Department of Energy
Advanced Manufacturing Office
EnPI V5.0 Tool Algorithm

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Contents

Definition of Symbols

The following symbols and abbreviations are used in the *Facility Level Calculations* and *Corporate Level Calculations* sections of the document.

AI	Annual Improvement (Annual change) in Energy Intensity for Current Year (%)
$AEC_{5, 10, 15}$	Energy Consumption for 5%, 10%, 15% Improvement Projections
BY	Baseline Year
CI	Cumulative Improvement (Total Change) in Energy Intensity from Baseline Year (%)
CS	Energy Cost Savings
CY	Current Year
Corp	Corporate level total
$\widehat{EC}$	Modeled Source (Primary) Energy Consumption (MMBtu)
EC	Actual Source (Primary) Energy Consumption (MMBtu)
EI	Energy Intensity or Energy Normalized for Relevant Factors (MMBtu/ Unit of Production or MMBtu/sq ft)
Energy Cost_p	Energy cost for a given time interval (e.g. day, week or month)
Energy Savings_i	The energy savings for a given time interval (e.g. day, week or month)
$EnPI_{TTM}$	SEP Trailing Twelve Month Energy Performance Indicator
ES_{TTM}	SEP Trailing Twelve Month Energy Savings
I	Interval of time in which the data is entered (e.g. daily, weekly, monthly, etc.)
MY	Model Year
N	Number of plants within the company
PY	Previous Year
SEnPI	Superior Energy Performance Indicator
Unit Cost	Unit energy cost

Facility Level Calculations

The following section describes the calculation methods used for the facility level calculations.

Calculation Methods when Actual Values are used

When "Use Actual" is selected as the calculation method in the EnPI tool, the following calculations are used.

Energy Intensity (MMBtu/Unit of Production or MMBtu/sq ft)

$$Production\ EI_{CY} = \frac{EC}{Total\ Production}$$

$$Building\ EI_{CY} = \frac{EC}{Total\ Building\ Square\ Footage}$$

Cumulative Improvement (Total Change) in Energy Intensity from Baseline Year (%)

When using Production Energy Intensity:

$$CI_{CY} = {(Production\ EI_{BY} - Production\ EI_{CY})}\big/{Production\ EI_{BY}}$$

When using Building Energy Intensity:

$$CI_{CY} = {(Building\ EI_{BY} - Building\ EI_{CY})}\big/{Building\ EI_{BY}}$$

Annual Improvement (Annual Change) in Energy Intensity for Current Year (%)

$$AI_{BY} = CI_{CY} - CI_{PY}$$

Annual Savings (Total Energy Savings) since Baseline Year (MMBtu/year)

The following equation is used to calculate the savings for each energy type (e.g. electric, natural gas, etc.) and for the total of all the energy sources entered into the tool.

$$Annual\ Savings_{CY} = EC_{BY} - EC_{CY}$$

New Energy Savings for Current Year (MMBtu/year)

$$New\ Energy\ Savings_{CY} = Annual\ Savings_{CY} - Annual\ Savings_{PY}$$

Estimated Annual Cost Savings ($/year)

First, the unit cost for each energy type (e.g. electric, natural gas, etc.) for each time interval is calculated by dividing the energy cost by the energy consumption.

$$Unit\ Cost_i = \frac{Energy\ Cost_i}{EC_i}$$

Next, the daily, weekly or month energy savings is calculated for each energy type by subtracting the current year consumption for the time interval from the baseline year consumption for the same time interval (e.g. September 2010 (baseline) electric – September 2013 (current year) electric].

$$Energy\ Savings_i = EC_{BY\ i} - EC_{CY\ i}$$

The unit cost for each energy type and time interval is then multiplied by the energy savings for each energy type and time interval.

$$CS_i = Unit\ Cost_i \times Energy\ Savings_{\ i}$$

Finally, the cost savings for each energy type (e.g. electric, natural gas, etc.) and time period is summed to determine the annual cost savings.

$$Annual\ Cost\ Savings = \sum_{i=1}^{N} CS_{Electric\ i} + \sum_{i=1}^{N} CS_{Natural\ Gas\ i} + \sum_{i=1}^{N} CS_{Energy\ type\ X\ i}$$

Calculation Method when Normalized Values are used

When "Regression Analysis" is selected as the calculation method in the EnPI tool, the following calculations are used.

SEnPI (unitless)

Forecasting (Model year = baseline year)

Calculation for the model year:

$$SEnPI_{MY} = 1$$

Calculation for all years after the model year:

$$SEnPI_{CY} = \frac{EC_{CY}}{EC_{MY}} \times \frac{\widehat{EC}_{MY}}{\widehat{EC}_{CY}}$$

Chaining (Model year does not = baseline year, and does not = last reporting year)

Calculation for all years prior to the model year, including the baseline year:

$$SEnPI_{CY} = \frac{\widehat{EC}_{CY}}{EC_{CY}}$$

Calculation for the model year:

$$SEnPI_{MY} = 1$$

Calculation for all years after the model year:

$$SEnPI_{CY} = \frac{EC_{CY}}{EC_{BY}} \times \frac{\widehat{EC}_{BY}}{\widehat{EC}_{CY}}$$

Backcasting (Model year = last reporting year)

Calculation for all years prior to the model year, including the baseline year:

$$SEnPI_{CY} = \frac{\widehat{EC}_{CY}}{EC_{CY}}$$

Calculation for the model year:

$$SEnPI_{MY} = 1$$

Cumulative Improvement (Total Change) in Energy Intensity from Baseline Year (%)

Forecasting (Model year = baseline year)

$$CI_{CY} = (1 - SEnPI_{CY}) \times 100$$

Chaining (Model year does not = baseline year, and does not = last reporting year)

Calculation for the model year, and all years prior to the model year:

$$CI_{CY} = \{[(1 - SEnPI_{PY}) - (1 - SEnPI_{CY})] \times 100\} + CI_{PY}$$

Calculation for all years after the model year:

$$CI_{CY} = (1 - SEnPI_{CY}) \times 100$$

Backcasting (Model year = last reporting year)

$$CI_{CY} = \{[(1 - SEnPI_{PY}) - (1 - SEnPI_{CY})] \times 100\} + CI_{PY}$$

Annual Improvement (Annual Change) in Energy Intensity for Current Year (%)
Forecasting (Model year = baseline year)

$$AI_{CY} = CI_{CY} - CI_{PY}$$

Chaining (Model year does not = baseline year, and does not = last reporting year)

Calculation for the model year, and all years prior to the model year:

$$AI_{CY} = [(1 - SEnPI_{PY}) - (1 - SEnPI_{CY})] \times 100$$

Calculation for all years after the model year:

$$AI_{CY} = CI_{CY} - CI_{PY}$$

Backcasting (Model year = last reporting year)

$$AI_{CY} = [(1 - SEnPI_{PY}) - (1 - SEnPI_{CY})] \times 100$$

Annual Savings (Total Energy Savings) since Baseline Year (MMBtu/year)
The following equations are used to calculate the savings for each energy type (e.g. electric, natural gas, etc.) and for the total of all the energy sources entered into the tool.

Forecasting (Model year = baseline year)

$$Annual\ Savings_{CY} = \widehat{EC}_{CY} - EC_{CY}$$

Chaining (Model year does not = baseline year, and does not = last reporting year)

Calculation for the model year, and all years prior to the model year:

$$Annual\ Savings_{CY} = Annual\ Savings_{PY} + \left[\left(EC_{PY} - \widehat{EC}_{PY}\right) - \left(EC_{CY} - \widehat{EC}_{CY}\right)\right]$$

Calculation for all years after the model year:

$$Annual\ Savings_{CY} = \widehat{EC}_{CY} - EC_{CY}$$

Backcasting (Model year = last reporting year)

$$Annual\ Savings_{CY} = Annual\ Savings_{PY} + \left[\left(EC_{PY} - \widehat{EC}_{PY}\right) - \left(EC_{CY} - \widehat{EC}_{CY}\right)\right]$$

New Energy Savings for Current Year (MMBtu/year)

$$New\ Energy\ Savings_{CY} = Annual\ Savings_{CY} - Annual\ Savings_{PY}$$

Estimated Annual Cost Savings ($/year)

First, the unit cost for each energy type (e.g. electric, natural gas, etc.) for each time interval is calculated by dividing the energy cost by the energy consumption.

$$Unit\ Cost_i = \frac{Energy\ Cost_i}{EC_i}$$

Next, the daily, weekly or month energy savings is calculated for each energy type and time interval using the equations below. In the equations "I" denotes the current time interval (e.g. day, week, or month). The subscripts "i-1" indicates the previous time interval. For example, if "I" is referencing September 2013, "i-1" indicates August 2013.

Forecasting (Model year = baseline year)

$$Energy\ Savings_i = \widehat{EC}_i - EC_i$$

Chaining (Model year does not = baseline year, and does not = last reporting year)

Calculation for the model year and all years prior to the model year:

$$Energy\ Savings_i = Energy\ Savings_{i-1} + \left[\left(EC_{i-1} - \widehat{EC}_{i-1}\right) - \left(EC_i - \widehat{EC}_i\right)\right]$$

Calculation for all years after the model year:

$$Energy\ Savings_i = \widehat{EC}_i - EC_i$$

Backcasting (Model year = last reporting year)

$$Energy\ Savings_i = Energy\ Savings_{i-1} + \left[\left(EC_{i-1} - \widehat{EC}_{i-1}\right) - \left(EC_i - \widehat{EC}_i\right)\right]$$

The unit cost for each energy type and time interval is then multiplied by the energy savings for each energy type and time interval.

$$CS_i = Unit\ Cost_i \times Energy\ Savings_{\,i}$$

Finally, the cost savings for each energy type (e.g. electric, natural gas, etc.) and time period is summed to determine the annual cost savings.

$$Annual\ Cost\ Savings = \sum_{i=1}^{N} CS_{Electric\ i} + \sum_{i=1}^{N} CS_{Natural\ Gas\ i} + \sum_{i=1}^{N} CS_{Energy\ type\ X\ i}$$

SEP Calculations

The following outputs are displayed when "Regression Analysis" is selected as the calculation method in the EnPI tool. These calculations were developed for the SEP Program but may be valuable to general users and Better Plants Participants as well.

SEP Trailing Twelve Month Energy Performance Indicator

In the following calculations trailing 12 months indicates the sum of the current plus previous 11 months values. For example, if the value is calculated for December 2013, the trailing 12 month sum would be the sum of the Jan 2013 through Dec 2013 values.

Forecasting (Model year = baseline year)

$$EnPI_{TTM} = \frac{\sum_{Trailing\ 12\ months} \mathrm{EC}_{CY}}{\sum_{Trailing\ 12\ months} \widehat{\mathrm{EC}}_{\boldsymbol{CY}}}$$

NOTE: Energy consumption above is the total source consumption for all energy sources.

Chaining (Model year does not = baseline year, and does not = last reporting year)

$$EnPI_{TTM} = \frac{\widehat{EC}_{BY}}{EC_{BY}} \times \frac{\sum_{Trailing\ 12\ months} EC_{CY}}{\sum_{Trailing\ 12\ months} \widehat{EC}_{CY}}$$

NOTE: (1) The energy consumption in above equations refers to total source consumption for all fuel sources. (2) Trailing 12 months refers to 12 month period which includes month 1 after the mid-term model year.

This value is not calculated when backcasting is selected.

SEP Trailing Twelve Months Energy Savings

Forecasting (Model year = baseline year)

$$ES_{TTM} = \sum_{Trailing\ 12\ months} \widehat{EC_{CY}} - \sum_{Trailing\ 12\ months} EC_{CY}$$

NOTE: monthly energy consumption above is the total source consumption for all energy sources.

Chaining (Model year does not = baseline year, and does not = last reporting year)

$$ES_{TTM} = \left(EC_{BY} - \widehat{EC}_{BY}\right) + (\sum_{Trailing\ 12\ months} \widehat{EC}_{CY} - \sum_{Trailing\ 12\ months} EC_{CY})$$

NOTE: (1) Energy consumption in above equations refers to total source consumption for all fuel sources. (2) Trailing 12 months refers to 12 month period which includes month 1 after the mid-term model year.

This value is not calculated when backcasting is selected.

Energy Consumption for 5%, 10%, 15% Improvement Projections
The following values indicate the amount of energy that should be used in order to save 5%, 10%, or 15%.

Forecasting (Model year = baseline year)

$$AEC_{5,10,15} = \left(1 - \left(\frac{Target}{100}\right)\right) \times \sum_{Trailing\ 12\ Months} Monthly\ Modeled\ Energy\ Consumption$$

Chaining (Model year does not = baseline year, and does not = last reporting year)

$$AEC_{5,10,15} = (1 - \frac{Target}{100}) \times \frac{EC_{BY}}{\widehat{EC}_{BY}} \times \sum_{Trailing\ 12\ months} \widehat{EC}_{CY}$$

This value is not calculated when backcasting is selected.

5%, 10%, 15% projected energy savings and actual energy savings
Forecasting (Model year = baseline year)

$$ES_{5,10,15} = \sum_{Trailing\ 12\ Months} \widehat{EC}_{CY} - AEC_{5,10,15}$$

Chaining (Model year does not = baseline year, and does not = last reporting year)

$$ES_{5,10,15} = \left(EC_{BY} - \widehat{EC}_{BY}\right) + (\sum_{Trailing\ 12\ Months} \widehat{EC}_{CY}) - AEC_{5,10,15}$$

These values are not calculated when backcasting is selected.

SEP CUSUM (MMBtu)
For all regression methods, the following equation is used to calculate CUSUM.

$$CUSUM = \left(EC_{Current\ Interval} - \widehat{EC}_{Current\ Interval}\right) + CUSUM_{Previsou\ Interval}$$

In the equation above, "Interval" represents the time interval entered by the user (e.g. month, week, day). For the first data point after the model year when chaining is selected as the regression method the "previous interval" refers to the last data point before the model year.

Corporate Level Calculations

This section lists the calculations for the corporate roll up. These calculations are appropriate whether all participating plants selected "use actual", "regression analysis", or a blend of the two methods.

Current Year Total Primary Energy Use (MMBtu/year)

The following equation is used to calculate the savings for each energy type (e.g. electric, natural gas, etc.) and for the total of all the energy sources entered into the tool.

$$EC_{Corp} = EC_{Plant\ 1} + EC_{Plant\ 2} + \cdots + EC_{Plant\ N}$$

Adjustment for Baseline Primary Energy (MMBtu/year)

$$Adjustment\ for\ Baseline\ EC_{CY\ Corp} = Annual\ Savings_{CY\ Corp} + EC_{CY\ Corp} - EC_{BY\ Corp}$$

Adjusted Baseline Primary Energy (MMBtu/year)

$$Adjusted\ EC_{BY\ Corp} = EC_{BY\ Corp} + Adjustment\ for\ Baseline\ EC_{CY\ Corp}$$

Cumulative Improvement (Total Change) in Energy Intensity from Baseline Year (%)

$$CI_{CY\ Corp} = \frac{\left[\left(\widehat{EC}_{BY\ Plant\ 1} \times CI_{CY\ Plant\ 1}\right) + \left(\widehat{EC}_{BY\ Plant\ 2} \times CI_{CY\ Plant\ 2}\right) + \cdots + \left(\widehat{EC}_{BY\ Plant\ N} \times CI_{CY\ Plant\ N}\right)\right]}{\widehat{EC}_{BY\ Plant\ 1} + \widehat{EC}_{BY\ Plant\ 2} + \cdots + \widehat{EC}_{BY\ Plant\ N}}$$

*When a plant that selects “use actual” as the calculation method is included in the roll-up, $EC_{BY\ Plant}$ should be used in place of $\widehat{EC}_{BY\ Plant}$.

Annual Improvement (Annual Change) in Energy Intensity for Current Year (%)

$$AI_{CY\ Corp} = CI_{CY\ Corp} - CI_{PY\ Corp}$$

Annual Savings (Total Energy Savings) since Baseline Year (MMBtu/year)

$$Annual\ Savings_{CY\ Corp} = Annual\ Savings_{CY\ Plant\ 1} + Annual\ Savings_{CY\ Plant\ 2} + \cdots + Annual\ Savings_{CY\ Plant\ N}$$

New Energy Savings for Current Year (MMBtu/year)

$$New\ Energy\ Savings_{CY\ Corp} = Annual\ Savings_{CY\ Corp} - Annual\ Savings_{PY\ Corp}$$

Least Squares Regression Analysis[i]

This section outlines the equations that are used for the regression analysis in the EnPI V3.0 tool. The tool uses a Microsoft Excel add-in to perform the regression analysis. The add-in uses the equations listed below to predict the energy consumption based on the independent variables entered by the user.

Regression analysis is a statistical method for predicting the behavior of a dependent variable based on the independent variables. The table below defines the symbols that will be used in the regression analysis equations outlined in this section.

Equation Symbols and Definitions

Symbol	Definition
y	Dependent variable predicted by the regression model (i.e. predicted energy use)
y*	Measured dependent variable (i.e. measured energy use)
p	Number of independent variables and coefficients
x_i (i=1, 2… p)	The ith independent variable from total set of p variables (i.e. production, HDD, CDD, etc.)
b_i (i=1, 2… p)	The ith coefficient corresponding to x_i
b_0	Intercept or constant
k=p+1	Total number of parameters including intercept
n	Number of observations
i=1, 2… p	Independent variables' index
j=1, 2..n	Data points index
R^2	Coefficient of determination
r	Residual (or error, or deviation)
SS_E	Residual (error) sum of squares (or regression sum of squares)
SS_R	Regression sum of squares
SS_T	Total sum of squares

For the EnPI V3.0 tool, the dependent variable is the energy consumption by the facility. The independent variables can be production, cooling degree days (CDD), heating degree days (HDD), etc. If the user selects more than one independent variable, a multivariable linear regression equation is needed to predict the dependent variable or energy consumption at the facility.

Regression analysis determines the formula that can be used to predict the dependent variable based on the independent variables. The general formula for a multiple linear model is:

$$y = b_0 + b_1x_1 + b_2x_2 + \dots b_px_p$$

In this formula, y is the predicted dependent variable. The measured dependent variable is depicted by the y*. The difference between the predicted and measured dependent variable is called the residual (also known as error or deviation).

$$r_j = y_j^* - y_j$$

The goal of regression analysis is to determine the coefficients ($b_{1, 2\ldots i}$) that result in a minimized error sum of squares. The error sum of squares (SSE) is calculated by:

$$SS_E = \sum_j^n (r_j - r_{avg})^2$$

Microsoft Excel calculates the error sum of squares (SS_E) for each combination of coefficients and determines the combination of coefficients that minimize the SS_E. The coefficients that result in the lowest error sum of squares are entered into the regression model to produce an equation that can be used to estimate the dependent variable given the independent variable(s).

Along with determining the model that best predicts the relationship between the independent and dependent variables, Microsoft Excel also calculates the coefficient of determination. The coefficient of determination (R^2) is a measure of how well future outcomes are likely to be predicted by the model. A regression model is a good fit for the data if the R^2 value is close to 1. In order to calculate the R^2 value, the regression sum of squares (SS_R) and the total sum of squares (SS_T) first need to be defined. The regression sum of squares is defined as:

$$SS_R = \sum_j^n (y_j - y*_{avg})^2$$

And the total sum of squares is calculated using the following equation:

$$SS_T = \sum_j^n (y*_j - y*_{avg})^2, \text{ where } y*_{avg} = \left(\sum_j^n y*_j\right)/n$$

The total sum of squares can also be defined:

$$SS_T = SS_E + SS_R$$

Now that the residual, regression, and total sum of squares have been defined, the coefficient of determination can be defined as:

$$R^2 = \frac{SS_R}{SS_T} = 1 - SS_E/SS_T$$

[i] Source: Cameron, Colin. "Excel 2007: Multiple Regression." *UC-Davis Economics*. University of California Davis Department of Economics, n.d. Web. 3 Oct 2012. <http://cameron.econ.ucdavis.edu/excel/ex61multipleregression.html>.