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# Comparison of energy data for green-certified and non-certified buildings in the 2012 Commercial Buildings Energy Consumption Survey (CBECS)

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## ABSTRACT

This study uses energy intensity data from the 2012 Commercial Buildings Energy Consumption Survey (CBECS) dataset with validated information about whether the building was certified as ENERGY STAR or LEED to address the question, *Are green-certified buildings more efficient than non-certified buildings?* The 2012 CBECS introduced experimental questions regarding green building certification in response to the rise in popularity of the ENERGY STAR, LEED, and similar programs. A 2016 research study examined the quality of the self-reported responses to the green building certification questions by linking the 2012 CBECS buildings with validated lists of certified buildings. As the CBECS is a statistically representative sample of the U.S. commercial building stock, the record linkage process provided the first nationally representative dataset of validated green and non-green buildings.

The dataset with validated green certification status from the 2016 study was used to compare the energy use of large green office buildings with the energy use of similar non-green buildings. Tabulated summary intensities for green-certified and non-certified buildings were first compared. Then, three different statistical techniques—a multiple linear regression model, propensity score matching, and a regression tree—were used to control for building characteristics that may have an effect on energy intensity to see if the green and non-green buildings remain different with respect to energy intensity. All three methods showed a statistically significant difference, with less energy use in the green certified buildings than those that were not certified.

## Introduction

The Commercial Buildings Energy Consumption Survey (CBECS) is a national multistage probability sample survey of commercial buildings, for which the overall objective is to collect basic statistical information on energy-related characteristics and energy usage in the sampled buildings. The CBECS is the only national-level data source for this information. It has been conducted periodically since 1979 by the U.S. Energy Information Administration (EIA), which is the independent statistical agency within the U.S. Department of Energy (DOE). The most current survey data available are from the 2012 CBECS, which was the tenth iteration.

Between 2003 and the 2012, the previous two CBECS reference years, there was a dramatic increase in the number of certified green buildings in the United States. In 2003, fewer than 2,000 buildings had been certified under the U.S. EPA's ENERGY STAR program; by 2012 more than 20,000 had been certified. The U.S. Green Building Council's widespread LEED certification program shows similar growth, with less than 100 buildings in the U.S. certified by 2003 and more than 11,000 certified by 2012 (Michaels and Webb 2016).

In the years since these certification programs have become popular, a number of studies have been undertaken in an attempt to study whether or not green-certified buildings have lower energy usage than their non-certified, conventional counterparts. For instance, one study paired energy data from 100 LEED-certified buildings with *similar* CBECS buildings, based on characteristics such as activity, climate zone, age, and size. The results were mixed, showing that, on average, LEED buildings used 18-39% less energy per square foot than their conventional counterparts, but that 28-35% of LEED buildings used more energy than the individual counterpart (Newsham, Mancini, and Birt 2009). Another study used New York City office building data that had been made public through Local Law 84. It compared 21 LEED-certified buildings from the database with 953 non-LEED buildings and found that overall the LEED buildings did not use any less source energy, with the exception of the LEED Gold certification, for which buildings did exhibit lower energy use (Scofield 2013). Finally, another study used monthly utility electricity data from more than 175,000 commercial buildings in Los Angeles and matched buildings participating in DOE's Better Buildings Challenge, LEED, or ENERGY STAR to similar, non-participant buildings. The study used a few different sophisticated matching strategies with a large number of covariates. The results showed that energy savings for the participating buildings ranged from 18% to 30%, depending on the program (Asensio and Delmas 2017). While these studies have many merits, the conclusions have various limitations: definitional issues in matching program characteristics to CBECS, use of data that may not be standard or may not have been verified, usage limited to electricity, focus on one geographic region, and none of them are statistically representative of the U.S. population.

For the 2012 CBECS, EIA introduced questions about green building certification to the survey. In a 2016 study (Michaels and Webb 2016), the validity of these respondent-reported certification questions was examined by linking the respondent reported data to published lists of ENERGY STAR and LEED buildings. The study found that the survey responses did not have high validity. However, as a result of the record linkage process from that study, the true green certification status is known for every building in the 2012 CBECS. This new study takes advantage of the unique advantages of the CBECS—being a statistically representative sample of the entire U.S. commercial building stock with rigorously reviewed total energy data for each building *and* having a validated indication of green certification status—to compare the energy use intensity between green certified and non-certified (which will also be referred to as *non-green)* buildings.

# Data and Methods

## Overview of the 2012 CBECS green building certification questions and validation effort

The 2012 CBECS data collection resulted in 6,720 completed building cases. The 2012 iteration was the first CBECS to include questions about green building certification. These questions were introduced following discussions with program managers for EPA ENERGY STAR and with building technology experts in DOE's Office of Energy Efficiency and Renewable Energy. The intent was to allow tracking of market penetration of certified green buildings and analysis of the characteristics and energy use of certified and non-certified buildings.

The first question asked: *In the past 3 years, has this building been certified as a "green building," such as ENERGY STAR, LEED, or Green Globes?* Respondents who selected *Yes* were then asked: *Which type of certification did the building receive? Was it ENERGY STAR, LEED, Green Globes, or did it receive some other green building recognition?* and were directed to select all certification types that applied to their building. Overall, ENERGY STAR certification, either alone or in combination with another type of certification, was the most frequent certification type selected (reported by 4% of sampled buildings), followed by LEED (2%).

Because these questions were new to the CBECS, a project was undertaken to validate the responses. CBECS responses were linked with records in publicly accessible ENERGY STAR and LEED directories, using a two-step automated and manual matching process. The Green Globes directory was not downloadable so it would not have been feasible to check for false responses. The responses of *other* type of certification ranged widely in type and specificity so they were also not validated.

The results showed that more than 20% of respondents in certified buildings did not know that their building was certified, and roughly 40% of respondents who said that their building was certified were incorrect, with variation by certification type (Michaels and Webb 2016). The CBECS data file was augmented with indicator variables for ENERGY STAR and LEED certification (from 2009 to 2012 to match the *in the past 3 years* stipulation of the CBECS question) as verified from the directories, and these variables were used for the analysis that is the subject of the rest of this discussion.

## Validated green certified buildings in the CBECS dataset

After the validation effort, there were 266 buildings in the CBECS dataset with ENERGY STAR or LEED certification[1]. The green-certified buildings were predominantly large and predominantly offices. A comparison of the sample size by building size category and building activity for the green-certified and non-certified buildings is shown in Table 1.

According to EPA's Data Trends (EPA 2013), the majority of ENERGY STAR certified buildings are offices (34% of certifications) and education buildings (32%). Large office buildings were chosen as the focus of this analysis because of their prevalence in the green-certified subset of CBECS data. Among the 138 large green-certified office buildings, 78 were certified only as ENERGY STAR, 18 were only LEED, and 42

[1] 158 buildings were certified ENERGY STAR only, 62 were LEED only, and 46 were both ENERGY STAR and LEED certified.

were both ENERGY STAR and LEED certified. Unfortunately the CBECS sample size for green-certified education buildings (n=36) would not permit a precise enough analysis.

**Table 1. Sample counts by building size and activity**

| | Number of green-certified buildings in CBECS sample | Number of non-certified buildings in CBECS sample |
|---|---|---|
| All buildings | 266 | 6,454 |
| Building floorspace (square feet) | | |
| 1,001 to 10,000 | 7 | 2,607 |
| 10,001 to 100,000 | 44 | 2,252 |
| Over 100,000 | 215 | 1,595 |
| Principal building activity | | |
| Office | 147 | 1,209 |
| Education | 36 | 719 |
| Inpatient health care | 30 | 379 |
| Retail/Mall | 15 | 684 |
| Public assembly | 13 | 401 |
| All others | 25 | 3,062 |
| Large (over 100,000 square feet) office buildings | 138 | 259 |

## Analysis methods

The validated green certification status of the large office buildings from the nationally representative CBECS sample invites the follow-up question *do green certified buildings use energy differently than non-green buildings?* To address this question, the validated green buildings dataset was first used to compare the average energy use intensity (EUI), which is defined as the sum of site major fuel consumption[2] (thousand Btu) per square foot, in the green large office buildings to the average of the non-green buildings. The difference was checked for statistical significance.

Many building characteristics can affect a building's EUI and some of these characteristics are systematically different in the green and non-green buildings. For example, on average, the green certified buildings are newer, have fewer hours of operation, have less heating degree days, and have more cooling degree days than the non-green buildings. Therefore, a more extensive analysis was performed to determine if there is still a difference in EUI in the green and non-green buildings while accounting for these factors. Three different statistical techniques were used in the analysis: multiple linear regression, propensity score matching, and a regression tree. Each is described below.

[2] Major fuel consumption is defined as the sum of all electricity, natural gas, district steam, and district hot water used in the building, measured in thousand Btu.

In the first method, a multiple linear regression model was used to assess the effect of the green certification status on the building-level EUI, while controlling for other building characteristics that may also have an effect on EUI. If the green certified buildings are, for example, newer on average than non-green buildings, it is possible that the age of the building is driving the difference in EUI. The linear regression controls for these characteristics and determines if the certification variable is still a significant predictor of EUI, and how strong the relationship is.

The log of EUI was the dependent variable in the regression model. Log transformations are often used in linear regressions when the distribution is right skewed (Neter, Wasserman, and Kutner 1989), which is the case with the EUI values in the large office buildings in the dataset. The green certification status was included as an independent variable, along with the following building characteristics from the CBECS: the year the building was constructed, number of workers per thousand square feet, weekly hours of operation, cooling degree days (CDD), percent occupancy, and the percent of the building that was a datacenter[3]. The parameter estimates and significance of each of these variables were examined.

The second statistical method used was propensity score matching. This technique matched each green certified large office building to a comparable non-green office building using nearest neighbor matching. The goal of propensity score matching is to reduce bias due to confounding variables. For example, the green certified buildings may be newer on average, or more concentrated in certain geographic regions compared to non-green buildings. The matching technique pairs each green certified building to its most similar counterpart in the non-green group using observed building characteristics so that the groups can be compared without the presence (or reduced presence) of selection bias.

The first step in the propensity score matching analysis was to perform a logistic regression with green certification status as the binary dependent variable. The predictor variables are building characteristics potentially related to the likelihood of green certification status that may also have an effect on EUI: year of construction, number of workers per thousand square feet, number of computers per thousand square feet, CDD, HDD, hours of operation, percent occupancy, percent cooled, and percent data center. The logistic regression model produces a predicted probability (also known as a *propensity score*) of being green certified based on the values of the characteristics in the model. Then each certified building was matched to a non-certified building using nearest neighbor matching. The MatchIt package in R was used to perform the matching (Ho, Imai, King, and Stuart 2011). A paired t-test was then performed to assess the difference in EUI in this matched set of green and non-green buildings.

In the final method, a regression tree was used to predict the value of a building's EUI value based on its building characteristics. Regression trees, also called decision trees, use recursive partitioning to classify data by splitting it into groups based on the values of independent variables. Unlike linear regression models, regression trees are nonparametric and do not rely on underlying assumptions about the data structure. The results are presented in a tree-like graphic that show which independent variables are

[3] Initially the following variables were also considered in the modeling process: heating degree days (HDD), number of computers per square foot, percent of the building was heated, and percent of the building was cooled. These were correlated with other variables in the model (for example, the number of computers per square foot is highly correlated with the number of workers per square foot, and the percent the building is heated is highly correlated with the percent occupancy) so these variables were removed to avoid multicollinearity.

most predictive of the dependent variable, and how their values are related to those of the dependent variable. The methodology for constructing the regression tree in this paper is described in Hothorn, Hornik, and Zeileis 2006 and the Partykit package in R was used to create the tree (Hothorn and Zeileis 2015).

The tree was constructed with EUI as the dependent variable, and the following building characteristics as independent variables: green certification indicator, year of construction, number of workers per thousand square feet, number of computers per thousand square feet, CDD, HDD, hours of operation, percent occupancy, percent cooled, and percent data center. The goal is to see which of these characteristics, particularly the green certification indicator, show up in the regression tree and in what order.

# Results

## Comparison of overall kBtu per square foot

The mean EUI estimates and their relative standard errors (RSEs)[4] for the green certified and non-green office buildings larger than 100,000 square feet are shown below in Table 2. The mean EUI estimates are 66.8 kBtu and 110.7 kBtu for the green certified and non-green buildings, respectively. The non-green buildings use an average of 43.9 kBtu per square foot more than the green buildings, a statistically significant difference. This is a simple difference of means, not controlling for any variations from building characteristics variables.

[4] Relative standard error is a measure of sampling error, calculated as the standard error divided by the estimate, multiplied by 100.

**Table 2. Mean EUI in office buildings > 100,000 square feet**

| Green certified | | Non-green | | Difference (non-green - green) | |
|---|---|---|---|---|---|
| Mean EUI (kBtu per square foot) | RSE | Mean EUI (kBtu per square foot) | RSE | Mean EUI (kBtu per square foot) | Significant at .05 level |
| 66.8 | 3.7 | 110.7 | 15.6 | 43.9 | Yes |

## Regression model results

The estimated regression coefficients from the multiple linear regression model are shown below in Table 3. The green certification variable is significant ($p < .05$) with a parameter estimate of -0.295. This means that green certified buildings have $e^{-.295} = .745$ of the EUI than non-green buildings on average (in other words, green certified buildings use about 25% less energy per square foot), controlling for all other variables in the model. Cooling degree days and workers per thousand square feet are also statistically significant predictors of EUI in this model at the 0.1 level, however the green certification status is the most statistically significant predictor, as indicated by having the smallest p-value.

**Table 3. Estimated regression coefficients from multiple linear regression model of large office buildings with log (EUI) as independent variable**

| Estimated Regression Coefficients | | | | | |
|---|---|---|---|---|---|
| Parameter | Estimate | Standardized Estimate | Standard Error | t Value | Pr > \|t\| |
| Intercept | 2.078 | 0.000 | 2.822 | 0.740 | 0.463 |
| Valid green certification | -0.295** | -0.210 | 0.096 | -3.070 | 0.003 |
| Year constructed | 0.001 | 0.040 | 0.001 | 0.580 | 0.566 |
| Workers per thousand square feet | 0.085* | 0.191 | 0.048 | 1.770 | 0.078 |
| Hours of operation | 0.004 | 0.270 | 0.003 | 1.360 | 0.174 |
| Cooling degree days (hundred) | -0.009** | -0.132 | 0.003 | -2.530 | 0.012 |
| Percent occupancy | 0.005 | 0.134 | 0.004 | 1.550 | 0.124 |
| Percent data center | 0.010 | 0.052 | 0.015 | 0.640 | 0.521 |

* Significant at p < .1

** Significant at p < .05

## Propensity score matching analysis results

Each of the 138 green certified buildings were matched to their closest 138 non-green certified counterparts using propensity score nearest neighbor matching (the remaining 121 non-green buildings that were not matched are discarded for this analysis). The diagnostics of the matched cases are presented to verify that the variables are balanced in the green certified and non-green certified buildings. Table 4 shows the mean values of characteristics before and after matching. Prior to matching, on average the green buildings were 11 years newer, had 253 fewer heating degree days and 189 more cooling degree days, and were open 12 fewer hours per week than the non-green buildings (the other characteristics were very similar). After matching, these differences were considerably reduced, suggesting the matching was reasonably successful.

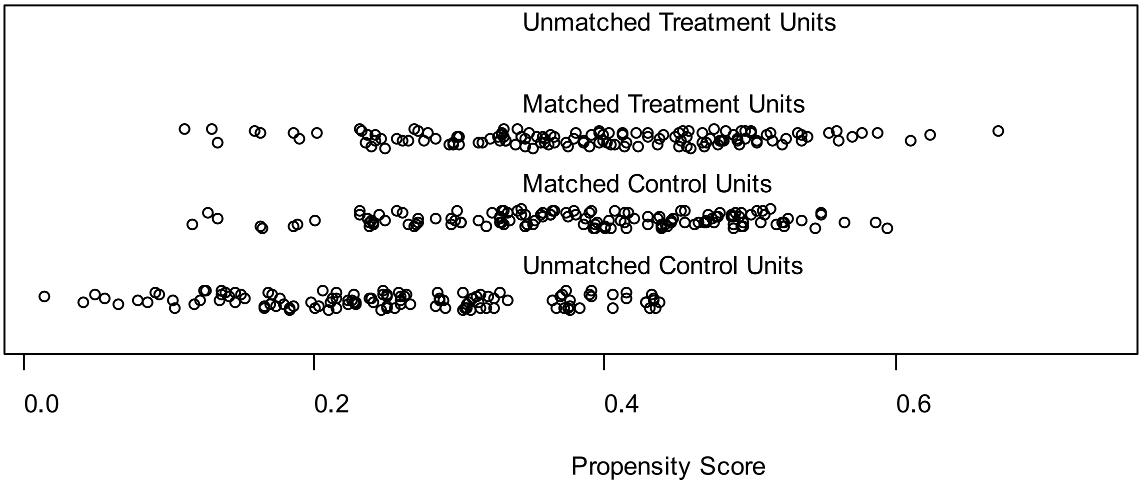
Figure 1 shows the distribution of the propensity scores of the matched treatment units (the 138 green certified buildings) and the control units (the 138 non-green buildings in the match), along with the unmatched control units (the 121 non-green buildings that were not matched to any green buildings)[5]. The distributions of the matched treatment and control units are similar, again indicating that the matching was effective.

### Table 4. Mean values of characteristics before and after matching

| | Unmatched data means | | | Matched data means | | |
|---|---|---|---|---|---|---|
| **Variable** | **Green certified** | **Non-green** | **Difference** | **Green certified** | **Non-green** | **Difference** |
| Year constructed | 1982.9 | 1971.8 | 11.1 | 1982.9 | 1983.3 | -0.5 |
| Percent data center | 0.9 | 1.3 | -0.4 | 0.9 | 0.8 | 0.1 |
| Workers per thousand square feet | 2.4 | 2.3 | 0.1 | 2.4 | 2.4 | 0.0 |
| Computers per thousand square feet | 2.3 | 2.2 | 0.1 | 2.3 | 2.3 | 0.0 |
| Heating degree days | 3445.2 | 3698.5 | -253.3 | 3445.2 | 3493.1 | -47.9 |
| Cooling degree days | 1724.3 | 1535.8 | 188.5 | 1724.3 | 1698.3 | 25.9 |
| Hours of operation | 72.1 | 83.8 | -11.7 | 72.1 | 75.5 | -3.4 |
| Percent occupancy | 88.1 | 87.2 | 0.9 | 88.1 | 86.6 | 1.4 |
| Percent cooled | 90.8 | 91.4 | -0.5 | 90.8 | 91.5 | -0.6 |

[5] There were no unmatched treatment units, shown by the absence of data points in the first graph.

**Figure 1. Distribution of propensity scores of treatment and control units**




In comparing the mean EUIs in the green certified buildings with their matched counterparts, the green certified buildings had an average of 68.4 kBtu per square foot versus 91.5 kBtu per square foot in the non-green buildings, a difference of 23.1 kBtu per square foot. The paired t-test shows that the difference is statistically significant ($p < .0001$). The results are shown in Table 5.

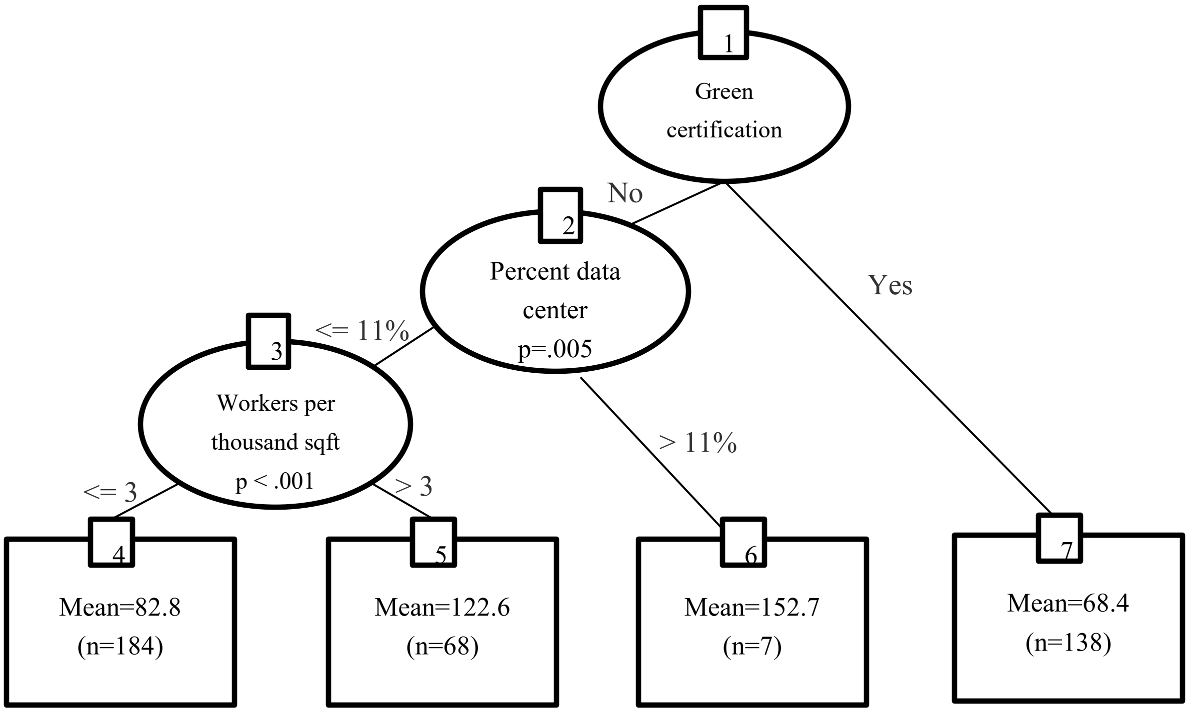
**Table 5. Difference in EUIs for green and non-certified matched buildings**

| **Mean EUI** | | | | |
|---|---|---|---|---|
| **Green** | **Non-green** | **Mean difference** | **t Value** | **Pr > \|t\|** |
| 68.4 | 91.5 | 23.1 | 4.0 | 0.0001 |

## Decision tree results

The decision tree with EUI as the dependent variable is shown below in Figure 2. The first split of the tree is the green certification variable, indicating that this variable is the most statistically significant predictor of EUI. If the building is green certified, there are no further splits and the average EUI is 68.4 (node 7). If it is not green certified, the next split is the percentage of the building that is a data center. If the building has a data center that is more than 11% of the floorspace, there are no further splits and the mean EUI is 152.7 (node 6). If the data center floorspace is 11% or less, there is an additional split on workers per thousand square feet. If workers per thousand square feet is more than 3, the mean EUI is 122.6 (node 5); if it is 3 or less, the mean EUI is 82.8 (node 4).

Figure 2. Decision tree results




# Discussion and Conclusion

This study presented a comparison of green certified (ENERGY STAR and LEED) and non-green office buildings larger than100,000 square feet on a national level from buildings selected in the 2012 CBECS, a statistically representative sample survey. In a comparison of the mean EUI of all green certified buildings with the mean EUI of all non-green buildings, the green buildings use 43.9 less kBtu per square foot than the non-green buildings, a statistically significant difference. Beyond the simple comparison, three different statistical techniques were used to assess if there was a difference in EUI between the two building types, controlling for other building characteristics.

The multiple linear regression model with EUI as the dependent variable showed that controlling for other building characteristics that have an effect on EUI, the green certification status was a statistically significant predictor, with green buildings using 25% less kBtu per square foot than non-green buildings.

A different approach, a propensity score matching technique, was used to match each green building to its closest non-green counterpart based on building characteristics such as building age, heating and cooling degree days, and percent occupancy. The matching was successful in reducing differences in means in characteristics. When the means of the matched data were compared, the green buildings had 23.1 less kBtu per square foot than their non-green equivalents, a statistically significant difference.

Finally, a nonparametric regression tree using recursive partitioning was created, with EUI as the dependent variable, and building characteristics, including green certification status, as the predictor variables. Green certification status was the first and strongest split; the green buildings had no further splits and the non-green buildings were split again by percent data center floorspace and workers per thousand square feet. The green certified buildings were in the terminal tree node with the least kBtu per square foot, 68.4.

Each statistical technique approached the question, *are green buildings more efficient than non-green buildings?* differently. The statistical conclusion was the same for each: accounting for other building characteristics, the data analyses suggest that green buildings use less total energy per square foot than non-green buildings.

## Limitations and future research

The conclusions of this study are limited to a specific building size and type—office buildings larger than 100,000 square feet. This is due to the small number of green certified buildings in other building types and sizes of the 2012 CBECS sample, which prevented meaningful data analysis. It is possible that different building types might yield different results. Furthermore, CBECS collects a limited number of building characteristics. There may be other characteristics not collected in CBECS that could be driving the difference in EUI.

The CBECS uses a statistical sample to estimate characteristics and consumption of the national commercial building stock instead of collecting data on all buildings, which would be prohibitively expensive. As such, there is sampling error and potentially non-sampling error that are common in every survey. There is a small but non-zero chance that a different sample would yield different statistical conclusions.

Finally, these results do not lend any insight into causality; that is, does becoming a *green* building lead to reduction in energy use, or is it simply that the more energy-efficient buildings are the ones for which certification is sought? The act alone of placing a label on a building certainly does not decrease the energy use, but how much of a motivating factor is the reward of a label? Does the possibility of a green label encourage building owners, managers, and perhaps occupants, to undertake improvements or change their energy-related behavior? If a building is planning for renovations, will energy efficiency be more of a consideration if certification is one of the goals? Perhaps future studies may serve to answer these questions.

Due to the low validity of the respondent reported data on green certification status, the next CBECS (reference year 2018) will not include the green certification questions. However the record matching with published lists can be done again to assign the green building certification status. Therefore this analysis could be performed again with the 2018 CBECS data. The sample size for the 2018 CBECS is planned to be larger than the 2012 and there is some promise that this analysis can be done on other building types, such as schools, if the sample yields enough green buildings. There are no plans to oversample green buildings to perform the analysis.

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