ENERGY STAR® Performance Ratings
Technical Methodology

This document provides technical details on the ENERGY STAR performance ratings for commercial buildings, including specifics on the statistical methodology employed. The document is structured as follows:

I. Overview

The national energy performance rating is a type of external benchmark that helps energy managers to assess how efficiently their buildings use energy, relative to similar buildings nationwide. The rating system's 1-100 scale allows everyone to quickly understand how a building is performing; a rating of 50 indicates average energy performance while a rating of 75 or better indicates top performance. Organizations can evaluate energy performance among their portfolio of buildings while also comparing performance with other similar buildings nationwide. Additionally, building owners and managers can use the performance ratings to help identify buildings that offer the best opportunity for improvement and recognition. The EPA rating system was originally released for Office Buildings in 1999. Since that time it has expanded to include the following space types:

Bank/Financial Institutions	Hotels	Retail Stores
Courthouses	K-12 Schools	Supermarkets
Dormitories	Medical Offices	Warehouses
Hospitals	Office	Wastewater Treatment Plants

EPA continually reviews its technical approach to the development of the rating system to ensure accurate, equitable, and statistically robust ratings. Because each building type has unique features that impact energy efficiency, EPA evaluates and as appropriate modifies the rating system separately for each building type. Nevertheless, certain underlying steps of the general methodology apply to the development of all ratings. The process to develop a rating includes the following elements:

- A nationally representative dataset is used. The US Department of Energy's Energy Information Administration conducts the Commercial Building Energy Consumption Survey (CBECS) every four years, which is the basis for most, but not all, rating models.
- Building energy performance is compared in terms of source energy consumption, which includes energy consumed at the site as well as energy used in generation and transmission. This is the most equitable approach for comparing properties that use different fuel mixes.
- A statistical regression analysis is completed on the reference data set to identify key drivers of energy consumption for each building type, which may include weather, hours of operation, number of workers, etc.
- The nationally representative dataset is used to determine the distribution of energy performance across the entire population of buildings. A table is created and the rating is based on the ratio of actual energy consumption to that predicted by the regression analysis. This allows EPA to express ratings such that 1 point equals one percent of the population.

Each of the elements in the development of EPA's energy performance rating system is discussed in more detail in the remainder of this document. Additionally, details on specific analytical results are included in individual documents for each space type.

II. Background

The EPA rating system was originally released for Office Buildings in 1999 and since then has expanded to include a variety of other building types. The rating system is now available for about 60% of the commercial building square footage across the US. EPA continuously reviews the rating system and updates it as new data and techniques become available. In response to newly available market data, EPA conducted a thorough review of all procedures between 2005 and 2007. In light of this review, EPA has modified the current methodologies.

The analysis described herein is completed separately for each type of building in order to provide accurate peer comparisons. As a result of the recent technical review, the rating procedures for each building type are being updated. The following models have been completed and published in Portfolio Manager using all of the procedures detailed herein:

- Office Buildings, Bank/Financial Institutions, and Courthouses
- Retail Stores
- Wastewater Treatment Plants

In addition, EPA continues to rate the following building types. Although EPA is in the process of updating these models with more recent data and methodologies, it must be emphasized that these existing approaches continue to provide statistically valid assessments of energy performance.

- Dormitories
- Hotels
- Hospitals
- K-12 Schools
- Medical Offices
- Supermarkets
- Warehouses

While this document contains the fundamental technical details of EPA's rating methodology, EPA creates and posts unique technical information to describe the details for each building type. This information includes the full list of operational characteristics examined, the final regression equation results, the final lookup table showing energy use for each rating level, and an example of how to rate a building.

III. Criteria for Energy Performance Ratings

In order for the energy performance rating to serve as a valuable management tool, it must provide an accurate and equitable assessment of a building's energy performance. To achieve these objectives, the ratings must meet the following criteria.

1. **Evaluate energy performance for the whole building**. Rather than examining specific pieces of equipment within a building, a whole building metric accounts for the

interactions among the various system components. For example, a particular HVAC system may be designed with efficient components, but if it is over-sized relative to the actual heating and cooling loads it will not perform efficiently. A robust analysis must account for energy use of the whole building.

2. **Reflect actual billed energy data.** The rating must reflect the actual billed energy consumption at a building. It cannot be based on predicted or simulated energy use, as simulations often fail to account for the impact of building operation and maintenance patterns.
3. **Normalize for Operation**. The rating cannot introduce bias with respect to the operating constraints at the building. The rating must normalize correctly for operational characteristics that define the building activity. These characteristics may include the required hours of operation or number of occupants.
4. **Provide a peer group comparison**. To provide a useful benchmark the rating must also provide a meaningful comparison to the building's peer group. A given building's peer group is defined by those buildings that have the same primary business function (e.g. retail store), and similar operating characteristics. In order to achieve this goal the rating must be based on an analysis of national data that accurately reflect the distribution of energy use for each building type.

IV. Reference Data

In order to meet all four of EPA's criteria, the rating system must rely on a statistically robust set of data. The data sample must be based on a nationally representative sample of buildings, it must collect and verify actual billed energy data at the whole building level, and it must collect information on key operational characteristics.

Approximately every four years, the US Department of Energy's Energy Information Administration collects this type of data through the Commercial Building Energy Consumption Survey (CBECS). The survey samples over 6,000 buildings across the United States, collecting complete billing data and operational details for a wide variety of commercial building types. More information on this survey, including complete data files, is available at: http://www.eia.doe.gov/emeu/cbecs/contents.html.

EPA uses the CBECS data as the basis for the majority of the rating models. However, in a couple of instances, EPA uses other data sources that provide more comprehensive data for a particular segment of the market. Please refer to the specific building type documents to learn what data set was used for each rating.

It is important to note that EPA always uses a statistically robust national dataset. The performance ratings *are not based* on information from other buildings in entered into Portfolio Manager

V. Source Energy and Site Energy

Buildings use a variety of forms of energy, including electricity, natural gas, fuel oil, and district steam. In order to provide an un-biased rating, the methodology must add together all of the energy used in a building. To combine energy in an equitable way, the ratings use *source energy*. Source energy is the energy that is consumed at the site in addition to the energy used in generation and transmission.

To understand why source energy is the most equitable approach, it is instructive to consider how a building uses energy. Useful energy in a building comes in the form of heat and electricity. Either heat or electricity may be generated at the building or by a utility. For example, a building may use natural gas to produce electricity on-site through a combined heat and power cycle, or a building may purchase electricity produced by a power plant. Similarly a natural gas boiler can be used on site to provide heat to a building, or a building can be heated using steam generated by a utility and distributed via a district system.

Heat and electricity are considered *secondary energy*, useful energy that is created from a raw source. The heat content of the original source is considered *primary energy*. Primary and secondary energy are not directly comparable because one represents a raw fuel while the other represents a converted fuel. Therefore, in order to provide a fair comparison, it is necessary to bring these two types of energy into equivalent units. EPA accomplishes this goal by converting to primary (or, source) energy. This conversion accounts for the total thermodynamic requirement at the building. More information on these conversions is available at: http://www.energystar.gov/index.cfm?c=evaluate_performance.bus_benchmark_comm_bldgs

VI. Normalization for Operating Parameters

To normalize for differences in building operation, EPA performs a statistical regression to identify the key drivers of energy use. This section outlines the basic statistical techniques employed.

Regression Analysis Overview

The primary analysis is based on a weighted ordinary least squares regression. This basic form of regression allows for analysis of a dependent variable (i.e. source energy use intensity), subject to various independent characteristics (e.g. operation and weather). This linear regression will yield an equation of the form:

$$\textit{Predicted Source Energy Use Intensity} = C_o + C_1 * \textit{Chararacteristic}_1 + C_2 * \textit{Characteristic}_2 + \ldots$$

Source energy use intensity is the dependent variable. C_o represents a constant, with the other C values representing equation coefficients. Each coefficient is a number that represents the correlation between the operating characteristic it describes and the building's source energy use intensity. For example, if $\textit{Characteristic}_1$ represents gross floor area, then the value of C_1 represents the statistical correlation between building floor area and source energy use intensity. This correlation approximates the average relationship between square foot and source energy

use intensity across the population, while simultaneously adjusting for all other characteristics in the equation.

For each space type with an energy performance rating, EPA performs a thorough set of linear regressions on the CBECS data to examine all of the operating characteristics that meet the criteria for inclusion as independent variables (outlined below). EPA evaluates these equations using multiple statistical tests including residual plots, model R^2, and individual coefficient significance levels. Ultimately, the best equation for each building type is selected. The regressions are performed using survey sample weights. The weights are used to account for the sampling survey design; each CBECS observation represents a different number of buildings in the national commercial building population.

The final equation must contain adjustments for operating characteristics that meet the EPA standards for inclusion in the analysis and are found to have statistically significant correlations with energy use. For a specific building, each characteristic is entered into the equation, and multiplied by the respective coefficients to yield predicted source energy use intensity. This predicted value represents the amount of energy the building is expected to use, based on its operating characteristics.

A variety of other econometric techniques were examined as alternatives to ordinary least squares regression. These included data envelopment analysis and stochastic frontier analysis. The technical review concluded that these techniques do not offer an advantage over ordinary least squares regression. Ordinary least squares regression provides a technically rigorous approach and yields descriptive linear equations that are statistically valid and easily replicable.

Finally, it is important to reiterate that the regression analysis is performed on the CBECS data set, which is a nationally representative source of energy data. The analysis is *not* performed on the buildings that have been entered in Portfolio Manager.

Data Filters

One of the first steps in the regression analysis is to apply data filters to the CBECS data. Filters are applied in order to define the peer group for the rating comparison, and overcome any technical limitations in the data. Specifically, EPA applies some or all of the following four filters.

1. *Building Type* – First, a filter is applied to select only buildings with the same basic operation (e.g. office) for the analysis.
2. *EPA Program Filters* – Second, some basic program filters are applied, to define the peer group of evaluation. For example, EPA requires that buildings must operate at least 30 hours per week. This basic filter is a threshold for full time operation, and is a requirement for obtaining a rating and applying for the ENERGY STAR.
3. *Data Limitation Filters* – Third, it may be necessary to apply one or more filters to the data due to limitations in the way information is reported. For example, in the CBECS data, the amount of chilled water consumed is not reported. Therefore, buildings with

chilled water consumption are excluded, because the thermal requirement associated with the chilled water cannot be assessed.

4. *Analytical Filter* – Finally, once regression analysis begins, additional analytical filters may be required to eliminate outlier data points. In this case, certain outlier points may have different behavior that cannot be assessed accurately with the rest of the data. For example, in the analysis of office buildings EPA found that small office buildings (i.e. smaller than 5,000 ft^2) do not behave the same way as larger office buildings, and therefore EPA excludes these buildings from the data set. When these types of filters are applied, the same thresholds are entered into Portfolio Manager as a prerequisite for earning a rating.

All data filters are selected according to these criteria. The specific filters associated with a given rating model will depend on the available data and analytical results. Refer to the specific building type documents for a list of filters applied in each analysis.

Dependent Variable

The dependent variable is the main unit of analysis. It is the term that appears on the left hand side of the regression equations. EPA regression models are structured to have the dependent variable be source energy use intensity (source EUI). Source EUI is equal to the total source energy divided by the gross floor area of the building. The regression equation explains the variation in source EUI associated with each of the independent variables.

Previous EPA rating models employed natural log of source energy (LN(source)) as the dependent variable. During the technical review that occurred between 2005 and 2007, the relative characteristics of source EUI and LN(source) were reviewed. It was found that regression formulations using LN(source) and source EUI produce equally robust and consistent predictions.

However, source EUI is more appealing because it provides a unit that is easier to understand. Ln(source) is a measure of total energy consumption, while source EUI is a measure of energy per square foot. Square foot is itself a very important predictor of total energy consumption. It is expected that a very large building will use more energy than a very small building. A source EUI regression answers the question: does the larger building use more energy per square foot? For this reason, a comparison of the source EUI between two buildings is more instructive than a comparison of LN(source) between two buildings. Source EUI provides a unit of energy use that is easier for buildings of different sizes to compute and compare.

Finally, it is important to note that LN(source) and source EUI are not expressed in the same units. Therefore results of statistical tests such as R^2 cannot be directly compared without conversions. For example, the R^2 in an LN(source) model characterizes the variance in LN(source) whereas the R^2 in a source EUI model characterizes the variance in source EUI. In order to compare the R^2 values it is necessary to re-express both R^2 values so that they characterize the variance in *source energy*. After applying these conversions, it is clear that both formats are equally rigorous. EPA has chosen source EUI as the dependent variable because it is a more straightforward unit.

Independent Variables

Independent variables appear on the right side of the regression equation. They are used to explain the dependent variable, source EUI. Independent variables are selected and analyzed in order to meet the criteria of normalizing for building operation.

Building Characteristics Included in the Analysis

An equitable rating accounts for differences in operation that define the building activity. For example, an emergency services building with 24-hour a day operation, should not be penalized for using more energy than a building that is only open 9 hours per day. This example reflects EPA's guiding philosophy used in determining which types of building characteristics to include in the analysis:

- Variables Included – These characteristics are factors that explain *how* a building operates. In other words, factors that describe the physical operation, such as: square foot, hours per week, number of occupants, number of computers, cash registers, or number of refrigeration units
- Variables Excluded – These characteristics are factors that explain *why* a building performs the way it does. Because these variables do not describe the physical characteristics of a building, they are excluded from the regression model. These can be broken into two categories:
    - Technology Factors – Factors that describe technologies that may contribute to overall performance are excluded because they are not physical constraints on the building operation. The type of lighting present (e.g. T-12 vs. T-8) is excluded from the analysis, because it is within control of the building owner/operator and does not define the building activity. Correct management and operation of a more efficient technology (e.g. T-8 lights) will result in lower energy consumption and a higher rating. By excluding technologies from the regression, buildings that install and properly manage efficient technologies should and will receive higher scores.
    - Market Conditions – Factors that may influence why a building performs the way it does such as energy prices. These factors do not define activity within a building and are external to a thermodynamic assessment.

Using this guiding philosophy, EPA examines the survey data for operating characteristics associated with each building type. Any operating characteristics that meet the criteria for inclusion in the analysis are assessed.

Weather Adjustments

Weather is a unique type of independent variable. Weather terms must be included in the regression in order to account for the differences in weather experienced throughout the country. There are numerous weather conditions that may influence energy use, including: average daily temperature, temperature maximum and minimum values, humidity, and cloud cover. This section explains how proper weather adjustments are achieved in the EPA ratings.

To preserve confidentiality, the CBECS data set does not reveal the exact location of each building. The most specific geographical division available is the census division (a total of 10

in the country). However, CBECS does provide for each building a value for Heating Degree Days (HDD) and Cooling Degree Days (CDD). HDD and CDD measure the deviation from a temperature of 65 degrees over the course of the year. For each day with an average temperature lower than 65 degrees, HDD is the difference between the average temperature and 65 degrees. The annual HDD is the sum of this difference across all days with an average temperature below 65 degrees. CDD is calculated in a similar manner, to measure deviations above 65 degrees.

HDD and CDD are common measures that reflect the heating and cooling requirement of a building, relative to the average temperature. These variables are included in the EPA regression analysis. By including these variables in the regression analysis, EPA can estimate adjustments to reflect the typical relationship between HDD and energy intensity and between CDD and energy intensity. In most rating models, HDD and CDD are determined to have statistically significant impacts on energy use. Therefore, they are included and adjusted for in EPA ratings.

EPA performed analysis to determine whether humidity effects require additional adjustment beyond HDD and CDD. Because measures of humidity and dew point are not available in CBECS, these analyses required estimations. Through a series of estimations and regressions, EPA determined that a separate relationship for humidity was not statistically significant. Although removing moisture from the air requires energy, this energy requirement cannot necessarily be isolated in a specific building. The regression analysis simultaneously adjusts for each independent variable. It was observed that dew point is highly correlated with CDD. Therefore, in a regression analysis distinct statistically significant correlations for *both* CDD *and* dew point cannot be obtained. This indicates that the impact of dew point is accounted for by the inclusion of CDD variables in the analysis.

Most of the numerous weather characteristics that may influence a building's operation are correlated with each other. It is not feasible in a statistical analysis to identify separate adjustments for each characteristic. EPA's analysis reveals that HDD and CDD are good indicators of the weather conditions. Statistical correlations for these variables successfully account for weather differences across the country. Therefore, these are the only weather variables included in the regression analysis.

Centering Technique

To build a regression, the independent variables can be entered in their actual reported form, or the values can be centered relative to the mean. Take an example building that is open for 60 hours per week, and assume that the average weekly hours of operation in the dataset are 40. If the variable is entered in the actual reported form, then the value 60 would be used to perform the regression; if the variable is centered relative to the mean, then the value 20 is used (60-40=20).

Under both centered and un-centered approaches, the coefficients in the regression equation are *mathematically identical.* The only term that changes is the intercept (C_o). When the centered variables are employed, the intercept is equal to the average value of Source EUI in the population. If a building has exactly the average value for each operating characteristic, then the centered value for each characteristic will be zero and the prediction from the equation will be equal to the intercept:

$$Predicted\ Source\ EUI = C_o + C_1 * CenteredChararacteristic_1 + C_2 * CenterdCharacteristic_2 + \ldots$$

The complete equation lends itself to the following interpretation: the predicted source EUI is the average (C_o) plus a series of adjustments based on how much the building's operating characteristics differ from the population mean. Again, the use of this format does not change the size of the adjustments, but it does yield a more straightforward regression interpretation.

The original EPA models employed un-centered independent variables. EPA determined during the review period of 2005 to 2007, that the centering approach is preferable due to its simple interpretation. All rating models released October 2007 or later use this approach. Because the coefficients themselves do not change, the decision to center does not impact an individual building's rating in any way.

VII. Peer Group Comparison

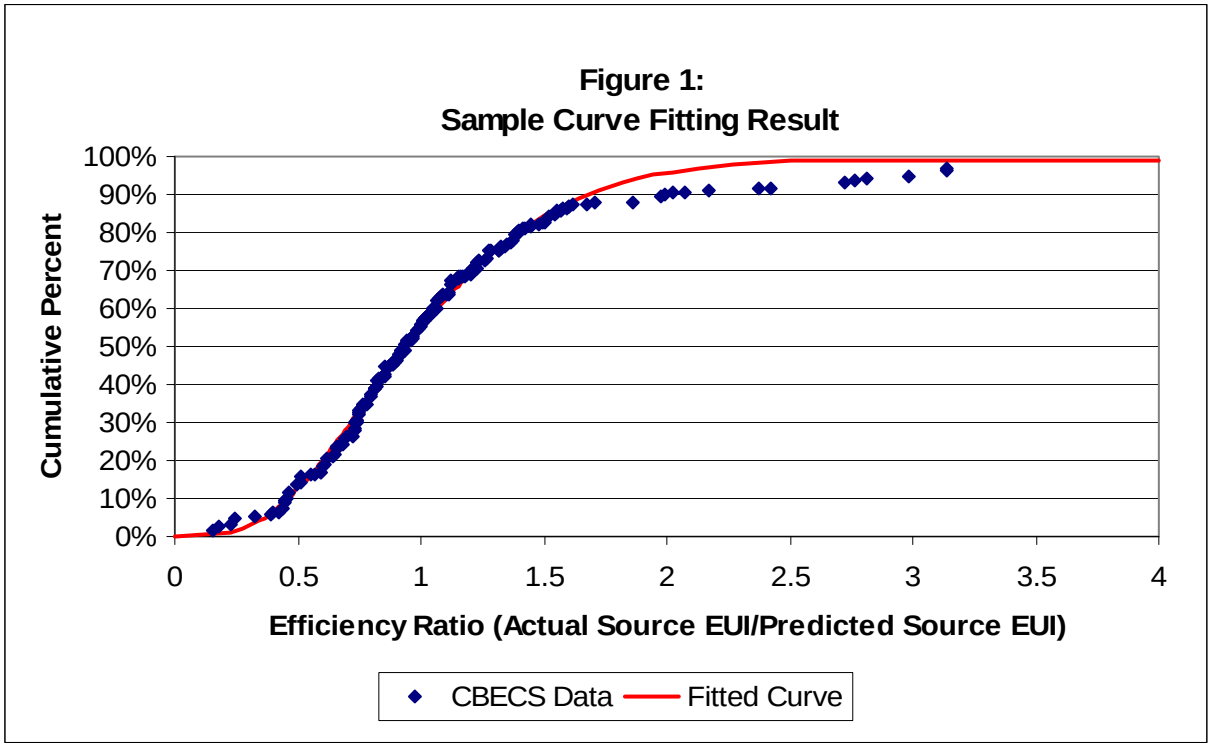
EPA's rating criteria also call for a valid peer group comparison. The peer group is defined as commercial buildings in the United States that have the same primary business function and similar operating characteristics. To achieve this objective, the information from the regression equation is used to describe the distribution of energy performance across the entire population. The regression equation answers the question: *how much energy do buildings use relative to their operation?* A second piece of analysis is required to answer the question: *how much energy do buildings use relative to each other?*

Distribution of Energy Performance

The regression equation yields a prediction of source EUI based on the building's operating constraints. Some buildings in the CBECS data sample will use more energy than predicted by the regression equation, while others will use less. The *actual* source EUI of each CBECS observation is divided by its *predicted* source EUI to calculate an energy efficiency ratio. Lower efficiency ratios indicate that the building uses less energy than predicted, and consequently is more efficient. Higher efficiency ratios indicate the opposite.

The efficiency ratios are sorted from smallest to largest. The best buildings may have ratios as low as 0.25, indicating that their source EUI is only 25% of the predicted source EUI. The worst buildings can use over 3 times as much energy as predicted, corresponding to ratios of 3.0. When the ratios are sorted from smallest to largest, the cumulative percent of the population at each ratio can be computed using the individual observation weights from the CBECS dataset. The weights are used because each CBECS observation represents a different number of buildings.

The percent of the population with a given efficiency ratio equals the weighted value for that observation divided by the sum of all weights. A plot is generated showing the cumulative percent of the population described at each ratio, working from smallest to largest. This plot shows the cumulative distribution of energy performance in the population. A sample plot is presented below, **Figure 1**.



ENERGY STAR Lookup Table

Ultimately, EPA expresses ratings on a scale of 1-to-100 such that 1 point equals one percent of the population. To do that, a smooth curve is fit to the cumulative distribution plot. The methodology for curve-fitting depends on the observed shape of the data. The routine seeks to minimize deviation from the data across the entire population, through a method such as minimizing the sum of square differences. Typically, EPA uses gamma distributions to fit the data. This routine yields a two-parameter gamma function describing a smooth curve through the data. The red line in **Figure 1** shows a typical curve-fitting result.

Once a smooth curve is fit to the data, it can be described by an equation. The curve's equation is used to compute the ratio for a given percent value. Through this equation the efficiency ratio can be calculated at each percentile (1 to 100) along the curve. EPA uses this calculation to create the ENERGY STAR lookup table, which lists the efficiency ratio associated with each percentile. Using the lookup table, the ratio of any building can be mapped to its ENERGY STAR performance rating. For example, the ratio on the gamma curve at 1% corresponds to a rating of 99; only 1% of the population has a ratio this small or smaller. The ratio on the gamma curve at the value of 25% will correspond to the ratio for a rating of 75; only 25% of the population has ratios this small or smaller. This ratio defines the threshold for the top quartile. Buildings that are in the top quartile may be eligible to apply for the ENERGY STAR. More information on the ENERGY STAR label and the application process is available at: http://www.energystar.gov/index.cfm?c=business.bus_bldgs.

VIII. Steps to Compute a Rating

All of the technical information described herein is built into EPA's Portfolio Manager tool. Anyone can open a Portfolio Manager account and enter, update, and manage data in a secure on-line environment. Complete information about Portfolio Manager and its features is available at: http://www.energystar.gov/benchmark. For many buildings in Portfolio Manager, a rating can be computed. These ratings are expressed on a scale of 1-to-100. The following details each step involved in computing a rating.

1. User enters building data into Portfolio Manager
    - Complete energy information includes all energy consumption at the building for a 12-month period.
    - The user must enter specific operational characteristic data. These characteristics are those included as independent variables in the EPA regression analysis.
    - Information on specific data entry requirements is available at: http://www.energystar.gov/index.cfm?c=eligibility.bus_portfoliomanager_eligibility.
2. Portfolio Manager computes the Actual Source Energy Use Intensity
    - Source EUI is computed from the metered energy data.
    - The total consumption for each energy meter entered by the user is converted into source energy using the source to site conversion factors.
    - Source EUI is the sum of source energy across all meters in the building divided by the gross floor area.
3. Portfolio Manager computes the Predicted Source Energy Intensity
    - Predicted Source EUI is computed using the regression equation for the specific building type.
    - For each operating characteristic entered by the user, the centered value is computed. The centered value is the difference between the user-entered value and the mean value in the CBECS population.
    - The terms in the regression equation are summed to yield a predicted source EUI.
    - The prediction reflects the expected energy use for the building, given its specific operational constraints.
4. Portfolio Manager computes the energy efficiency ratio
    - The energy efficiency ratio is:

      Actual Source EUI / Predicted Source EUI
    - The energy efficiency ratio expresses how much energy a building uses relative to its predicted energy use. A lower ratio indicates that a building uses less energy; while a higher ratio indicate the opposite.
5. Portfolio Manager looks up the efficiency ratio in the Lookup Table
    - The lookup table maps each energy efficiency ratio to a cumulative percent in the population.
    - The lookup table identifies whether the energy efficiency ratio for a building is bigger or smaller than the ratios of its peers.
    - The lookup table returns a rating on a scale of 1-to-100.
    - A rating of 75 indicates that the building performs better than 75% of its peers.
    - Buildings that earn a 75 or higher may be eligible to earn the ENERGY STAR.