ENERGY STAR® Portfolio Manager® Technical Reference

Climate and Weather

OVERVIEW

The climate of the area where your property is located and the annual fluctuations you experience in weather conditions can affect how much energy you need to operate your buildings. Portfolio Manager includes metrics designed to incorporate these effects and help you understand your energy performance. These procedures rely on temperature data collected by weather monitoring stations and published by the National Climatic Data Center (NCDC), which is part of the National Oceanic and Atmospheric Administration (NOAA). To discuss how we use this data, it is helpful to introduce two concepts:

- **Climate.** Refers to regional variations in average weather conditions. For example, Florida has a warmer climate than Maine.
- **Weather.** Refers to annual variations at a single location over time. For example, this year we had a very hot summer.

In Portfolio Manager, there are two key metrics that account for these effects:

- **Weather Normalized Energy.** Weather normalized energy is the energy your building would have used under average conditions (also referred to as climate normals). The weather in a given year may be much hotter or colder than your building's normal climate; weather normalized energy accounts for this difference. Note that the adjustment is for ***weather only, but not climate***. That is, the metric evaluates your building over time, but does not account for differences between your building and other locations that have different average (normal) climates. Weather normalized energy is not available for new building design projects because they have not yet experienced years with different weather.

- **ENERGY STAR Score.** The 1 - 100 ENERGY STAR score is a percentile ranking, which compares your building to its peers. The ENERGY STAR score accounts for ***both climate and weather***. To provide a score, a regression equation is used to predict the energy your building is expected to use given its climate, weather, and business activity. Buildings that use less energy than this prediction score better and vice versa. The regression equation used for your prediction is based on a national analysis that includes buildings in all locations with different climates. Because of this national representation, regression coefficients on terms like Cooling Degree Days (CDD) and Heating Degree Days (HDD) incorporate the differences among these climates. To predict energy for your building in any given year, we will incorporate your actual experienced weather data for that year. Your building is predicted to use more energy in a very hot year, for example. In the case of a new building design, the ENERGY STAR score will use the average normal climate conditions to compute the energy prediction, as no actual weather has been experienced.

This document explains where we obtain weather and climate data and how we incorporate it into metrics:

GETTING CLIMATE AND WEATHER DATA

Portfolio Manager uses two main types of data: Daily Weather Data and Average (Normal) Climate Data. The appropriate weather and climate data is selected for your buildings by using the latitude and longitude of your postal code.

Daily Weather Data

EPA obtains daily weather data for stations all around the world using the Global Surface Summary of the Day (GSOD) dataset.[1] This dataset provides daily temperature, precipitation, air pressure and wind speed observed for weather stations around the world. This data is used to compute key weather metrics used in Portfolio Manager, including the actual average monthly temperature, Heating Degree Days (HDD), and Cooling Degree Days (CDD).[2]

The GSOD set includes thousands of weather stations. In order to determine which stations to use, EPA went through a rigorous process to identify stations with complete data going back to at least the year 2000.[3] Based on this analysis, there are 778 stations used for the United States, 153 stations used for Canada, and 2,368 stations used for other countries around the world. ***Figures 1 and 2*** illustrate the locations of these stations, demonstrating the diverse coverage of weather data offered in Portfolio Manager.

Figure 1 – Weather Stations in the U.S. and Canada

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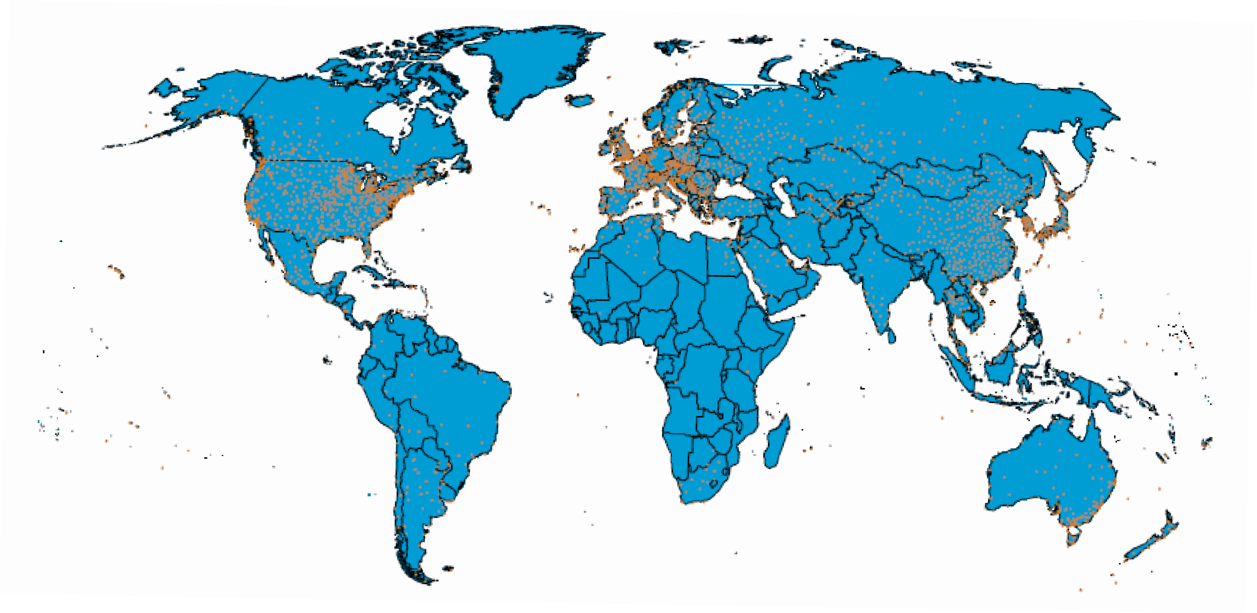
[1] To access the GSOD data from NOAA's ftp site, visit: http://www.ncdc.noaa.gov/cgi-bin/res40.pl?page=gsod.html.

[2] HDD and CDD measure the deviation from a temperature of 65 degrees Fahrenheit 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. Note that 65°F is equivalent to 18°C.

[3] The comprehensive review of GSOD data resulted in updates to weather stations in Portfolio Manager in July 2013. Annual review of weather stations is conducted to ensure continued data availability. In cases where stations no longer meet EPA's data availability requirements, an alternative station is assigned. Qualifying stations were most recently updated in August 2016.

Figure 2 – All Weather Stations in Portfolio Manager



Occasionally an individual station may be missing one or more days of data. When data is missing, EPA will fill in gaps by averaging the preceding and following days together. This process of averaging values together is consistent with how NCDC fills in gaps for their own datasets and analyses. In the case that an entire month is missing, EPA will use the climate normal value to fill in that month. If a weather station stops reporting data for a period of several months, then EPA will remove that station from our list and use a replacement station with accurate data.

NCDC updates the GSOD data on a regular basis as better information becomes available. To make sure data in Portfolio Manager is up-to-date, EPA reviews data regularly and will update historical data on an annual basis to accommodate any modifications and corrections from NCDC.

Average (Normal) Climate Data

The term "climate normals" is used to refer to average conditions within a certain climate region. Whereas daily weather data sets report actual measurements taken at individual stations, climate normal datasets are compiled based on a rigorous analysis of average trends. These datasets are generally reviewed and updated every 10 years. Because of these detailed procedures there are fewer sources of data, and many sources are country-specific. Portfolio Manager accesses three different sets of data for climate normals:

- **United States.** NCDC maintains a dataset of climate normals that is updated every 10 years. The most recent set expresses the average conditions experienced between 1981 and 2010 (http://www.ncdc.noaa.gov/oa/climate/normals/usnormals.html).
- **Canada.** Environment Canada maintains climate normals and updates this data over time. The most recent set expresses the average conditions experienced between 1981 and 2010. (http://climate.weather.gc.ca/climate_normals/index_e.html).
- **Other Countries.** The World Meteorological Organization publishes climate normals for other countries. However, this data does not include HDD and CDD, nor the daily data necessary to derive these fields. For this reason, it is not acceptable for Portfolio Manager. In its place EPA has computed 10-year climate normals from the GSOD daily data, using the average of reported data from 2001-2010.

Assigning a Weather Station to Your Property

In order to provide performance metrics to your specific building, we need to know which daily weather station and which climate normal to use:[4]

- **United States.** We use the latitude/longitude coordinates of the daily weather stations and the U.S. Zip Codes to determine which weather station is closest to each Zip code. This weather station is assigned to any properties located in that Zip code. In addition, based on the experience of ENERGY STAR partners benchmarking in coastal and mountainous regions with unique weather patterns, we have performed an additional manual review of some Zip codes to identify areas where the closest station may not provide a good representation of the weather. Fewer than 1.5% of Zip codes in the U.S. are mapped to a weather station other than the closest station.

- **Canada.** Geographic regions in Canada are identified by the first three digits of the postal code. The latitude/longitude of these postal code regions and the Canadian weather stations are used to determine which weather station is closest to each region. Through this process, the same weather station is assigned to all properties that have the same first three digits in their postal code.

- **Other Countries.** For other countries, Portfolio Manager does not include an up-to-date inventory of postal codes. When you are entering your property, you are able to select your own weather stations for use. A map is provided to help you identify the closest station, which you can then choose from a dropdown list.

WEATHER NORMALIZED ENERGY

Weather normalized energy is a means of adjusting for ***weather*** and should be used to compare a ***building to itself over time***. That is, the metric evaluates your building over time, but does not account for differences between your building and other locations that have different average (normal) climates.

How energy use varies with temperature

In order to normalize energy consumption for varying weather, we need to understand how energy use changes when it gets very hot or very cold. For most buildings, more energy is used at very extreme (hot or cold) temperatures. However, it is typical for commercial buildings to have a large baseload of energy that is used regardless of temperature. For example, energy associated with ventilation and with equipment such as lighting, computers, and copiers is not related to weather. ***Figure 3*** shows the typical variation between energy use and temperature for a commercial building.

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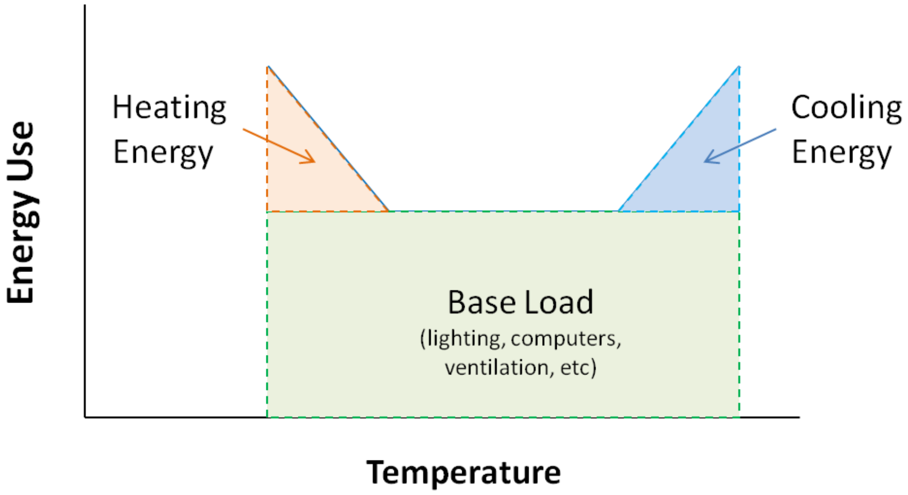
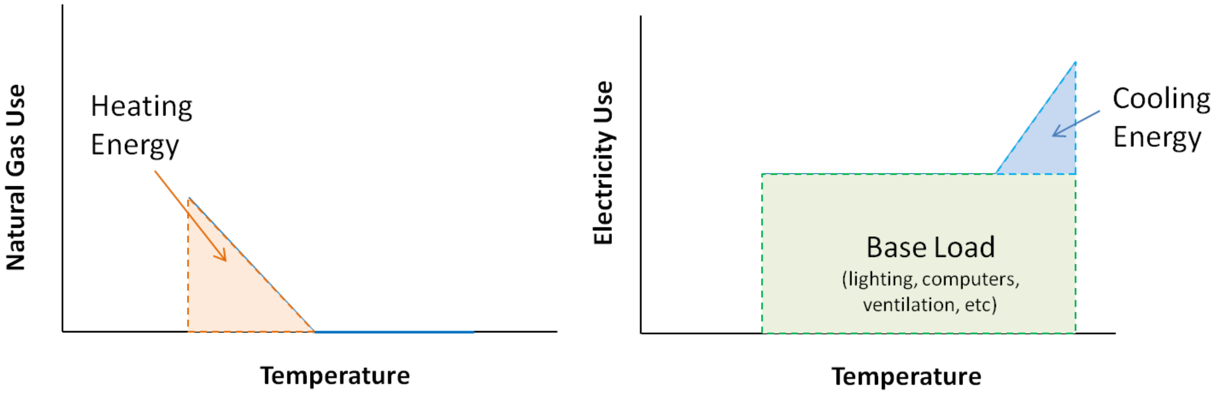
[4] The process of selecting weather stations with sufficient data and assigning them to properties in Portfolio Manager can be complicated, especially in certain geographic areas. In the event that a user submits a question regarding the weather station assignment for a specific property, EPA will review the request and consider alternative station assignment. Any station re-assignments will occur as part of a scheduled annual review.

Figure 3 – Typical Building Profile for Energy and Temperature



While energy may increase at higher and lower temperatures, there is a large amount of base load. For this reason, year-to-year weather changes in commercial buildings may not have as big of an effect as you might think. The purpose of weather normalization is to understand the energy to weather relationship in your building in order to make year-to-year comparisons. ***Figure 3*** shows the total energy use for an entire building, which may include multiple fuels. It is important to note that some fuels are not used for both heating and cooling. Plotting each fuel separately might look like ***Figure 4***.

Figure 4 – Example Energy Use by Fuel Type

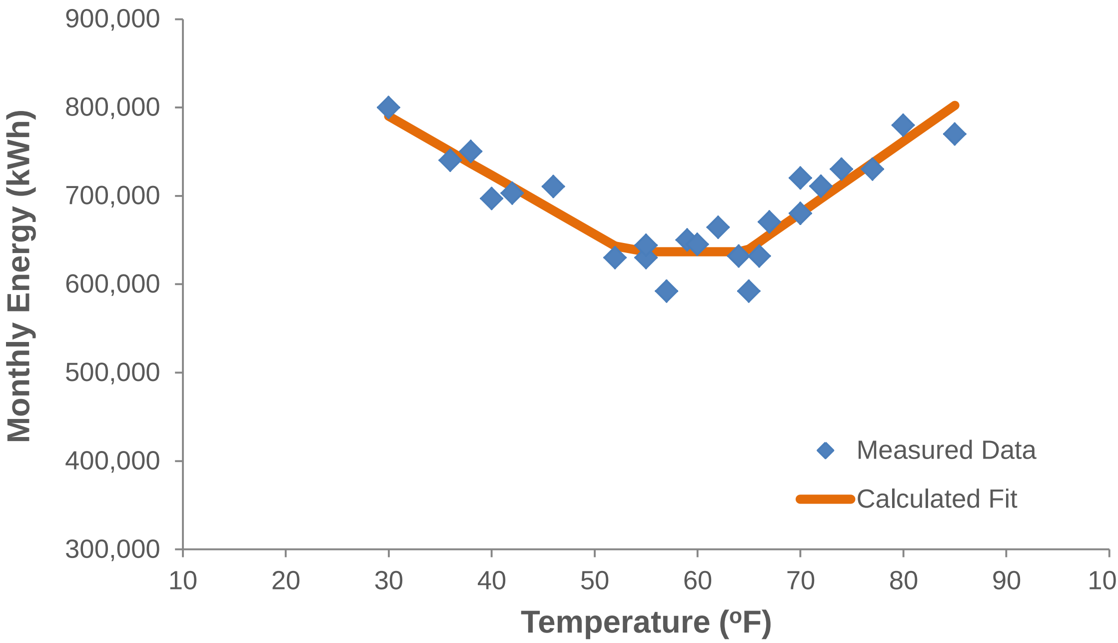


To account for the fact that different fuels will cover different loads in your building, the normalization process is performed separately for each fuel that is present (electricity, gas, district steam, etc.). The normalized values for each fuel are added together to get the normalized value for the property. Please note that the normalization process described below requires monthly data in order to determine the relationship between monthly energy consumption and monthly temperature. If you do not supply monthly data you will not be able to receive accurate normalization for that fuel.

Step-by-Step normalization process

To compute your weather normalized energy in Portfolio Manager, we plot the specific energy-temperature graph for your buildings. An example of this plot is shown in ***Figure 5***. We use this energy-temperature relationship to understand how much energy your building is expected to use in the current year as compared with a hypothetical year that has the average (normal) climate conditions. The relationship between these two values provides a normalization factor so that we can tell you how much energy you would have used under normal climate conditions. An overview of this process is presented in ***Figure 6***.

Figure 5 – Example Plot and Fit for 24 Months of Actual Energy and Weather Data



The methodology we use to weather normalize building energy data is based on E-Tracker, a software tool developed by Dr. Kelly Kissock of the University of Dayton. Information on this tool is available at: http://academic.udayton.edu/kissock/http/Weather/ (a copy of the tool may be downloaded for free for Educational or Non-Commercial uses). The initial code was updated by EPA in both 2007 and 2013 to streamline calculations, but conceptually the process has not changed.

Weather normalization is a calculation that is available for existing buildings only and does not apply to commercial building design. Inherently, the process of weather normalization requires information on actual experienced weather conditions, which are not available when a building is in the design phase.

Figure 6 – Steps to Normalize Energy for Weather

1 User Enters energy data into Portfolio Manager *(only step required by user)*

- Monthly bills in increments of 65 days or less are required for weather normalization because energy use is compared to monthly weather data. For this reason, it may not be available for fuels that are delivered in bulk.
- Normalization is based on the most recent 24 calendar months of data. If 24 calendar months of data are not available, the most recent 12 months are used.

2 Portfolio Manager splits energy data into whole calendar months

- Data is apportioned to calendar months based on the average energy use per day.
  For example, if a bill runs from January 10 through February 9, it covers 31 days: 22 in January and 9 in February. Of the total bill, 22/31 (71%) is assigned to January and 9/31 (29%) is assigned to February.

3 Portfolio Manager plots energy use and actual temperature for each fuel

- The ***actual*** temperature for each of the 24 calendar months is retrieved from the daily weather station.
- A plot is generated with energy on the vertical axis and temperature on the horizontal axis (***Figure 5***).
- Separate plots are created for each fuel type in the building.

4 Portfolio Manager calculates the relationships between energy and temperature

- For each individual fuel type, a series of linear regressions is performed to determine the equation of the best fit line for the building, based on the solution with the highest correlation (R^2).
- Different fits are explored to account for how a fuel is used in a particular building. A fuel may be used for heating, cooling, or a combination of heating and cooling. A fuel used for heating only is expected to have a graph that has a sloped line at cold temperatures and remains flat during warm temperatures. The opposite is true for cooling-only fuels. Fuels used for both heating and cooling will have opposite slopes at cold and warm temperatures. The regression process reviews all potential profiles and adjusts the “change” points where the curve shifts, in order to find the solution with the highest R^2.
- It is possible to have no calculated fit, meaning a building’s energy does not vary significantly as temperature changes. This may be true for buildings that use electricity for only the base load, buildings that have limited heating or cooling loads, or buildings with high internal loads like data centers and hospitals. EPA requires a minimum R^2 that varies based on the type of fit, ranging from 0.4 for simpler fits to 0.7 for more complex fits.

5 Portfolio Manager computes a normalization ratio for each fuel type

- For each fuel type, this is a ratio of the expected energy for the average (normal) climate year to the expected energy of the current year (12 month period selected).
- The expected energy values are computed using the relationship from Step 4, and solving for energy using the average (normal) climate temperatures and the actual daily temperatures, respectively. The expected values represent the energy a building would use if it exactly followed the regression equation.
  For example, if the current year is very hot, a building might be expected to use twice as much energy than under average (normal) climate conditions. The normalization ratio would be ½. The actual energy would be multiplied by ½ to determine what would have been used if it had not been so hot.

6 Portfolio Manager computes normalized energy

- The actual annual energy is multiplied by the normalization ratio to provide a weather normalized value for each individual fuel at the building.
- The weather normalized values of all fuel types are added together. This aggregate normalized value represents the energy the building would have used under average (normal) climate conditions.

Specific Example

Let us look at an example of how the process might work for a building with two fuels, as shown in ***Figure 7***. Based on the energy use and temperature values for the building, the relationships discovered in Step 4 of the process show that electricity is used for base load and cooling whereas the natural gas is used for heating only. Both of these relationships have strong fits with R^2 values of 0.85 and 0.90, respectively.

Using these relationships, two expected values are computed. The first is the expected value using the average (normal) climate temperatures; the second is the expected value using the actual daily temperature for the current year. The normalization ratio is the ratio of these two expected values. This shows, based on our fit, how much more (or less) energy we expect that the building should use in the current year relative to a hypothetical year with average (normal) climate conditions. Note that assuming a strong fit, the "expected value" of the current year should be very close the *actual* value in the current year (as shown in ***Figure 7***).

In this example, it must have been relatively hot in the summer and cold in the winter. We see this because the expected energy of the current year is higher than the expected energy in the average (normal) climate year. That is, the building had to use more energy because of the weather in the current year. For this reason, the weather normalized energy is ***lower*** than the actual energy. In an average year, the building would have used less.

For each fuel, the normalization ratio is multiplied by the actual annual energy consumption to yield weather normalized site energy. The individual normalized values for electricity and natural gas are separate metrics available in Portfolio Manager. In addition, aggregate weather normalized site energy for the building is obtained by adding together the normalized values for each individual fuel. Finally, weather normalized source energy for the building is obtained by multiplying the individual fuel-specific normalized values by their source energy factors.[5] You can learn more about source energy and the factors for both the U.S. and Canada at: www.energystar.gov/SourceEnergy.

Figure 7 – Example Calculation of Weather Normalized Energy

	Electricity	Natural Gas
Measured Values		
Annual Consumption (kBtu)	1,234,882	488,725
Aggregate Site Energy (kBtu)	1,723,607	
Aggregate Source Energy (kBtu)	4,390,691	
Weather Relationships		
Fit determined through regression process.	Energy for base load and cooling (R^2=0.85)	Energy for heating only (R^2 =0.90)
Normalization Ratio		
Expected Energy for a year with the Climate Normal Conditions (kBtu)	1,000,000	450,000
Expected Energy for the Current Year (kBtu)	1,200,000	475,000
Normalization Ratio	0.8333	0.9474
Normalized Energy		
Weather Normalized Site Energy (kBtu)	1,029,027	463,018
Aggregate Normalized Site Energy (kBtu)	1,492,045	
Aggregate Normalized Source Energy (kBtu)	3,717,314	

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[5] Source energy is the amount of raw fuel required to operate your building. In addition to what you use on-site, source energy includes losses from generation, transmission, and distribution of energy. Source energy enables the most complete and equitable energy assessment. Learn more at: www.energystar.gov/SourceEnergy. U.S. Factors for electricity (3.14) and natural gas (1.05) are used in this example.

ENERGY STAR SCORE

The ENERGY STAR score provides a peer group comparison that accounts for ***both weather and climate***. It should be used to compare your buildings with other buildings in your country (either the U.S. or Canada).

Calculation Overview

To compute your ENERGY STAR score, Portfolio Manager compares your actual, measured source energy use intensity (EUI) with a predicted source EUI. Those buildings that use less energy than predicted score relatively higher, and vice versa. A detailed description is available in our Technical Reference for the ENERGY STAR Score www.energystar.gov/ENERGYSTARScore. The predicted Source EUI is computed from a regression equation that is based on nationally representative data. This regression equation includes inputs for your use details (e.g., hours, workers, computers) along with inputs that capture weather and climate (e.g., HDD, CDD). For each of these inputs in the regression equation, your building's prediction is adjusted to account for the correlation between that input and EUI, when all other inputs are simultaneously considered.

- **Accounting for Climate.** Because the predictive equation is based on a nationally representative sample with buildings in locations all around the country (either the U.S. or Canada), the coefficients for HDD and CDD capture regional differences across the country and therefore account for the impact of the average (normal) climate in your area.

- **Accounting for Weather.** For any individual year when your prediction is computed, Portfolio Manager will use the actual experienced HDD and CDD for the daily weather stations closest to your building. Therefore, during a year with extremely hot and/or extremely cold temperatures your building will be predicted to use more energy. In this way, the ENERGY STAR score also accounts for weather effects from year to year.

When the ENERGY STAR score is computed for a design project, the average (normal) HDD and CDD values are used to generate the predicted score. This enables an adjustment for climate to help you during design stages. By definition, a design project has not experienced any actual weather conditions yet.

Value of HDD and CDD as Indicators of Climate and Weather

It is important to note that HDD and CDD are not the only ways to quantify climate and weather. There are other measures such as temperature, humidity, cloud cover, and precipitation. Many of these numerous weather characteristics are correlated with each other. For example, buildings with higher HDD tend to have lower CDD (i.e., colder climates). Similarly, buildings with higher CDD tend to have higher dew points (warmer, more humid climates). In general, a regression analysis will isolate the effect of one variable while simultaneously normalizing for the other variables. When two independent variables are highly correlated with each other, it is prudent to include only one of the two, because they end up capturing the same effect.

To explore the effects of humidity, EPA ran regression models that included HDD, CDD, and Dew Point. This analysis showed 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 as a statistically significant differentiator among buildings. 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 independent statistically significant correlations for both CDD and dew point cannot be obtained. This indicates that the impact of dew point can be accounted for by the inclusion of CDD.

EPA has also performed analysis to look at Average Temperature as an alternative (or addition) to HDD and CDD. It was not found that Average Temperature offered a separate (or superior) correlation with Source EUI than HDD and CDD on their own. Ultimately, we will typically use HDD and/or CDD as the primary indicators of weather conditions in the regression equations. Statistical correlations for these variables successfully account for weather differences across the country and additional terms for factors such as humidity are not shown to be effective.

Specific Example

Finally, it is helpful to consider how these calculations work in the context of an example building. ***Figure 8*** presents the calculation of the score in two office buildings. These buildings are the same size, with the same hours of operation and numbers of workers and PCs. These buildings are also experience the same number of HDD. Although HDD is the same, Building A is located somewhere with fewer CDD: 500 as compared with 1,500 at Building B.

Because Building B has higher CDD, it needs more energy to cool. This is reflected in ***both*** the predicted and the actual source EUI. That is, Building B is predicted to use more energy than Building A and it actually does use more energy. Ultimately, Building A and Building B earn the same score. This is because the prediction that is computed takes into account the higher cooling need at Building B. Because the prediction takes into account the actual experienced HDD and CDD for your buildings, buildings with all types of weather conditions are able to earn the same scores.

Figure 8 – Comparison of Two Buildings with Different CDD

	Building A (Low cooling load)	**Building B (High cooling load)**
Size	250,000	250,000
Hours	70	70
Workers	600	600
Computers	800	800
CDD	500	1,500
HDD	4,800	4,800
Predicted Source EUI	307.3	321.3
Actual Source EUI	270.4	282.8
Energy Efficiency Ratio	0.88	0.88
ENERGY STAR Score	**60**	**60**