pressure drop across unmaintained filters as compared to well-maintained filters, which results in a higher pressure requirement at the compressor. The 1% less compressor power for every 2 psi of decreased discharge pressure rule-of-thumb also applies to this type of estimation.

Boilers/Steam Systems

As mentioned for boiler/steam system maintenance opportunities, EERE's Steam Systems overview contains useful information and tools. Operational improvements of boilers and steam systems tend to yield significant savings, which will generally require customized engineering calculations supported with logged/measured data as key inputs. While the combination of combustion and steam tables (see discussions in the maintenance chapter) may satisfy the calculation for some improvement actions, others tend to have system level impact and change balances of steam flow. DOE's Advanced Manufacturing Office provides a detailed Steam System Modeler tool, which will model many operational improvement actions. Below are a couple of common energy performance improvement actions and resources for savings estimation:

DOE offers tools to assist facilities in improving boiler and steam system efficiency including EERE's Steam Systems overview and Chapter 9.1 of the O&M Best Practices Guide. Considering the complexity of steam systems and generally small savings from maintenance improvements, rule-of-thumbs are primarily used for estimating savings from these types of actions. Below are a few examples of such.

Pumps and Fans

One important operational energy performance improvement action for fans and pumps involves optimizing the sequencing in multiple fan/pump arrangements. The use of Pre- and Post-logged/measured data is generally recommended for verifying energy savings from such improvement actions. For assistance with analyzing systems with multiple pump arrangements, refer to Section 2-8 of the DOE's Improving Pumping System Performance: A Sourcebook for Industry. For assistance with analyzing systems with multiple fan arrangements, refer to Section 2-10 of the DOE's Improving Fan System Performance: A Sourcebook for Industry. For other types of improvement actions, such as adjusting flow rates or pressure, engineering calculations with pump/fan curves and spot readings/measurements will likely to serve a reasonable savings estimation.

Good maintenance for fans and pumps can contribute to energy performance improvement. Simple calculations and good engineering judgement can be used for estimating energy savings associated with such improvement, considering they are often of small impact (a few percent of equipment power or less). A few references for estimating savings are given below.

However, when repairs and significant adjustments are performed, the energy savings can be more significant and would warrant data logging/measurements and a more thorough analysis (see "Data Logging and Spot Measurements" section for details). DOE has tools that can assist facilities in this type of analysis. The Fan System Assessment Tool (FSAT) can help users identify problems such as high duct velocity, discharge dampers in locked position, obstructed inlets, incorrectly sized fans and degraded impellers. Similarly, the Pumping System Assessment Tool (PSAT) can help identify pumping systems that could benefit from improved performance. In addition, Chapter 8-8 of the DOE's Motor Driven Systems Guidebook for Industry provides details for analyzing fluid movement systems. A basic maintenance checklist for pumps and fans includes:

Table 3: Basic Maintenance for Pumps and Fans

Pumps	Fans
Bearing lubrication and replacement	Periodic inspection of all system components
Mechanical seal replacement	Bearing lubrication and replacement
Packing tightening and replacement	Belt tightening and replacement
Wear ring adjustment or replacement	Motor repair or replacement
Impeller replacement	Fan cleaning
Pump/motor alignment	
Motor repair or replacement	

For a detailed description of each of these items, refer to Section 2-3 of DOE's Improving Fan System Performance: a Sourcebook for Industry and Section 2-5 of DOE's Improving Pumping System Performance: A Sourcebook for Industry. A generic rough energy-saving figure that might be expected from maintenance-related performance improvement associated with pumps and fans are given below:

- **Maintain pumping systems**. According to the US Industrial Electric Motor Systems Market Opportunities Assessment (page 58 & 59), the energy savings from regularly replacing worn impellers, inspecting and repairing bearings, lip seals, packing and other mechanical seals will likely be 2-7%.
- **Maintain fan systems**. According to the US Industrial Electric Motor Systems Market Opportunities Assessment (page 61), improved fan maintenance practices, such as tightening belts, cleaning fans and changing filters regularly, can yield energy savings of 2-5% savings.

Motors

Energy performance improvement of motor systems from good maintenance practices can vary largely, from 2-30% according to the US Industrial Electric Motor Systems Market Opportunities Assessment (page 55). Certain types of motor-driven equipment, such as air compressors, can benefit more savings than the others. Due to the large variation of potential savings, we recommend power logging/measurements for determining the actual energy savings from maintenance activities (see "Data Logging and Spot Measurements" section for details). The Office of Energy Efficiency and Renewable Energy also provides resources and tools to assist facilities seeking to improve motor system performance. One tool of such is MotorMaster+ – an online software which can help optimizing drive systems, analyzing repair vs. replace cost effectiveness for in-service motors, and providing motor purchasing information.

For a detailed list of suggested motor maintenance practices, refer to Improving Motor and Drive System Performance: A Sourcebook for Industry (page 29) as well as Chapter 9.10 of the O&M Best Practices Guide.

For a detailed description of the best maintenance practices for each energy end-use, consult the DOE's guide to O&M Ideas for Major Operating Equipment Types.

- **Cover heated, open vessels**. Refer to DOE Steam Tip Sheet #19 for a detailed example of calculations.

HVAC/Chiller Systems

Maintenance-related energy performance improvement for HVAC equipment, such as packaged air conditioners (ACs), air handling units (AHUs), chillers and cooling towers, can yield a very wide range of energy savings from small to very significant. For this reason, we recommend that the actual savings should be determined by analysis of site-specific data whenever feasible, although rule-of-thumbs can assist sanity checks. Multiple interactive measures can also be combined for a total improvement analysis as appropriate.

HVAC

Options for centrifugal chiller maintenance for energy performance improvement include:

- Clean chiller tube bundle;
- Monitor and address reduced condenser flow;
- Properly maintain refrigerant levels;
- Eliminate oil contamination in refrigerant;
- Repair leaks in the compressor;
- Sustain proper water treatment.

Actions for rooftop unit maintenance for energy performance improvement include:

- Repair/adjust economizer;
- Adjust thermostat settings;
- Clean evaporator and condenser coils;
- Check refrigerant charge;
- Unoccupied fan controls.

Institute for Building Efficiency has provided reference energy savings range for a spectrum of chiller and rooftop units maintenance measures. Utility commercial HVAC quality maintenance programs have also established a set of maintenance measures which lead to energy performance improvement. Below are some examples of these measures. Additional resources on chilled water systems analysis include Chapter 9.4 of DOE's O&M Best Practices Guide and the Chilled Water System Analysis Tool (CWSAT).

Summary

Non-capital energy performance actions include behavioral, maintenance-related, and operational actions. There are three methods that are commonly used for estimating the Pre- and Post-equipment/system energy consumption, as well as energy savings associated with an action under evaluation: 1) utility meter analysis, 2) data logging and 3) engineering calculations. As described in this guide, energy savings estimation methodologies for non-capital energy performance improvement projects/actions (energy performance actions) can vary significantly, and the M&V and level of detail of the energy savings calculation methodology should be aligned with the potential savings.