Revised Report

Assessment of Efficiency Ratings of the CBSA Buildings Using EPA's ENERGY STAR® Portfolio Manager

Revised July 25, 2009

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1. Introduction

In January 2008, The Cadmus Group's Energy Services Group (formerly Quantec, LLC)[1] was retained by the Northwest Energy Efficiency Alliance (NEEA) to update the Northwest Commercial Building Stock Assessment (CBSA) database. The project is funded jointly by NEEA, the Bonneville Power Administration and two regional utilities.

An initial CBSA study, completed in 2003, was a first-of-its-kind effort to characterize the physical and energy-use characteristics of commercial facilities in the Pacific Northwest by integrating and updating information from several previous regional data collection efforts. That study's resulting database has served as a resource for regional energy planners and researchers, thus facilitating energy efficiency initiatives in the region. The database includes about 1,165 commercial facilities, representing three cohorts (pre-1987, 1988 to 1994, and 1995–2001).

The work undertaken by Cadmus has sought to augment the original CBSA sample and update the database information through 2005, thus supplying new information necessary for various regional planning and policy development initiatives, including preparation of the Northwest's 6th Regional Power Plan by the Northwest Power and Conservation Council.

The recent CBSA update has relied on various data collection methods, including scheduled technical audits and unscheduled "walk-in" surveys to collect information for each facility on structural characteristics, fuel use, energy system and equipment saturations, operating characteristics and monthly consumption histories. The data collection phase is now complete. The final database, to become available in October 2009, is expected to include information, with varying degrees of quality, for approximately 2,000 facilities in the Northwest. We note, however, that the monthly consumption data are not consistent across the database. For some buildings, for example, the annual data come from 2002; for others, the annual data come from subsequent annual periods, up to 2007.

In October 2008, the Energy Trust of Oregon (ETO) and the NEEA asked the Energy Services Group to use the U.S. Environmental Protection Agency's (EPA's) energy performance rating system in Portfolio Manager to analyze the energy performance of a sample of 400 to 500 facilities in the CBSA database. We selected buildings with adequate data in four market segments (offices, schools, warehouses and retail) and compared their ratings with those of similar buildings in the country. We then developed and analyzed the distribution of ratings for the four building market segments in the CBSA sample. The principal goal of this analysis was to "provide regional policymakers with an understanding of the applicability of Portfolio Manager to commercial buildings in the Northwest." Secondarily, ETO and NEEA were interested from a policy perspective in knowing whether incentives (resources) could be allocated in a fair manner using the EPA rating as a decision rule where hydropower (or non-carbon based fuels) is used as a major energy source.

[1] Quantec LLC was acquired by The Cadmus Group in May 2008.

The results of that study were summarized in a report delivered to ETO on March 13, 2009. Subsequently, comments were received from a number of internal and external sources, including substantive comments from EPA on April 24. The comments focused on three areas: data quality, analytical methods used, and conclusions drawn. Given the substantive nature of certain comments, we proposed to the ETO (and they accepted) that we be allowed to re-issue a revised report, instead of addressing the comments in a separate document. This document constitutes the revised report in which the report authors have sought to address all comments and make revisions where warranted.

2. Description of EPA's Portfolio Manager

Portfolio Manger (PM) is an online energy management tool for establishing baseline energy usage and for tracking energy performance of commercial buildings, including mid- to high-rise residential buildings, over time. By generating a Statement of Energy Performance (SEP) for each building with a PM account, users can summarize energy information and building characteristics such as site and source energy intensity, CO_2 emissions, gross floor area, and operating characteristics, such as number of personal computers.

For eligible commercial buildings—including bank/financial institutions, courthouses, hospitals, hotels, K-12 schools, medical offices, municipal wastewater treatment plants, offices, residence halls/dormitories, retail stores, supermarkets, and warehouses—the tool also calculates an energy performance rating on a scale of 1-100, called the EPA rating. The rating is available for about 60 percent of the commercial building square footage in the United States. The focus of this paper is the EPA rating, so a discussion of other metrics and features is only partially covered.

To obtain an EPA rating, users submit the building location (zip code is critical for weather normalization), building operating characteristics, and about one year of complete, interval energy consumption data (from actual bills). PM returns a rating between 1 and 100, indicating how energy efficient the building is relative to buildings of the same type. A higher rating indicates greater relative energy efficiency.[2] A rating of 75, for example, indicates the building is more energy efficient than 75% of buildings of the same type nationally. The tool also tracks data from water and wastewater utilities, but these are not used in the calculation of the EPA rating.

The basis of the rating is the *Energy Efficiency Ratio* (EER), which is a building's annual source energy use intensity (EUI), divided by its predicted annual source energy use intensity. This ratio shows how much energy the building actually consumes (per square foot (ft^2) of building space) relative to the expected consumption of a building of the same type and with the same operating characteristics. A building with a low EER indicates the building has less-than-expected consumption of energy and is relatively efficient. The EPA rating equals one minus the fraction of buildings of the same type that have a smaller EER. Technical documentation for PM available online describes the EPA rating methodology in greater detail.[3]

For each building type, predicted energy use is estimated using a regression model, with source energy use intensity as the dependent variable. The regression model controls for basic operating characteristics, which vary by building type (e.g., square feet, number of occupants and hours of operation) and weather, but not for specific energy efficiency measures used in the building or

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[2] EPA also uses the rating system to designate ENERGY STAR qualified buildings. To earn the ENERGY STAR, a building must achieve a rating of 75 or higher (which means be in the top 25% nationwide) and satisfy indoor environment criteria.

[3] http://www.energystar.gov/index.cfm?c=evaluate_performance.bus_portfoliomanager, and http://www.energystar.gov/index.cfm?c=evaluate_performance.bus_portfoliomanager_model_tech_desc

energy prices.[4] EPA established a separate regression model for each building type using data from the 2003 Commercial Buildings Energy Consumption Survey (CBECS), carried out every four years by the U. S. Department of Energy. Updated algorithms underlying Portfolio Manager have been phased in since 2007 (for offices, banks, retail stores, etc.). The most recent update was completed for K-12 schools in February 2009. The tool also has procedures for rating buildings with more than one primary space. When all spaces are properly defined, the facility will have a rating that accounts for the energy contributions of each defined space. Computer centers and parking garages are examples of secondary spaces.

PM converts all site energy to source energy (renewable energy generated and consumed on site may be treated differently). PM uses the average national source-site ratio, and thus does not account for regional or local differences in resource mix or generation efficiency. Per the EPA methodology, use of *national* site-to-source ratios in Portfolio Manager means buildings are not credited (or penalized) for the efficiency or inefficiency of their local energy providers. It is important to note that EPA does use a regional source mix for greenhouse gas conversions based on eGRID for emissions calculations. For each eligible building, the Statement of Energy Performance includes both site and source energy, and the EPA rating.

We also note that Portfolio Manager allows for tracking aggregate utility costs. However, as an energy management tool, PM does not track peak demand or demand charges. Although these variables are not relevant in the analysis of energy consumption, they are important in the determination of policies related to energy efficiency.

[4] PM uses heating degree days (HDD) and cooling degree days (CDD) to control for the effects of weather on energy use. User-supplied zip code information is used to identify the nearest national weather station with information about temperatures needed to calculate CDD and HDD.

3. Selection of CBSA Building Data for Analysis

A sample of the buildings in the CBSA database was chosen to analyze the EPA rating obtained in Portfolio Manager. Four building types—offices and banks, retail establishments, K-12 schools, and warehouses—were selected.[5] As noted earlier, the CBSA data were primarily intended to characterize the building stock in the Northwest, not for use in Portfolio Manager. Therefore, the data set has limitations for the analysis of EPA ratings. The CBSA data contains relatively reliable information on physical attributes. Data on certain variables critical to PM, such as hours of operation, number of occupants and number of personal computers, are missing for many sites in the sample.

Seven data quality criteria were applied to the CBSA data before submitting them to PM to ensure that reliable, quality data were used in the analysis. The application of these criteria led to **the elimination** of buildings in the following categories:

- Buildings that did not have a minimum of 12 months of actual electricity and gas consumption data (as required by PM).

- Buildings with missing fuel data. CBSA did not record the consumption of fuels other than electricity and natural gas.

- Buildings that did not satisfy PM's minimum requirements for floorspace and hours of operation. (PM will not accept buildings with a floor space below 5,000 square feet [banks excepted], or ones that operate for fewer than 30 hours per week [schools excepted]).

- Buildings with seemingly anomalous or incomplete consumption history or floorspace data.

- Buildings improperly categorized as office, retail, school or warehouse. For example, a number of self-storage facilities with very small energy use intensities that were improperly categorized as warehouses were eliminated.

- Buildings with EUIs below the 1st or above the 99th percentile of EUIs for buildings in the same category in CBECS.[6] (Buildings with EUIs in the extreme tails of the CBECS distribution were assumed to have erroneous billing or floor space data.)

[5] In estimating the energy performance rating, Portfolio Manager treats small banks (floor space ≤ 50,000 sq ft.) differently than large banks and other office buildings. The predicted energy use regression model incorporates a dummy variable for small banks, and separate interaction variables between gross floor space and number of workers. In the sample of 108 offices submitted to PM for analysis, there were four banks, two of which were less than 50,000 sq. ft. Our results are not sensitive to the inclusion of banks.

[6] In comparing EUIs, buildings were differentiated by business (office, school, etc.) and principal heating fuel (natural gas or electricity).

– Buildings for which information about physical characteristics was collected by surveying the exterior of the building. For such buildings, it is likely that floor space and other feature measurements risk significant error.

As shown in Table 1, after applying the above-mentioned filters, 108 offices, 72 retail buildings, 36 K-12 schools, and 43 warehouses remained in the final sample. Although the sample of CBSA buildings was significantly reduced, the remainder was of higher quality and reliability.

Table 1. The Effects of Data Quality Controls on the CBSA Samples

		OFFICES, RETAIL, K-12 SCHOOLS, AND WAREHOUSES	OFFICES	RETAIL	K-12 SCHOOLS	WAREHOUSES
	Buildings in CBSA	**834**	**273**	**255**	**140**	**166**
1	Buildings without Complete Billing Data	445	125	150	87	83
2	Buildings Using Fuels Other than Electricity and Natural Gas	20	11	6	3	0
3	Buildings that did not meet PM Data Quality Requirements	39	14	13	5	7
4	Buildings Improperly Categorized	18	0	0	0	18
5	Buildings with EUI'S in Extreme Tails of CBECS Distribution	27	7	7	8	5
6	Buildings with Structural Information Based on External Inspection	26	8	7	1	10
	Buildings Retained in the Analysis	**259**	**108**	**72**	**36**	**43**

Table 2 compares the population-weighted characteristics of buildings in the CBSA sample before and after filtering, and shows buildings that survived the filtering process tended to be larger but otherwise similar to buildings in the unfiltered sample. For each of the four categories, the difference in building size between the initial and the final samples stems principally from PM's minimum building size requirement of 5,000 ft^2 and decreases significantly if this requirement is imposed on the unfiltered data.[7] This suggests that buildings in the final sample are fairly representative of the CBSA data for office, retail, warehouse, and school buildings exceeding the size threshold.

[7] With the imposition of only the building size filter, the average size of CBSA buildings greater than 5,000 square feet was close to the average size of buildings in the filtered sample: retail, 27,000 ft^2; office, 46,000 ft^2; warehouse, 26,000 ft^2; and schools, 48,000 ft^2.

Table 2. CBSA Samples Before and After Screening

	PRE-Screening CBSA SAMPLE				POST-Screening CBSA SAMPLE			
BUILDING TYPE	**Variable**	**N**	**Mean**	**Std Dev**	**Variable**	**N**	**Mean**	**Std Dev**
RETAIL	FLOOR SPACE	255	18,199	302,447	FLOOR SPACE	72	31,154	316,663
	YEAR BUILT	255	1971	189	YEAR BUILT	72	1976	137
	ELECTRIC HEAT	255	0.279	3.629	ELECTRIC HEAT	72	0.290	2.688
	GAS HEAT	255	0.623	3.921	GAS HEAT	72	0.679	2.764
OFFICE	FLOOR SPACE	273	24,665	566,170	FLOOR SPACE	108	54,467	576,480
	YEAR BUILT	273	1986	126	YEAR BUILT	107	1987	100
	ELECTRIC HEAT	273	0.389	3.598	ELECTRIC HEAT	108	0.500	2.641
	GAS HEAT	273	0.547	3.675	GAS HEAT	108	0.487	2.640
WARE-HOUSE	FLOOR SPACE	166	18,107	383,519	FLOOR SPACE	43	34,877	469,685
	YEAR BUILT	166	1982	141	YEAR BUILT	40	1983	169
	ELECTRIC HEAT	166	0.227	3.820	ELECTRIC HEAT	43	0.256	2.928
	GAS HEAT	166	0.415	4.489	GAS HEAT	43	0.702	3.067
SCHOOL	FLOOR SPACE	140	23,355	263,244	FLOOR SPACE	36	62,030	200,319
	YEAR BUILT	140	1983	114	YEAR BUILT	36	1980	98
	ELECTRIC HEAT	140	0.246	2.977	ELECTRIC HEAT	36	0.167	1.595
	GAS HEAT	140	0.703	3.160	GAS HEAT	36	0.833	1.595

Note: Data are weighted by CBSA sampling weights.

As discussed earlier, data on certain variables, such as building occupants and the number of PCs, were missing for a number of sites and had to be imputed. Table 3 shows the percentage of buildings with missing values for three key variables in the analysis: building occupants, PCs, and hours of operation. All buildings in the sample were missing data on building occupants. Sixty-four percent of buildings had missing data on PCs, and 24 percent had missing data on operating hours.

Table 3. Percentage of Buildings with Missing Values for Selected CBSA Variables

Variable	All building types	Office	Retail	School	Warehouse
Number of occupants	100%	100%	100%	NA*	100%
PCs	64%	56%	64%	31%	42%
Operating Hours	24%	22%	31%	22%	19%

* The revised K-12 model no longer requires number of occupants. This is a change from the March 13, 2009 paper.

Using the 2003 CBECS data, missing values for number of PCs and number of occupants were imputed using regression analysis with floor space as the independent variable. We recognize, as pointed out by EPA in its April 24 comments, that there is an inherent weakness in this approach: the imputed variables will likely be correlated because they were both estimated as functions of floor space. It is important to note, however, that with the exception of the number of occupants, this method was used to impute missing values for a limited number of observations, as noted in Table 3. For variables such as operating hours, which could not be predicted from other building characteristics, we used either default values in PM or the average values in the 2003 CBECS sample. Appendix Table A.1 describes in more detail the PM inputs for each building type and how missing variables were imputed.

To check the external validity of the final sample, we compared the characteristics of the four building types in the final sample to buildings in the 2003 CBECS database. The results, as shown in Appendix Figures 5.1 to 5.8, indicated similar distributions for source EUI between the CBECS and CBSA samples for both raw and population-weighted source EUI. Distributions of source EUIs for the four building types are summarized in Table 4. As can be seen, NW retail and warehouses appear to consume more energy per ft^2 than the national average.

This analysis does not consider weather normalization. Given that the CBECS data represent data for 2003, and the CBSA data were available for dates ranging from 2002 to 2007, there is an additional margin of error to consider in a future analysis.

Table 4. Summary of Distribution of Source EUI for CBECS and CBSA Buildings

Building type	Office						School					
	a	b	c	d	e	f	a	b	c	d	e	f
Data source	CBECS	CBSA	CBECS	CBSA	b/a	d/c	CBECS	CBSA	CBECS	CBSA	b/a	d/c
Weighted	no	no	yes	yes			no	no	yes	yes		
Sample Size	764	108	359762	2987			566	36	230346	641		
Lower quartile	136.9	143.8	100.9	148.2			105.4	112.4	84.9	105.8		
Mean	222.9	192	183.4	193.1	0.86	1.05	159.2	147.1	144.5	154.9	0.92	1.07
Median	201.1	187.7	162.8	188.1	0.93	1.16	144.6	138.8	136.8	156.9	0.96	1.15
Upper quartile	285.9	240.6	242.7	244.3			192.2	185.7	184.8	188.1		
Bandwidth	98.8	94.9	27.4	48.5			61.1	89.4	21.1	56.5		

Building type	Retail						Warehouse					
	a	b	c	d	e	f	a	b	c	d	e	f
Data source	CBECS	CBSA	CBECS	CBSA	b/a	d/c	CBECS	CBSA	CBECS	CBSA	b/a	d/c
Weighted	no	no	yes	yes			no	no	yes	yes		
Sample Size	246	72	214958	2491			375	43	283734	1891		
Lower quartile	74.1	152.4	60.9	115.8			30.7	43.4	27	43.4		
Mean	191.3	217.9	153.9	186.7	1.14	1.21	90.3	107.7	78.5	107.4	1.19	1.37
Median	159.9	213.4	118.9	160.7	1.33	1.35	60.8	72.3	50.9	72.1	1.19	1.42
Upper quartile	271.6	270.5	200.8	255.5			117.3	111.3	98.9	144.5		
Bandwidth	164.2	125.6	30	73.1			66.2	80	14.6	55.9		

Ratio1=un-weighted CBSA/CBECS; ratio2=weighted CBSA/CBECS

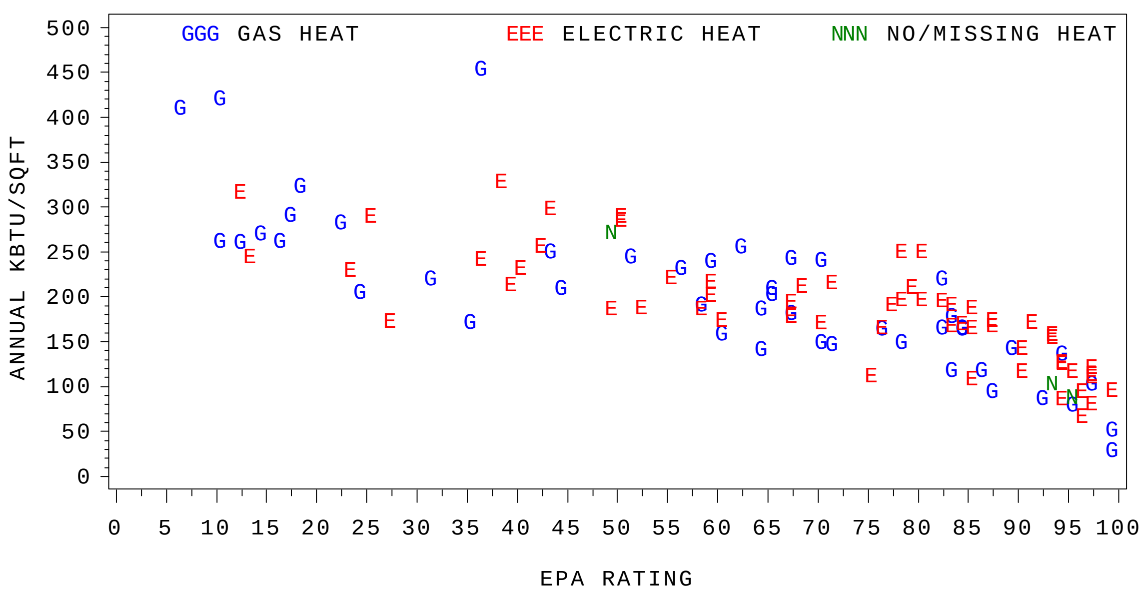
4. Analysis of EPA Ratings for CBSA Buildings

Ratings were obtained for 259 buildings. As a first step in the analysis, EPA ratings were plotted against source EUI, and distributions of EPA ratings were generated for each of the four building types. In interpreting the results, it is important to keep in mind the limitations of the data described in the preceding section. In particular, source EUI in CBSA facilities reflects different weather years and the values of some variables for some facilities were imputed.

Figures 1a through 1d show scatter plots of annual source EUI against EPA ratings for CBSA offices, retail buildings, schools and warehouses. Annual source EUI is measured along the vertical axis, and the EPA ratings against the horizontal axis. Each building and heating source fuel is represented by "E" for electricity, "G" for natural gas, or "N" if the building is not heated (or information about the heating fuel source is missing).[8] There should be a negative relationship between the ratings and EUI, as buildings with high EUI are expected to be less energy efficient.

Figure 1a. Source EUI versus EPA Rating – Office Buildings[9]

(N=108, R^2=0.63)



[8] The Appendix contains scatter plots of small, medium, and large buildings and old and new construction for each building type.

[9] Note that source EUIs in CBSA facilities were calculated using actual consumption histories from different periods. Energy consumption in facilities constructed before 2002 is generally from the 2002-2003 period and energy consumption for facilities constructed after 2003 is from the 2006-2007. Analysis of temperature data for the two periods, however, indicated no large differences in HDD and CDD between these periods. See NOAA website: http://www7.ncdc.noaa.gov/CDO/CDODivisionalSelect.jsp. Also, the values of some variables for some facilities were imputed. See the preceding section and the Appendix for details.

Figure 1b. Source EUI versus EPA Rating – Retail[10]

(N=72, R^2=0.69)

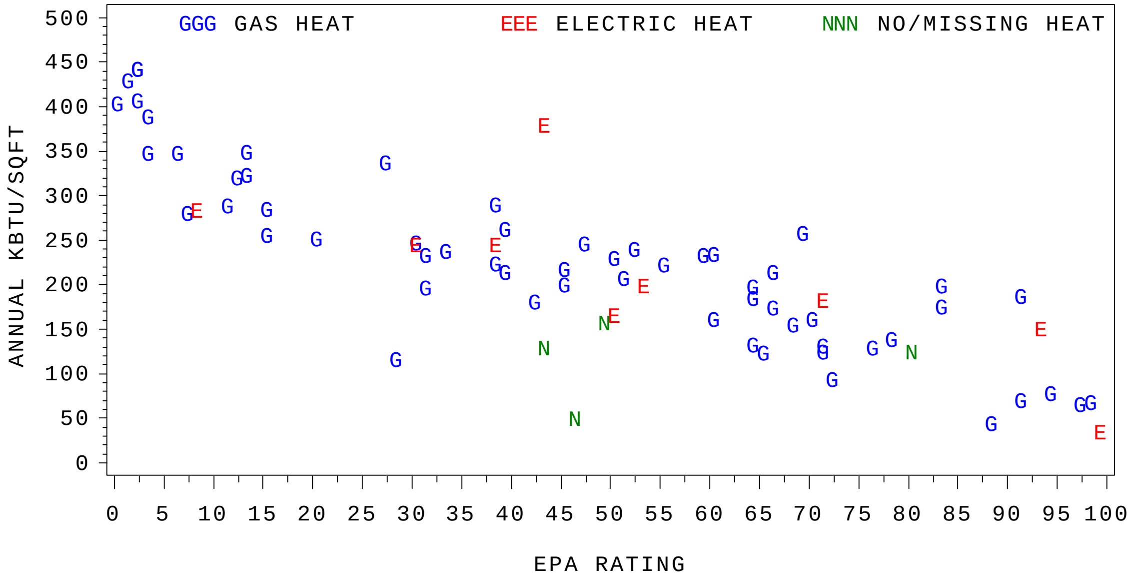
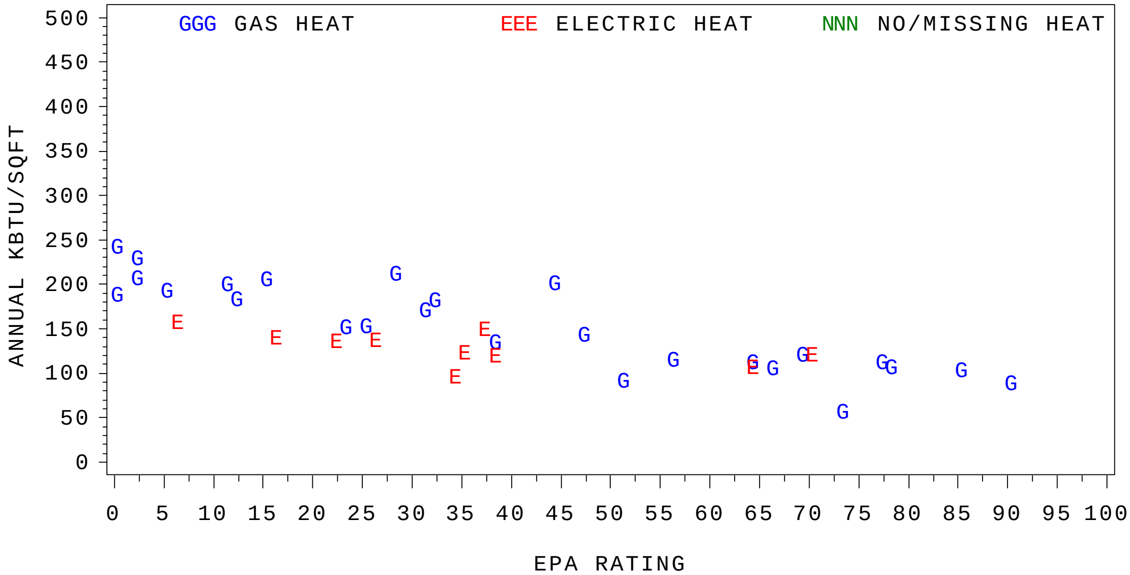


Figure 1c. Source EUI versus EPA Rating – Schools[11]

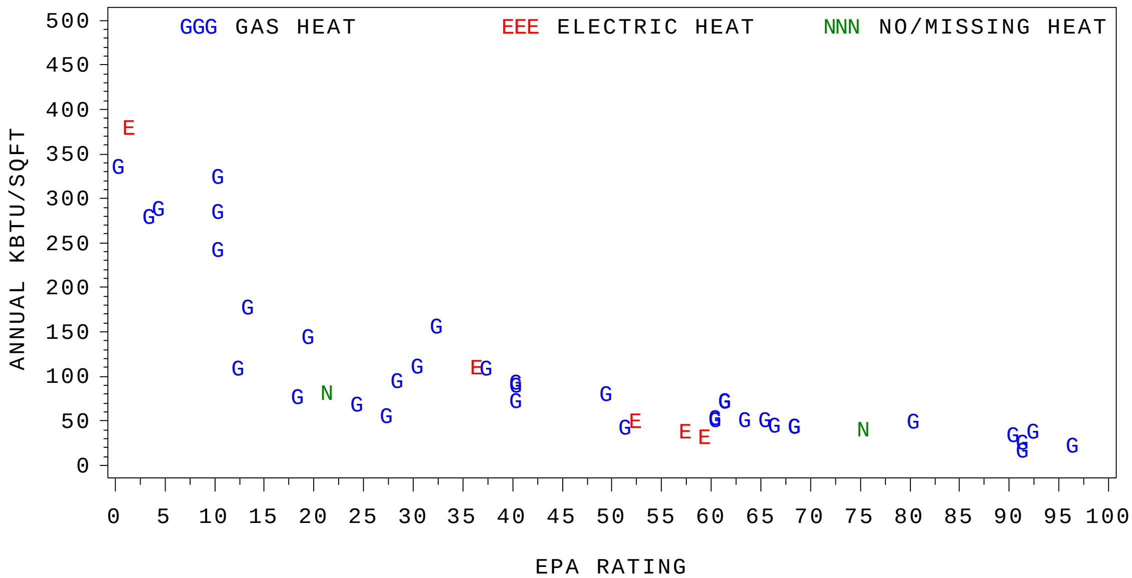
(N=36, R^2=0.63)



[10] See preceding footnote.
[11] See footnote 9.

Figure 1d. Source EUI versus EPA Rating – Warehouses[12]

(N=43, R^2=0.63)



The figures show the expected negative relationships and suggest PM captures the variations in energy efficiency among Northwest buildings. Ordinary Least Squares (OLS) regressions of source EUI on the EPA rating also demonstrate a negative and statistically significant relationship for all four building types (see Table 5). The weakest relationship between EUI and the EPA rating is shown for offices and schools, for which there is a fairly wide range of ratings over a narrow band of source EUIs (Figures 1a and 1c). These patterns indicate that buildings with very different energy use profiles (after controlling for building operating characteristics) can have similar EUIs. This result demonstrates the benefits of a normalization tool such as PM.

Table 5. Regression Analysis of Source EUI

REGRESSION ANALYSIS OF SOURCE EUI ON EPA RATING				
	OFFICE	RETAIL	SCHOOL	WAREHOUSES
INTERCEPT	341.65*	356.05*	199.24*	229.98*
	(11.92)	(12.85)	(8.27)	(17.26)
EPA RATING	-2.25*	-2.85*	-1.33*	-2.69*
	(0.17)	(0.23)	(0.18)	(0.32)
R^2	0.63	0.69	0.63	0.63
N	108	72	36	43
Notes: Dependent variable is source EUI. All models are estimated by OLS. * Denotes statistically significant at the 1 percent level.				

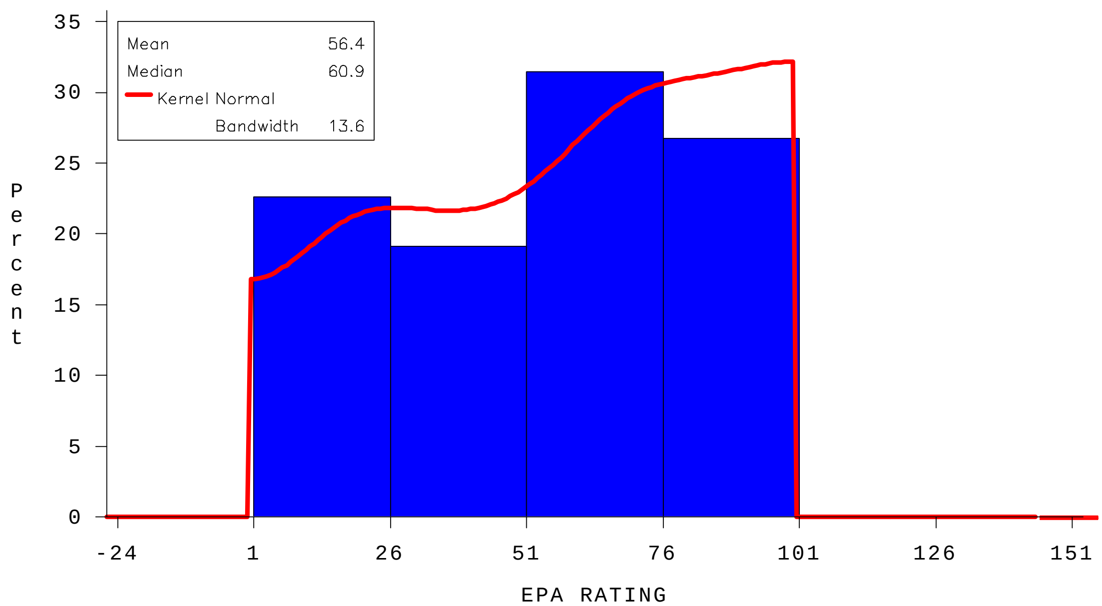
[12] See footnote 9.

Distribution of EPA Ratings

Figures 2a through 2d show population-weighted distributions of the EPA ratings by building type. Each figure displays a histogram of ratings obtained by dividing the range of ratings (1,100) into quartiles and counting the number of ratings that fall within each quartile. Also shown are smoothed probability distributions of EPA ratings obtained from a non-parametric density estimator. The smoothed curves show continuous representations of the rating distributions. The buildings in the CBSA sample are assigned a sample case weight to ensure the sample is representative of the population of buildings in the Northwest.

The ratings distributions in Figures 2a through 2d show the efficiency of Northwest buildings relative to buildings in the rest of the U.S. If the two populations are similar, then we would expect approximately 25% of CBSA buildings to have ratings of 25 or lower, 50% to have ratings of 50 or lower, and so on. Further, the histograms and probability density curves in Figures 2a through 2d would approximate a uniform probability distribution.[13] If the CBSA buildings are less or equally efficient than buildings in the rest of the country, then the probability distributions are expected to be equal or negatively skewed. As discussed in the previous section comparing CBECS and CBSA source EUI, the CBSA offices and schools appeared to be similar to buildings in the rest of the country; however, retail and warehouses tended to be more energy intensive.

Figure 2a. Distribution of EPA Ratings for CBSA Offices (N=108)[14]



[13] A probability distribution is uniform if every point in the distribution has the same probability of occurring. In the figures, a uniform probability density function would have zero slope, and the bars of the histograms would have uniform height.

[14] Note that values of some variables for some facilities were imputed. See Section 3 and the Appendix for details.

Figure 2b. Distribution of EPA Ratings for CBSA Retail (N=72)[15]

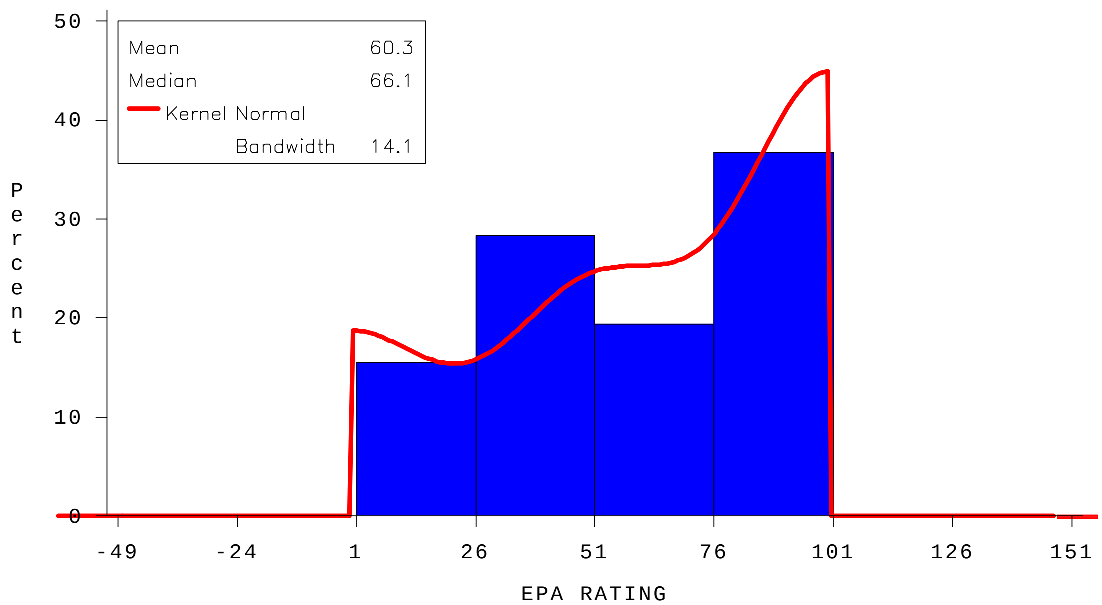
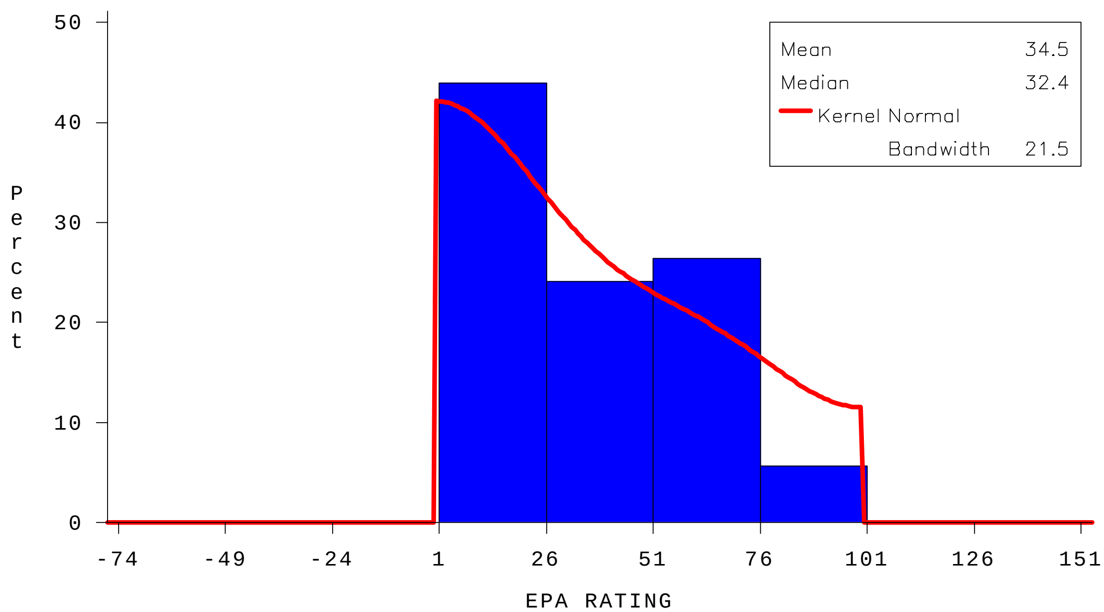
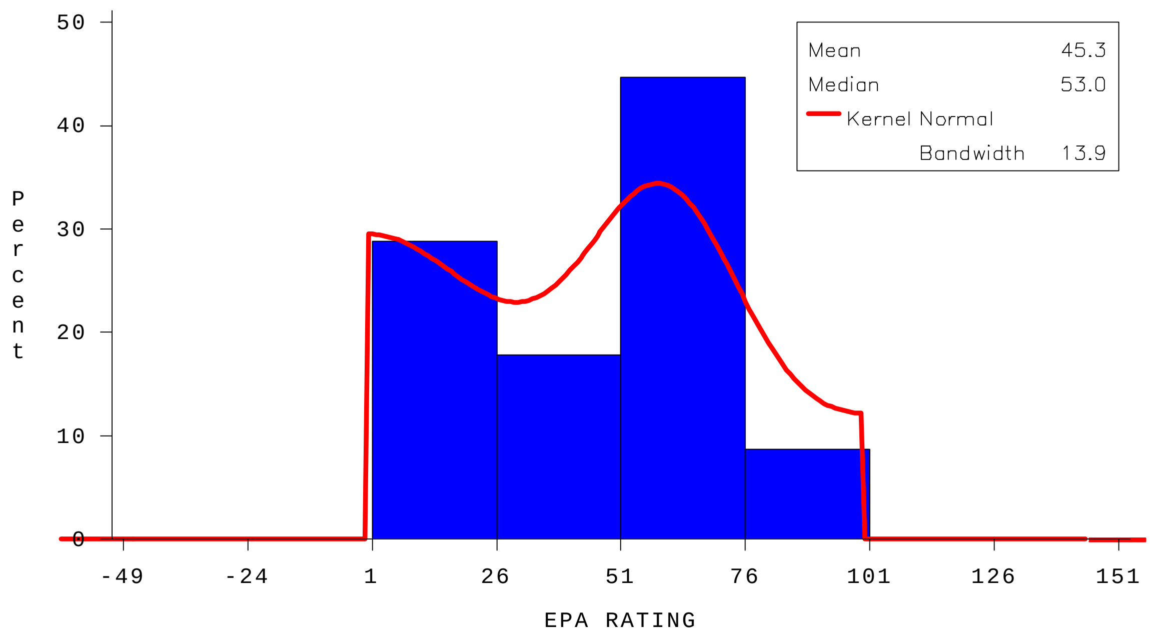


Figure 2c. Distribution of EPA Ratings for CBSA Schools (N=36)[16]



[15] See footnote 14.
[16] See footnote 14.

Figure 2d. Distribution of EPA Ratings for CBSA Warehouses (N=43)[17]



As seen in Figures 2a through 2d, the distributions exhibit significant skewness. Based on χ^2 tests of homogeneity, we can reject the hypothesis that buildings in the CBSA sample are distributed evenly across the rating quartiles of 1-25, 26-50, 51-75, and 76-100 for each building type.[18] PM shows Northwest offices in the CBSA sample to be more efficient than offices in the rest of the country, as 50% of Northwest buildings have EPA ratings of 60 or higher. PM also indicates Northwest retail buildings are relatively efficient, as 50 percent of retail buildings have a rating of 66 or higher. This is opposite of what can be seen from the distribution of source EUI for CBECS and CBSA data. Figure 2c shows Northwest schools are significantly less efficient than schools in the rest of the U.S. Figure 2d shows warehouses in the Northwest and the rest of the country have similar efficiencies.

The ratings distributions show that, relative to similar building types in the rest of the country, buildings in the Northwest sample are either more efficient than the national distribution, such as retail or offices, or less efficient, as in the case of schools. The distribution of ratings of Northwest schools appears particularly anomalous, as the population-weighted median rating for schools is 32.[19] As discussed before, while the CBSA and CBECS samples of schools exhibit similar distributions for source EUI, the EPA rating distribution for schools is skewed.

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[17] See footnote 14.

[18] The test statistics are as follows: office $\chi^2(3) = 99.6$, $p<0.0001$; retail $\chi^2(3) = 269.2$, $p<0.0001$; school $\chi^2(3) = 176$, $p<0.0001$; and warehouse $\chi^2(3) = 397.7$, $p<0.0001$.

[19] This version of the report analyzes ratings from EPA's updated school model. Also, the sensitivity of the ratings for schools to estimating missing values of some variables was checked. First, the ratings distribution was similar

The premise of a rating system such as PM is that EUI alone is not a good predictor of building energy performance. This suggests that the discrepancy between the source EUI distributions and the EPA rating distribution for schools may be explained by the operating characteristics of the buildings, which are not reflected in source EUI. Further analysis of NW buildings will provide a better understanding on how PM captures these differences.

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when schools are assumed to be open 12 months of the year instead of 10 months. Second, the rating distribution was similar when we assumed that some schools are open on the weekends. Consistent with the PM default value of "not open on the weekend", CBECs shows that in 2003 only 22 percent of schools in the Pacific census region were open during the weekend. This suggests that the default value of "not open" will be accurate for most schools. However, we also re-estimated the distribution of EPA ratings after randomly assigning 22 percent of schools in the CBSA sample the value of "open during the weekend." The sample has a slightly higher mean rating (37.5) than before, but the distribution of ratings is still significantly skewed. (These results are not presented but available from the authors upon request.)

5. Application of PM to Northwest Buildings

The EPA ratings of the CBSA sample were analyzed to explore possible explanations for the observed distribution patterns, namely specification error and measurement error. We further investigated how the source-site energy conversion ratios are applied and the resulting implications in terms of the applicability of the EPA rating system to buildings in the Northwest.

Analysis of EPA Rating Distributions

We began the analysis of rating distributions with two working hypotheses regarding possible explanations for the observed distributions: specification error in the underlying PM regression model and measurement error in input variables. The analysis detailed below did not provide conclusive evidence of specification error.

Potential for Specification Error

In PM, the ratio of actual energy use to predicted energy use serves as the basis for the efficiency rating. PM predicts energy use with regression models developed for each building type and estimated using a nationally representative sample of buildings from CBECS. The dependent variable in the energy-use regression model is source energy-use intensity, and the explanatory variables are climate variables such as heating and cooling degree days (HDD and CDD), basic physical characteristics such as floorspace, and operating parameters such as number of occupants and hours of operation. These vary depending on building type.

The models do not account for the energy efficiency of the installed energy systems, energy prices, or other behavioral factors likely to affect energy use. The models implicitly assume these variables are uncorrelated with other building variables endogenous to the model. In our initial report, we had hypothesized that this assumption may not hold, and the regression models may be subject to what is known as "omitted variable bias." Omitted variable bias occurs when a variable affecting energy use is correlated with other covariates and excluded from the model. When such "relevant" variables are omitted from the model, coefficients on covariates in the model tend to be biased, resulting in inaccurate predictions of energy use.

For instance, a potential source of omitted variable bias is the omission of energy-efficiency measures from the energy use equation when it is estimated using CBECS data. HDD and CDD (interacted with the percent of the building heated or cooled) are included in the regression model to capture the effect of weather on energy demand. However, when energy-efficiency measures are omitted from the model, coefficients on HDD and CDD capture the effects on energy consumption of both outside temperature and the building's sensitivity to that temperature. We hypothesized that buildings in extreme climates are more likely to adopt energy-efficiency measures. The coefficients on CDD and HDD may be biased downward if CDD and HDD are positively correlated with installation of energy-efficiency measures.

Incorporating measures of the building's efficiency in the equation may improve the performance of the model.[20]

In addition, the omission of behavioral factors affecting energy use may lead to bias. For instance, the effects of weather on energy consumption may be sensitive to electricity prices.[21] In regions where prices are higher, the response of energy use to temperature may be moderated. If (peak) electricity prices are higher in climates with extreme temperatures, the coefficients on CDD and HDD may be biased downward.

We explored the potential effects of omitted variable bias by estimating the PM predicted energy use regression models using the CBSA data.[22] The test regression model used the same specification as the PM model, except it omitted banking dummy and banking interaction variables because of the small number of banks in our sample. We estimated two regression models, one with and one without an indicator for the presence of an energy management system (EMS), as an example of an energy efficiency measure expected to have a significant effect on the building's overall energy performance. Arguably, the benefit of EMS can be expected to be greater in severe climate zones; therefore, we would expect a relatively strong positive correlation between the presence of EMS and covariates such as CDD and HDD. We hypothesized that omitting EMS from the model would bias the coefficients on CDD and HDD downward.

In addition, we examined the relationships between HDD and CDD and the presence of energy efficiency measures in buildings in the CBECS sample. In separate models, we regressed HDD and CDD on indicators of the presence of EMS, heat pumps, variable air volume systems, insulation upgrades, window upgrades and other measures. If such measures are more likely to be utilized in extreme climates, the coefficients on the variables should be positive.

Neither analysis provided conclusive evidence of specification error. In the first regression analysis, the coefficient on HDD increases when EMS is included as an explanatory variable, but the difference is negligible. In the second regression analysis, although there were positive correlations between CDD and HDD and certain measures, the relationships were weak and in some cases negative. We therefore conclude that specification error does not appear to be a significant source of concern in the application of PM, but more research may be needed.

These additional analyses did not provide satisfactory explanations for the observed distributions of the EPA ratings of CBSA buildings. The findings on the Northwest data set lead us to conclude that further research is called for. Additional research could take the form of either collecting additional data on the buildings in CBSA for a consistent time period, particularly

[20] When predicting a building's energy use, the coefficients on energy efficiency measures would be set to zero, or equivalently the variables would be dropped from the model.

[21] Energy prices as well as the sensitivity of energy demand to prices in the residential and commercial sectors vary significantly between regions of the U.S. Bernstein, Mark A. and James Griffin. "Regional Differences in the Price-Elasticity of Demand for Energy." Rand Technical Report. 2005.

[22] We focus on the office sector as data for this sector were judged to be reliable and have sufficiently large sample sizes. Our preference would be to estimate the model using office buildings in CBECS. However, locations of the buildings in CBECS have not been identified; so we could not use them for this analysis.

schools, or performing an analysis on a fresh sample of buildings representative of the Northwest region.

Potential for Measurement Error

As is the case with all statistical models, the reliability of EPA ratings depends on accurate and verified data on key inputs such as energy consumption, floor space, number of computers, and hours of operation. Inaccurate measurement of these variables can produce biased estimates of a building's predicted energy use and affect the EPA ratings.[23] This problem is universally the case in all regression-based methods and is unrelated to the formulation of the underlying relationships in the model.

This analysis of the CBSA data highlights the potential for measurement error and its impact. Error in the measurement of key variables cannot be ruled out as one explanation of the observed distributions of EPA ratings of CBSA buildings, especially for schools. Many building inputs to Portfolio Manager are not typically collected in the Northwest. This is particularly true for operating characteristics of the building, such as number of PCs and hours of operation.

From a policy perspective, it should be noted that the complexity in measuring and reporting of variables may lend itself to gaming. If, as the Northwest is contemplating, local incentives (or allocation of resources) are tied to specific EPA ratings, building owners may be tempted to overstate the inputs that increase predicted (normal) energy use. Policymakers will need to keep this in mind when designing the quality assurance protocol.

Site-to-Source Energy Conversion Factors

PM applies the same source-site energy ratios to all sites in the U.S. The ratios account for energy lost in the generation, transmission, and storage of primary and secondary energy consumed on site and reflect national average losses. The rationale for this convention is buildings should not be penalized or credited for the energy efficiency of their suppliers in a national energy performance rating system.

Appropriately, PM focuses on source, rather than site, energy use. However, for certain policy applications the use of source-site ratios based on average mix of generation resources at the national level overlooks key differences in energy input requirements for power production between suppliers and different regions. This poses particular concerns in regions like the Northwest, where about 60 percent of the electric resource mix is hydro-based.

For example, suppose a policymaker is interested in accounting for the efficiency of suppliers when allocating energy efficiency resources (or incentives) between non-residential buildings. Consider two structurally and operationally identical buildings that consume the same kinds and

[23] In a recent NYSERDA analysis, misreporting of building size results in EPA rating changes between 15% and 33%, depending on the size of the building. The underreporting of energy consumption increases the EPA rating by between 5% and 25% depending on the building's size. "Benchmarking Commercial Real Estate." NYSERDA Focus on Commercial Real Estate Report, 2008.

amounts of energy but that have different electricity providers. Building A buys electricity from a supplier that generates electricity using hydropower. Building B buys electricity from a supplier that relies mostly on hydrocarbon fuels. For any amount of electricity consumed on site, the amount of energy lost in production and the true source energy use is going to be higher for Building B than for Building A. However, because they have identical on-site energy consumption, PM would assign the buildings the same EPA rating. If used to reward higher efficiency via incentives, the EPA rating may not result in an optimal allocation of energy efficiency resources between the buildings from a source energy standpoint.[24] The EPA rating system was designed to benchmark and measure improvements in site energy efficiency (i.e., to account for measures taken at the physical site of the building to improve efficiency). It was not designed to consider efficiency improvements at the generation source.[25] Therefore, the rating system would not be an appropriate tool to incentivize or account for source energy efficiency improvements. Because measuring source energy efficiency was not the intent of the EPA rating, it would be up to the policymaker to understand that the rating is strictly for building performance metrics.

It is also important to note that while such local analysis of resource supply is desirable, it may not always be practical. There may be limits to the ability of policymakers to distinguish between utilities because of the existence of regional grids and the dependence of some utilities on wholesale market purchases as a source of supply.[26]

The fact that source energy in Portfolio Manager does not correspond to the primary energy used in any given regional grid or individual state may be a topic worthy of further discussion in the Northwest as parties there consider different kinds of incentives for buildings with certain ratings, based on the local energy providers' fuel mix.

[24] In the Northwest, there are significant differences in the resource mix between NW electricity suppliers. Buildings are likely to vary significantly in their consumption of electricity produced from hydroelectric versus carbon sources.

[25] In effect, the EPA rating system is source energy neutral.

[26] A recent study sponsored by EPA addresses the use of national average source-site ratios in the calculation of EPA ratings. The study compared the EPA ratings of all-electric and not all electric offices and banks to determine whether all electric buildings are penalized by the EPA rating system. EPA found that in the U.S. all-electric buildings scored higher than not-all-electric buildings; while in Oregon and Washington the ratings of all-electric and not-all-electric buildings were statistically indistinguishable. These results suggest that all-electric buildings are not penalized in EPA's national performance system. In the same report, EPA also compared the EPA ratings of offices and banks in the Northwest and the rest of the country to determine whether stringent building codes in the Northwest increased EPA ratings and reduced opportunities for energy efficiency. EPA concluded that there were not significant differences. More study of the application of PM to the Northwest is needed if the Northwest wants to incentivize based on the energy efficiency of the suppliers, including comparisons of EPA ratings that allow for regional differences in source-site ratios.

6. Conclusions and Recommendations

Our evaluation of PM involved an analysis of EPA ratings for 259 CBSA nonresidential buildings, a review of PM technical documentation, and a regression analysis of energy use in CBSA office buildings. The sample of CBSA buildings appears generally representative of Northwest buildings with floor space greater than 5,000 ft^2; however, we found that retail and warehouses in the NW consume more source energy than the national average. We also recognize the data's limitations, including missing values for some variables and omissions from the sample of buildings that use energy sources besides natural gas or electricity.

Scatter plots of the EPA ratings of CBSA offices, retail, schools and warehouses showed the expected negative relationships between a building's rating and its source EUI. The relationship was close for each building type, indicating that the EPA rating is consistent with a rough but fundamental measure of energy efficiency (source EUI).

The distribution of EPA ratings was also produced for each building type. PM yielded skewed rating distributions. The skewness does not match the patterns observed when examining CBECS versus CBSA data, and did not reflect a uniform distribution. The distribution of schools was particularly anomalous, as most Northwest schools had low ratings and were in the bottom third of schools nationally.

We considered a number of hypotheses to explain the observed ratings distributions. We tested one hypothesis concerning specification error and explored another regarding measurement error as possible explanations for the distributions. The results of our tests of specification error were inconclusive, so we cannot accept this hypothesis. Error in the measurement of key CBSA variables cannot be ruled out as a possible explanation for the ratings distributions.

Lastly, we investigated the application of national source-site energy conversion ratios in Portfolio Manager and their implications in terms of the applicability of the EPA rating system to buildings in the Northwest. The use of national average ratios may limit the applicability of PM for some uses such as the distribution of incentives based on source fuel efficiency.

The analysis points to the need for further research, especially in regard to schools. One possibility would be to revisit the CBSA sample of schools analyzed to validate the available data and to collect information for the missing variables. Another possibility would be to construct a new sample of Northwest schools that is representative of the region and has information covering all of the PM inputs. As the use of PM expands in the NW, the larger data sample will allow this analysis to be carried out.

Appendix A:

Appendix Table A1: Portfolio Manager Inputs by Building Type						
Variable	**ESPM Variable Definition**	**Office Buildings**	**Retail Buildings**	**K-12 Schools**	**Warehouses**	**How variable was determined**
Gross Floor Area	The floor area for office spaces must include the floor area for all supporting functions, such as lobbies, stairways, restrooms, storage areas, elevator shafts, etc., in the facility.	CBSA	CBSA	CBSA	CBSA	
Weekly Operating Hours	The total number of hours per week that this office space is in operation, excluding hours when the facility is occupied only by maintenance, security, or other support personnel. For facilities with a schedule that varies during the year, "operating hours/week" refers to the total weekly hours for the schedule most often followed.	CBSA/CBECS average if missing	CBSA/CBECS average if missing	CBSA/CBECS average if missing	CBSA/CBECS average if missing	Office: If weekhrs= missing, then weekhrs=60. Retail: If weekhrs= missing, then weekhrs=79. School: If weekhrs=missing, then weekhrs=45. Warehouse: If weekhrs= missing, then weekhrs=61.
Workers on Main Shift	Indicates the total number of employees present during the main shift. It does NOT include visitors or employees in the building during other times. The normal worker density ranges between 0.3 and 10 workers per 1,000 square feet.	Impute using regression	Impute using regression		Impute using regression	Offices: From regression on polynomial in square feet, PCs, and refrigerators using CBECS data. Retail: From regression of number of workers on polynomial in square feet, PCs, and refrigerators using CBECS data. Warehouse: From regression of number of workers on polynomial of building square feet using CBECS data.
Number Of PCs	Indicates the total number of personal computers and servers in this office space.	CBSA/impute using regression if missing	CBSA/impute using regression if missing	CBSA/impute using regression if missing		Offices: If missing, value obtained from regression on polynomial in square feet using CBECS data. Retail: If missing, value obtained from regression on polynomial in square feet using CBECS data.

Appendix Table A1: Portfolio Manager Inputs by Building Type

Variable	ESPM Variable Definition	Office Buildings	Retail Buildings	K-12 Schools	Warehouses	How variable was determined
						School: If missing, value obtained from regression on polynomial in square feet using CBECS data.
Percent Heated	This is the percentage of the total floor space within the facility served by heating equipment. The percent heated cannot be greater than 100.	CBSA	CBSA	CBSA	CBSA	
Percent Air-Conditioned	This is the percentage of the total floor space within the facility served by mechanical cooling equipment. The percent cooled cannot be greater than 100.	CBSA	CBSA	CBSA	CBSA	
Number of Cash Registers	The total number of cash registers in the retail store.		CBSA/impute using regression if missing			Retail: If missing, value obtained from regression on polynomial in square feet.
Walk-in Refrigeration/ Freezer Units	Indicates the total number of large walk-in refrigeration or freezer units in use within the retail store. This typically includes large refrigeration units located in the back of a retail store in storage and receiving areas, and used to store refrigerated goods.		CBSA	CBSA		Schools: If missing, use PM default values.
Open and Closed Refrigeration/ Freezer Cases	The number of commercial refrigeration units (cases) used for the sale or storage of perishable goods. This includes display-type refrigerated open or closed cases and cabinets as well as display-type freezer units, typically found on the sales floor. Each case or cabinet section, typically 4 to 12 feet in length, should be considered 1 unit. Include cases located inside and immediately adjacent to the facility. This should not include any refrigerated vending (soda) machines.		CBSA			

Appendix Table A1: Portfolio Manager Inputs by Building Type

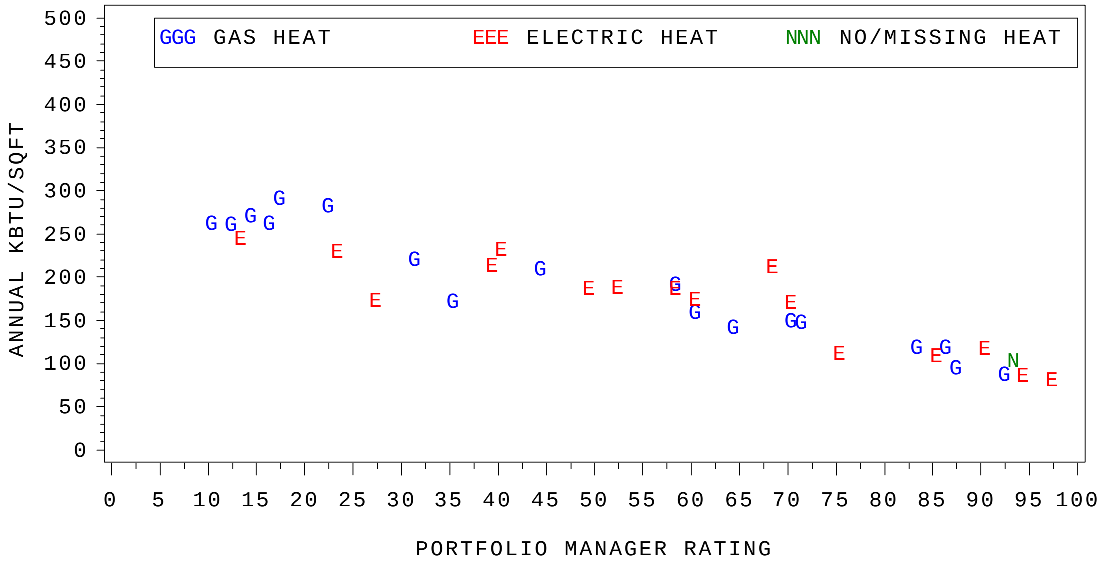
Variable	ESPM Variable Definition	Office Buildings	Retail Buildings	K-12 Schools	Warehouses	How variable was determined
On-Site Cooking Facilities?	If a school has dedicated facilities in which food is prepared and served to students, answer Yes. If a school has facilities in which food for students is only kept warm and/or served, or has only a galley used by teachers and staff, answer No.			CBSA		School: If building had two of the following: (at least one fryer, at least one oven, at least one grill, at least one range), then onsite_cooking='yes'; else onsite_cooking='no'.
Is the school a high school?	This is the school's classroom capacity: the number of students who can be seated in all classrooms at one time.			CBSA		
Months in Use	This is the number of months out of the year that the school is open for use. To calculate a benchmark score, this number cannot be less than 8.			CBECS median value		School: Months_in_use=10.
Mechanically Ventilated?	A building is defined as being mechanically ventilated if it relies on a system to deliver outside air into the building. Window air-conditioning units should not be counted as mechanical ventilation, but economizers and other systems, specifically designed to bring outside air in, should be counted as mechanical ventilation.			CBSA		School: If a school did not have an economizer or its primary heating equipment was a boiler or furnace, and it did not have cooling equipment, then mech_ventilation='no'; else mech_ventilation='yes'. Definition from ESPM portfolio documentation (p.3).
Open on the weekends?				PM default value		School: Open on the weekends='No';
Warehouse Type	Indicate Regrigerated if the warehouse is refrigerated, or Unrefrigerated if it is not.				CBSA	Warehouse: If ref_pct (% of floor space refrigerated) >=50, then warehouse type='refrigerated'; else warehouse type='non-refrigerated'.
Walk-In Coolers & Freezers	The number of commercial walk-in type freezers and coolers. These units are typically found in storage and receiving areas.				CBSA	

Appendix Table A1: Portfolio Manager Inputs by Building Type

Variable	ESPM Variable Definition	Office Buildings	Retail Buildings	K-12 Schools	Warehouses	How variable was determined
Warehouse Lighting	Indicate Yes if the warehouse is lit primarily by either high-density discharge or halogen lighting system, or No if it is not.				CBSA	Warehouse: If ihidwpct >= 30 or ihidwpct=missing then warehouse_lighting='yes' (ESPM default value); else warehouse_lighting='no'.

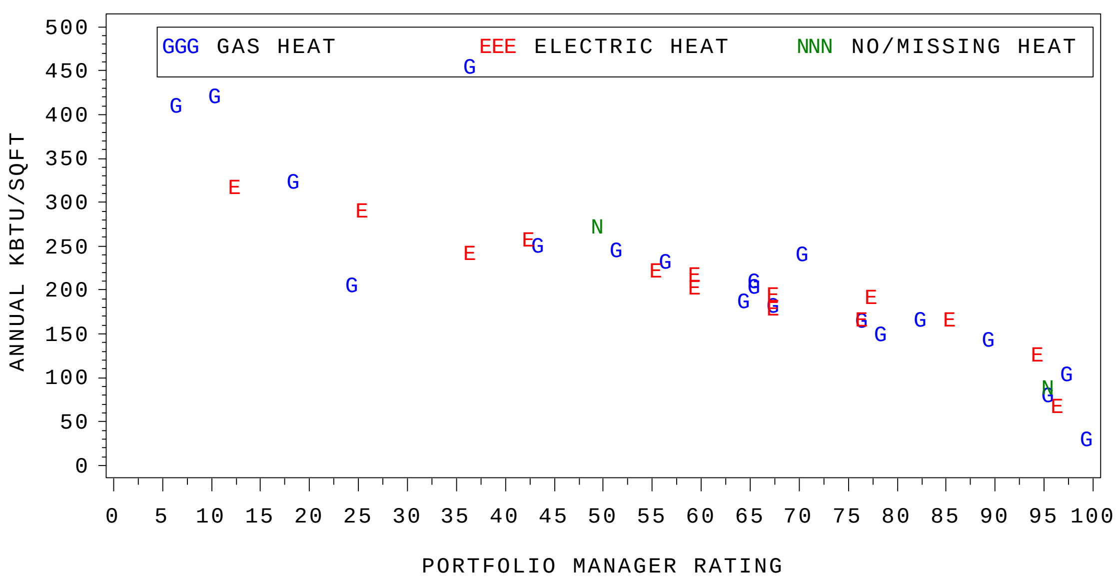
Appendix Figure 1a. Source EUI versus EPA Rating – Small Offices (ft^2 <25,000)[27]

(N=35, R^2 =0.87)



Appendix Figure 1b. Source EUI versus EPA Rating – Medium Offices[28]
(25,000 ≤ ft^2 <200,000)

(N=36, R^2 =0.79)

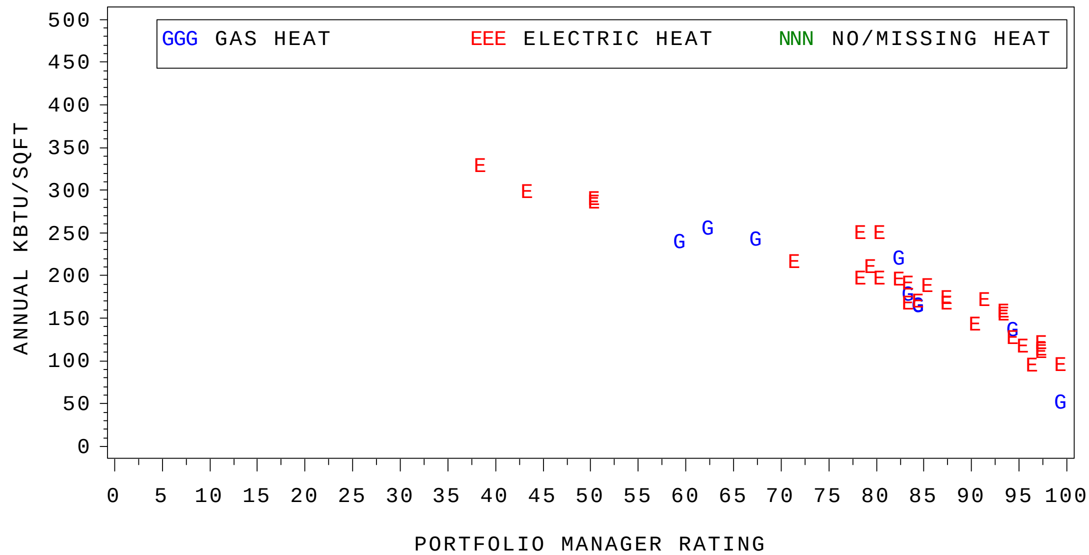


[27] Note that the values of some variables for some facilities were imputed and that the source energy use intensities reflect different weather years. See Section 3.

[28] See footnote 27.

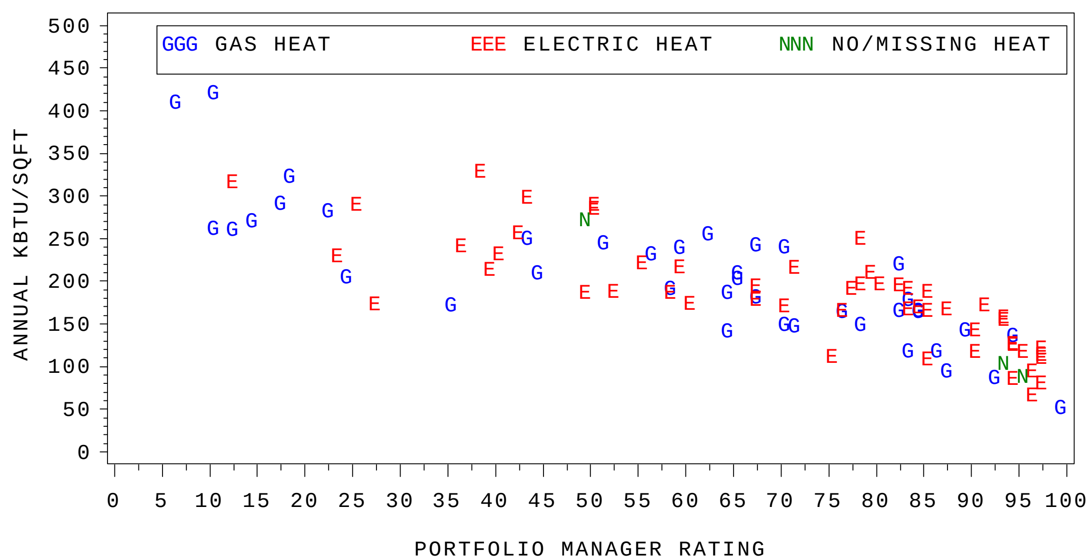
Appendix Figure 1c. Source EUI versus EPA Rating – Large Offices (ft² ≥ 200,000)[29]

(N=37, R^2 =0.86)



Appendix Figure 1d. Source EUI versus EPA Rating – Old Offices[30] (constructed before 2001)

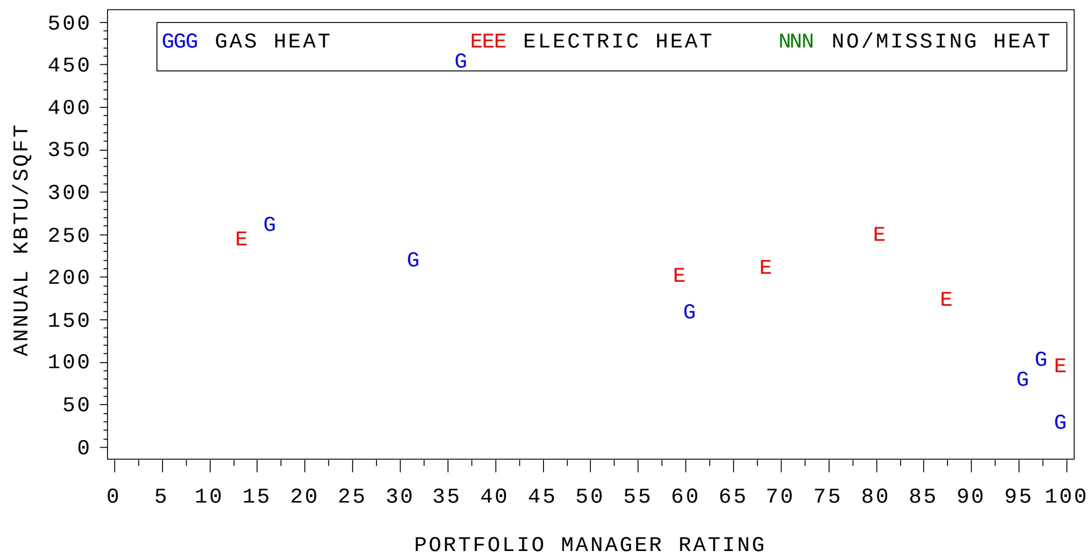
(N=95, R^2 =0.67)



[29] See footnote 27.
[30] See footnote 27.

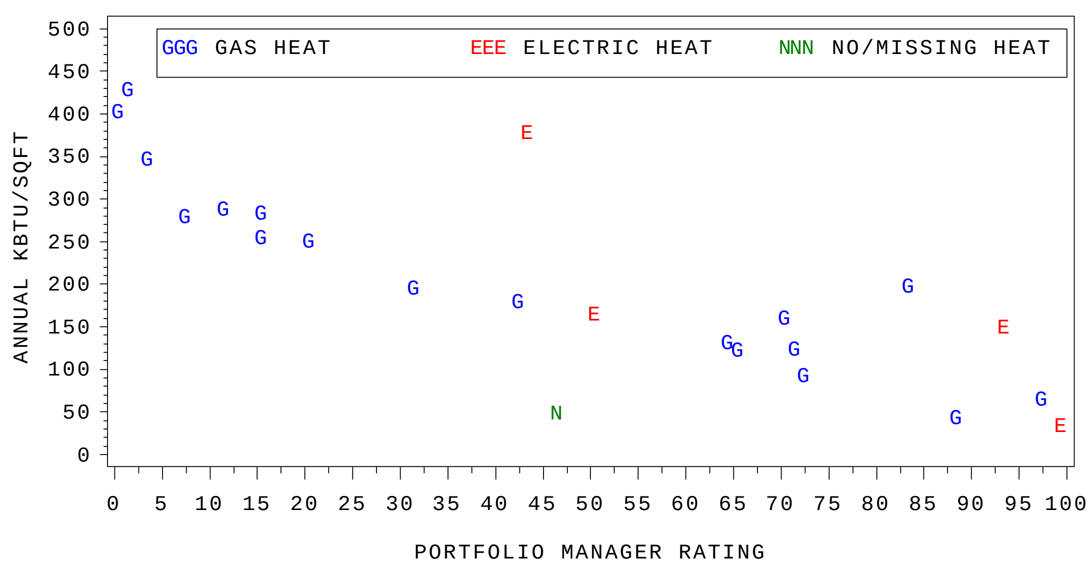
Appendix Figure 1e. Source EUI versus EPA Rating – New Offices (constructed in or after 2001)[31]

(N=13, R^2 =0.50)



Appendix Figure 2a. Source EUI versus EPA Rating – Small Retail (ft² <25,000)[32]

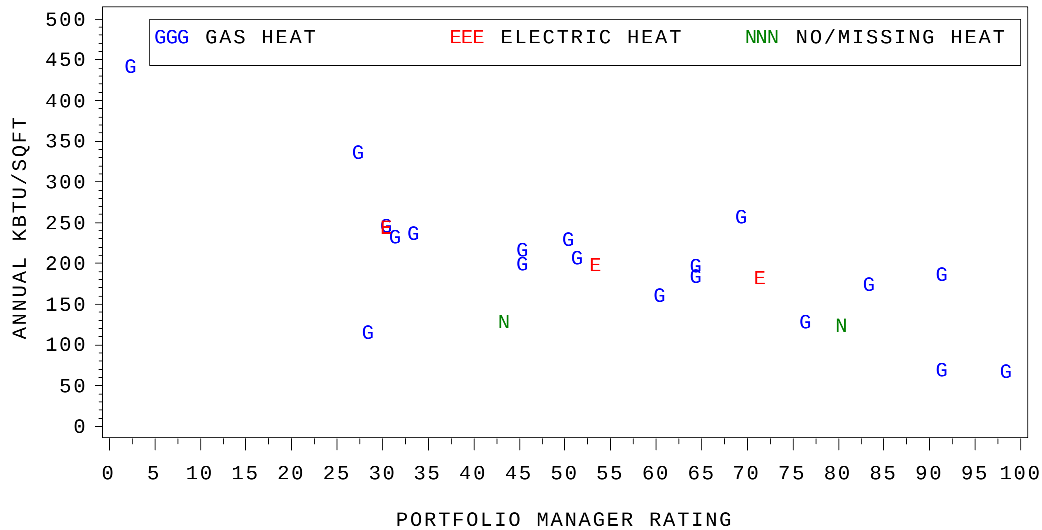
(N=23, R^2 =0.68)



[31] See footnote 27.
[32] See footnote 27.

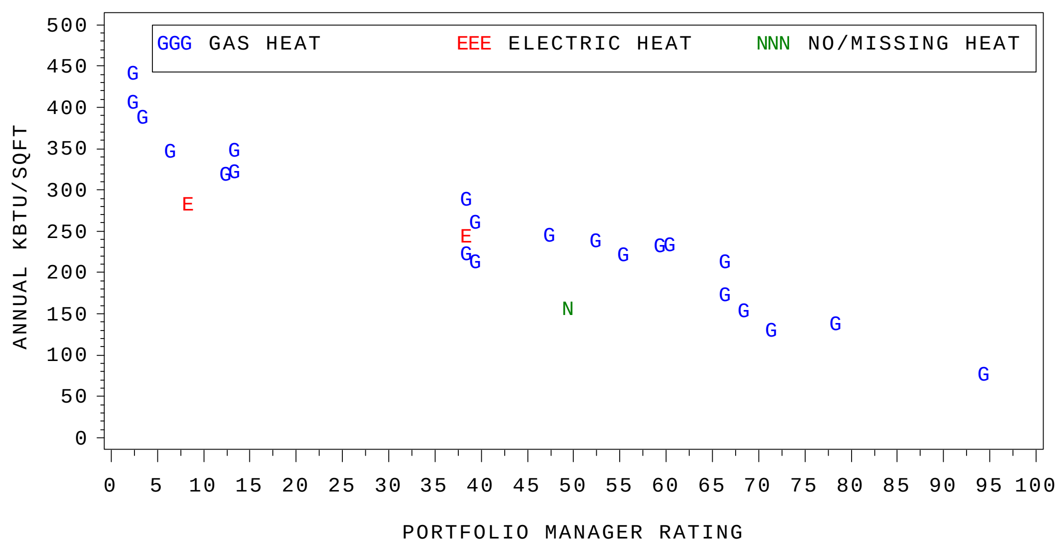
Appendix Figure 2b. Source EUI versus EPA Rating – Medium Retail (25,000 ≤ ft² <115,000)[33]

(N=24, R^2 =0.51)



Appendix Figure 2c. Source EUI versus EPA Rating – Large Retail (ft² ≥ 115,000)[34]

(N=25, R^2 =0.86)

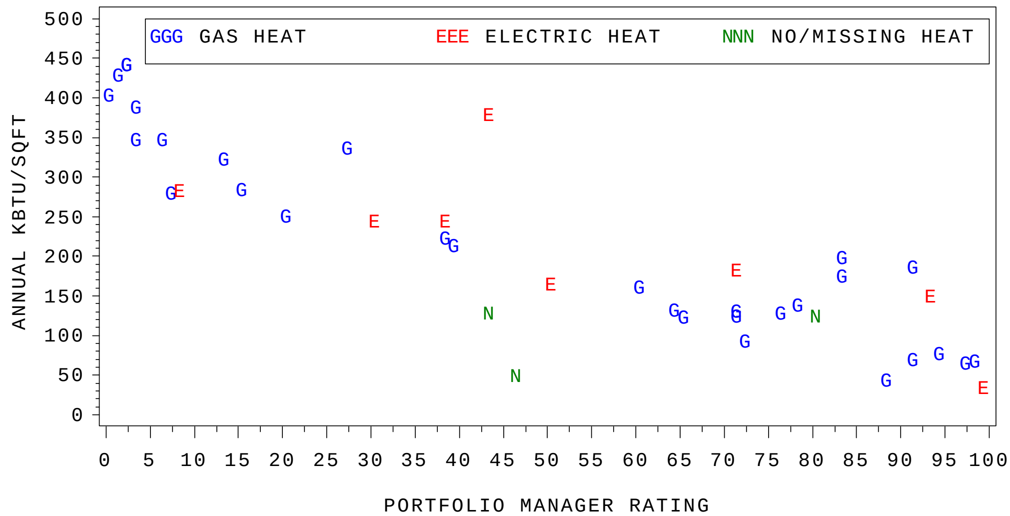


[33] See footnote 27.

[34] See footnote 27.

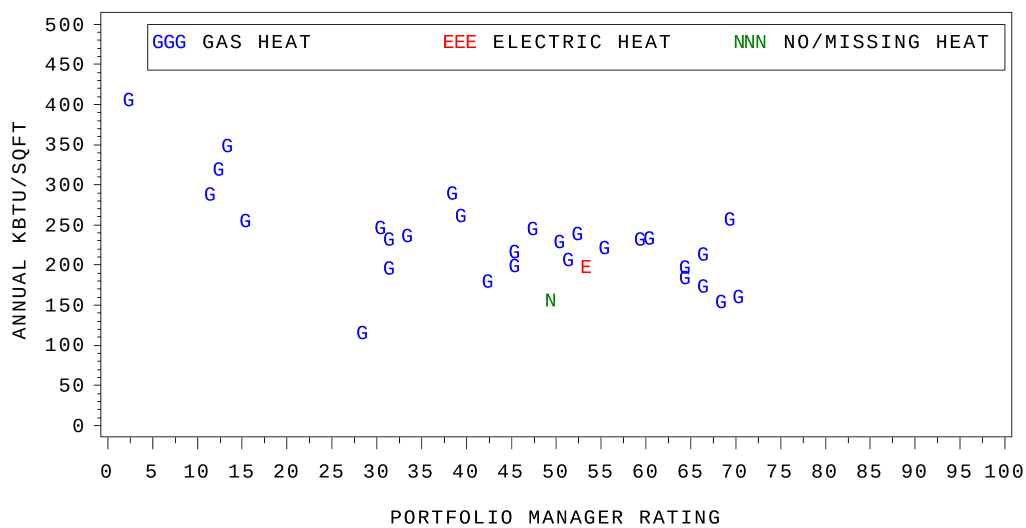
Appendix Figure 2d. Source EUI versus EPA Rating – Old Retail (constructed before 2001)[35]

(N=41, R^2 =0.76)



Appendix Figure 2e. Source EUI versus EPA rating – New Retail (constructed in or after 2001)[36]

(N=31, R^2 =0.41)

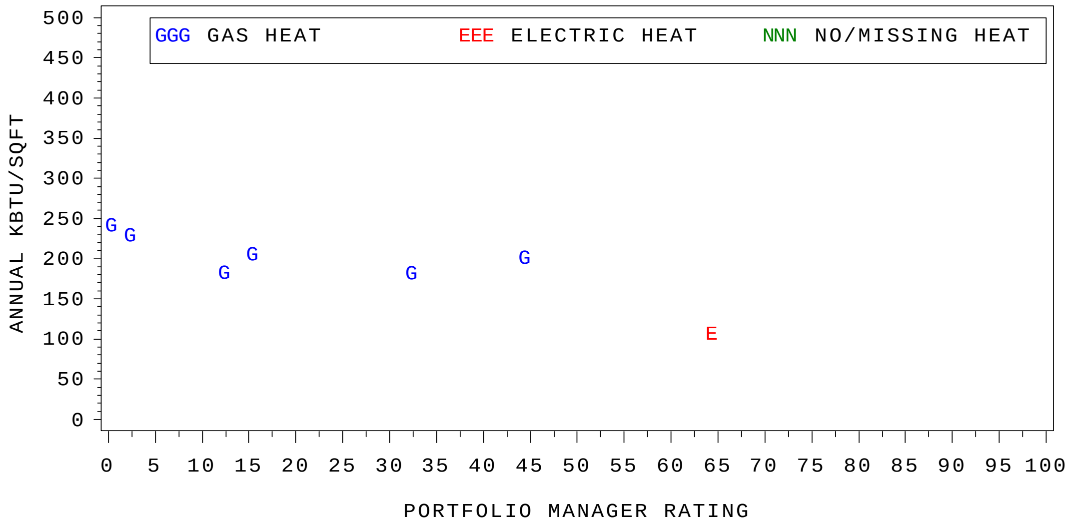


[35] See footnote 27.

[36] See footnote 27.

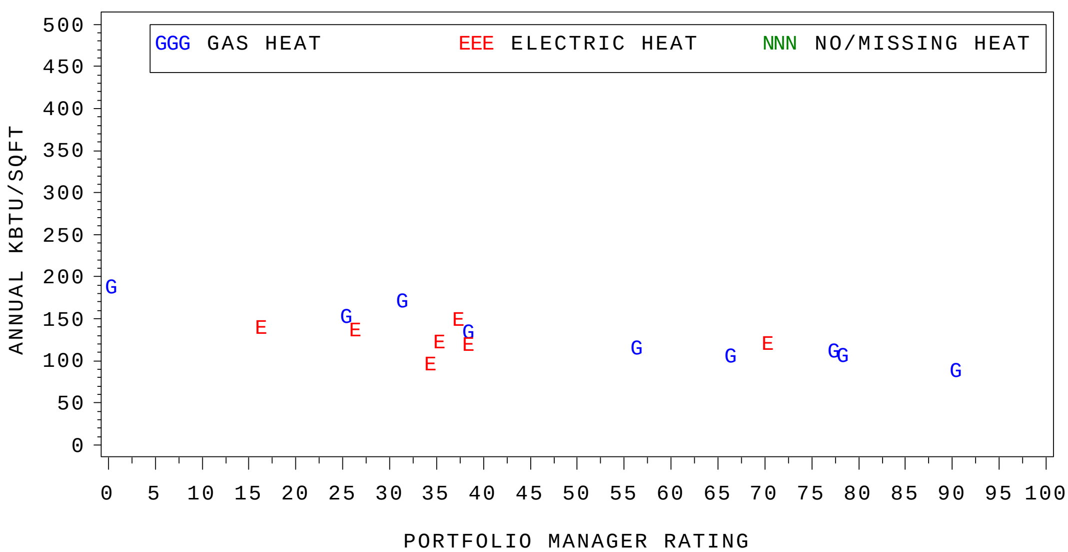
Appendix Figure 3a. Source EUI versus EPA Rating – Small Schools (ft^2 <50,000) [37]

(N=7, R^2 =0.74)



Appendix Figure 3b. Source EUI versus EPA Rating – Medium Schools (50,000 ≤ ft^2 <75,000) [38]

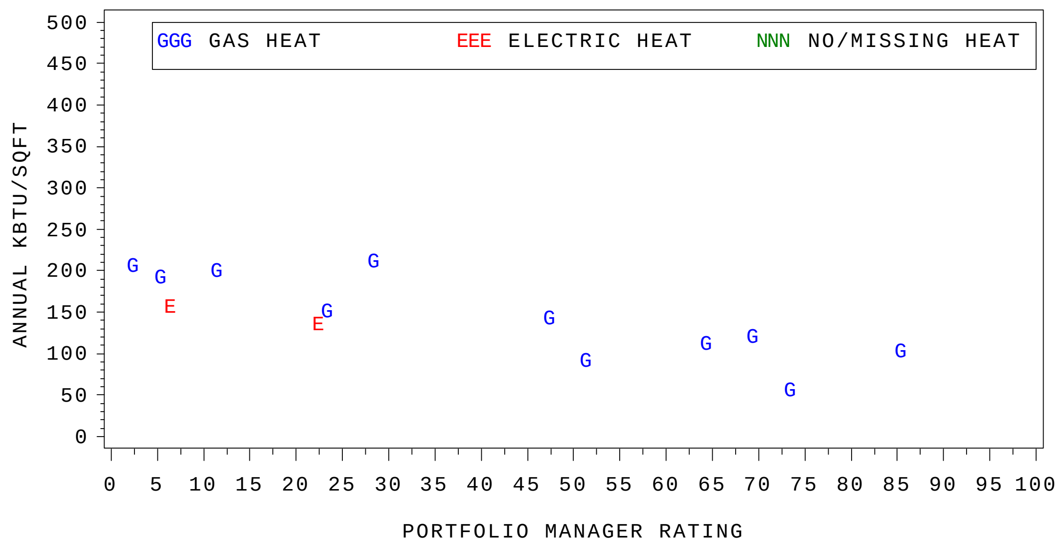
(N=16, R^2 =0.60)



[37] See footnote 27.
[38] See footnote 27.

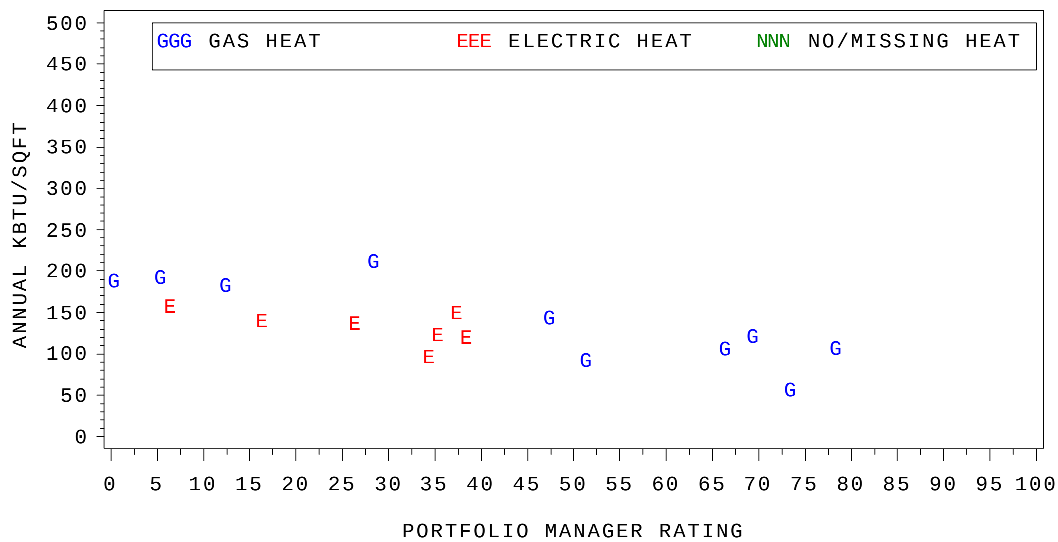
Appendix Figure 3c. Source EUI versus EPA Rating – Large Schools (75,000 ≤ ft²) [39]

(N=13, R^2 =0.67)



Appendix Figure 3d. Source EUI versus EPA Rating – Old Schools (constructed before 2001) [40]

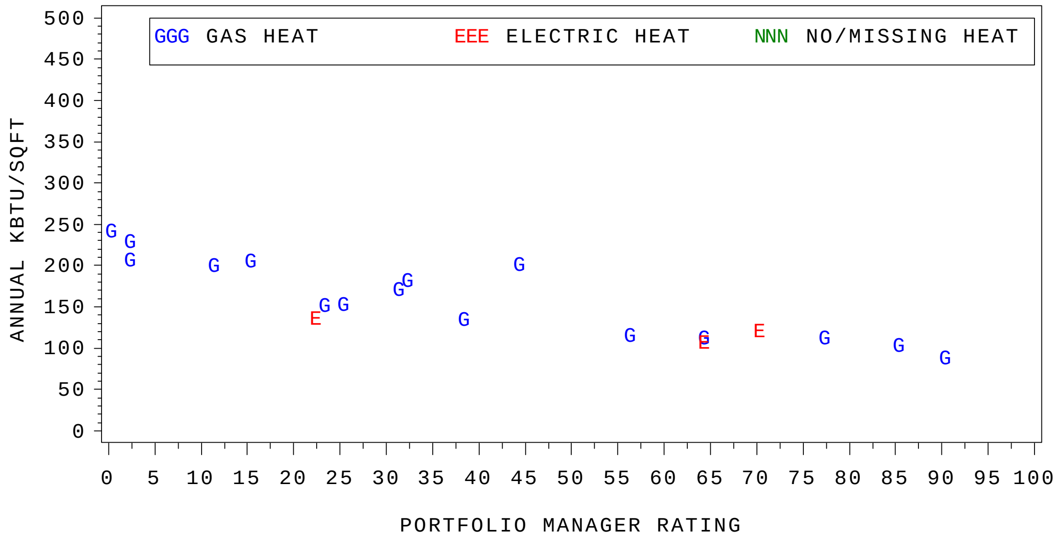
(N=17, R^2 =0.57)



[39] See footnote 27.
[40] See footnote 27.

Appendix Figure 3e. Source EUI versus EPA Rating – New Schools (constructed in or after 2001)[41]

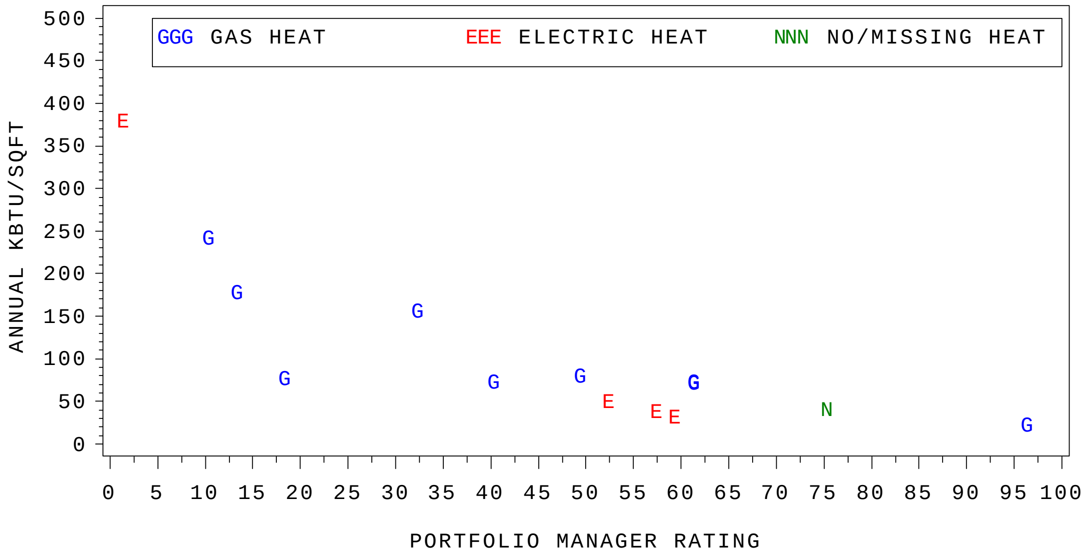
(N=19, R^2 =0.77)



[41] See footnote 27.

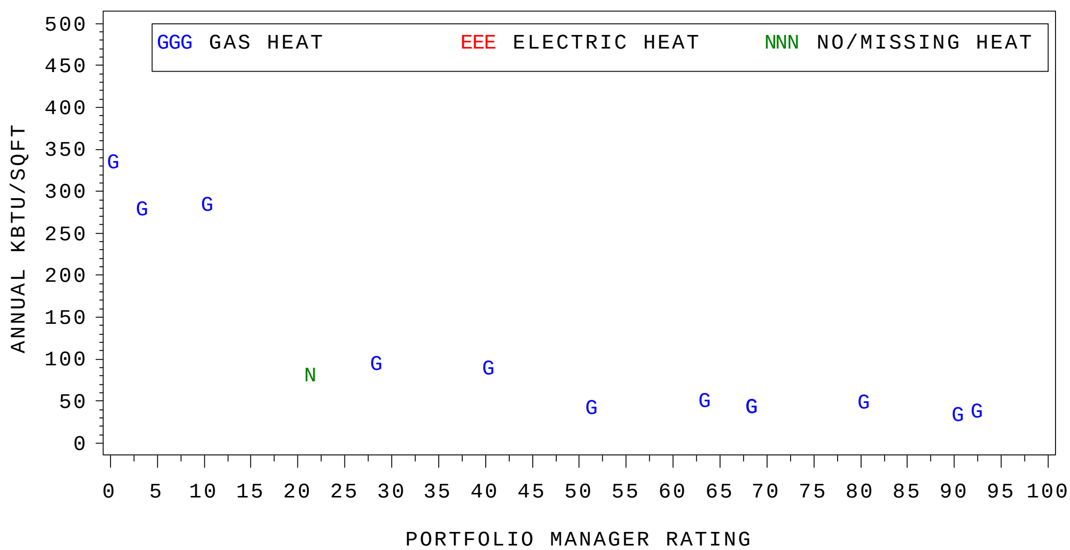
Appendix Figure 4a. Source EUI versus EPA Rating – Small Warehouses (ft^2 <25,000)

(N=14, R^2 =0.65) [42]



Appendix Figure 4b. Source EUI versus EPA Rating – Medium Warehouses (25,000 ≤ ft^2 <50,000) [43]

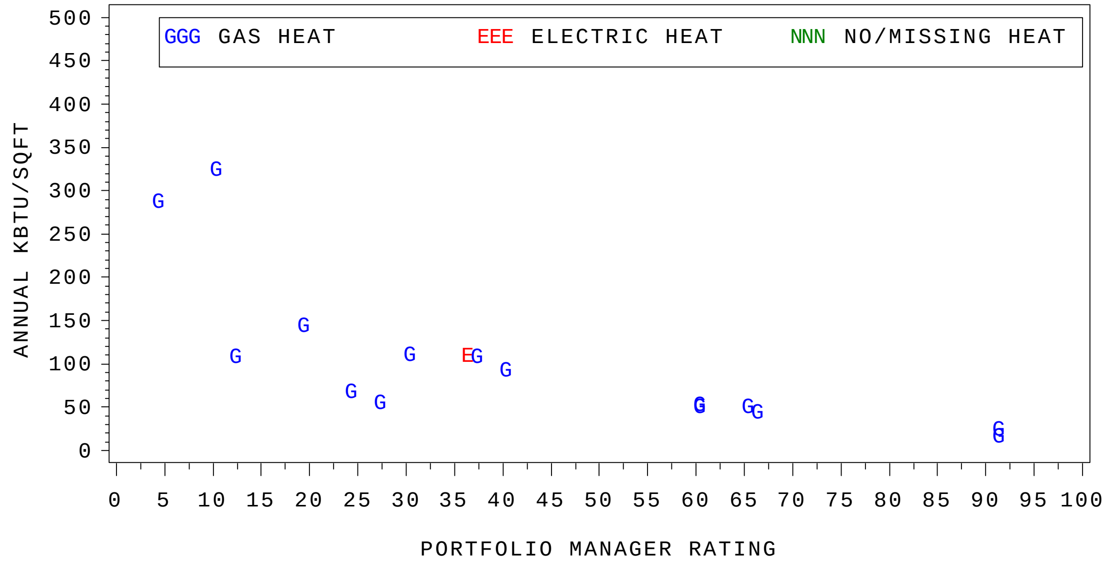
(N=13, R^2 =0.71)



[42] See footnote 27.
[43] See footnote 27.

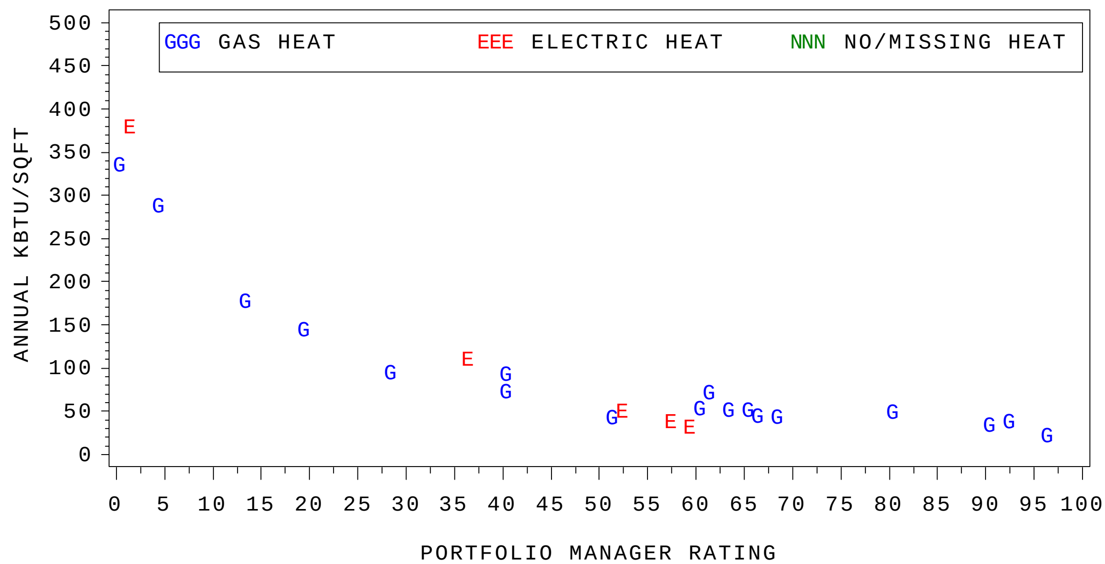
Appendix Figure 4c. Source EUI versus EPA Rating – Large Warehouses (ft^2 <50,000)[44]

(N=16, R^2 =0.55)



Appendix Figure 4d. Source EUI versus EPA Rating – Old Warehouses (constructed before 2001)[45]

(N=23, R^2 =0.72)

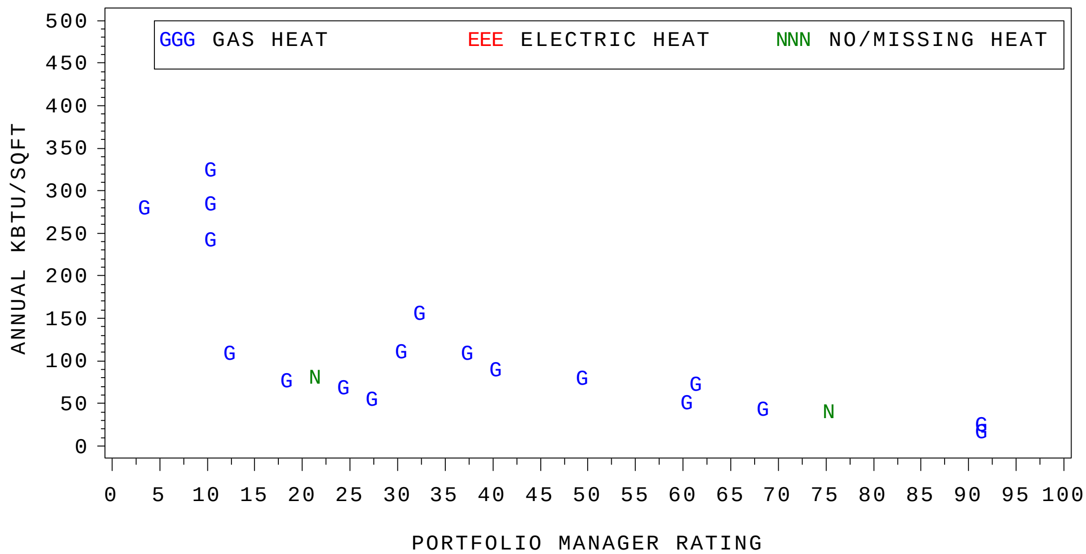


[44] See footnote 27.

[45] See footnote 27.

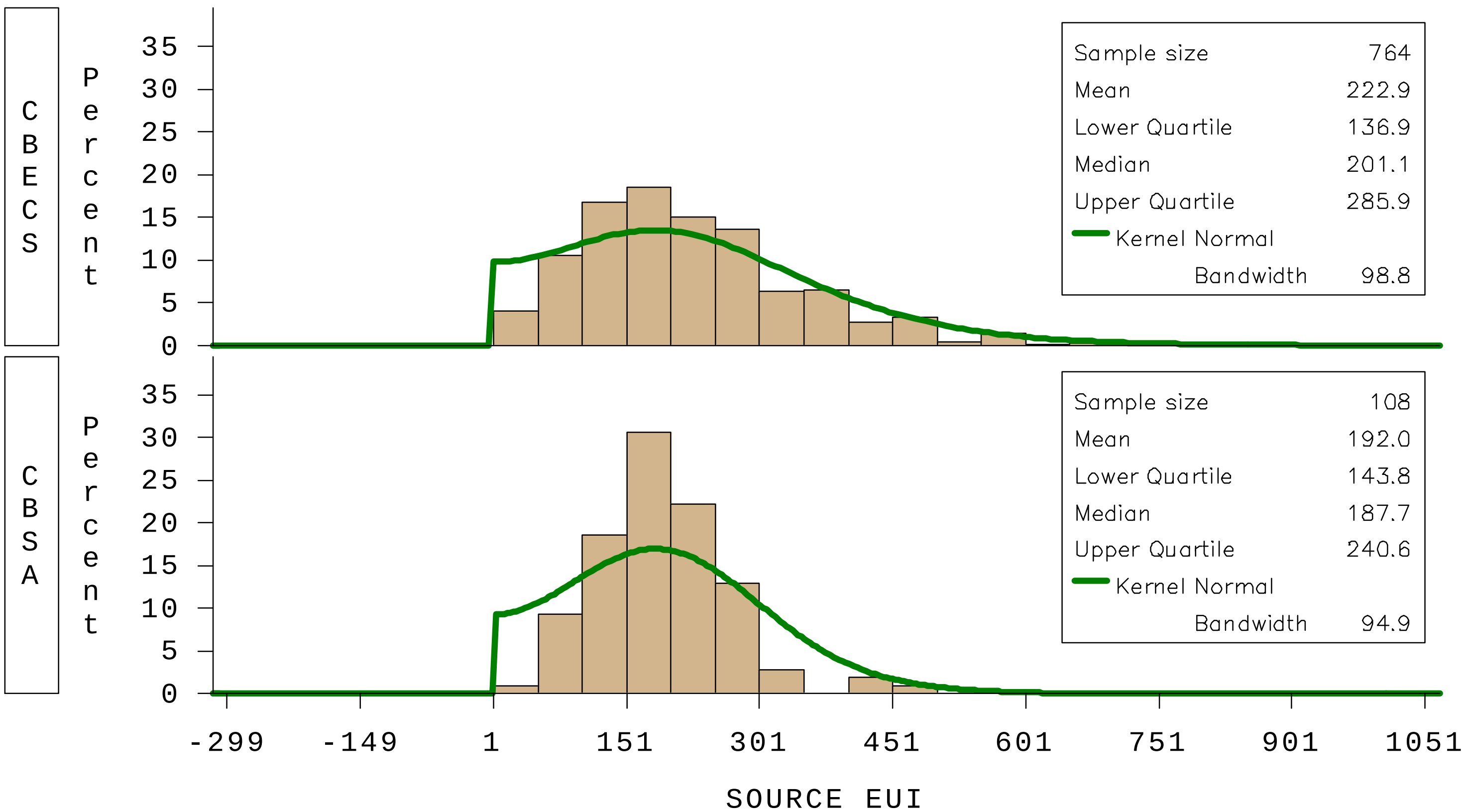
Appendix Figure 4e. Source EUI versus EPA Rating – New Warehouses (constructed in or after 2001)[46]

(N=20, R^2 =0.53)



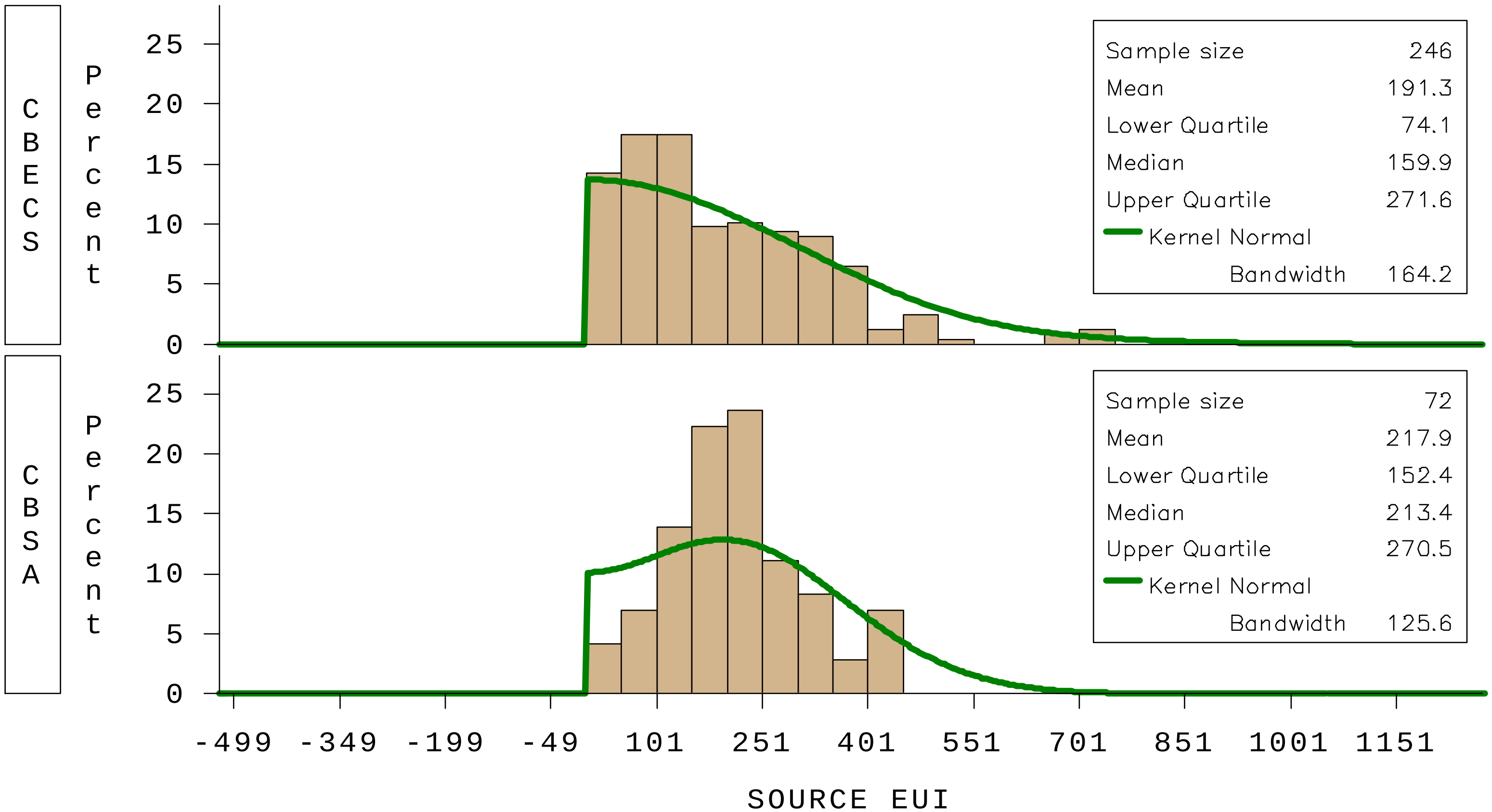
46 See footnote 27.

Appendix Figure 5.1. Distribution of Source EUI for CBECS and CBSA Offices[47]



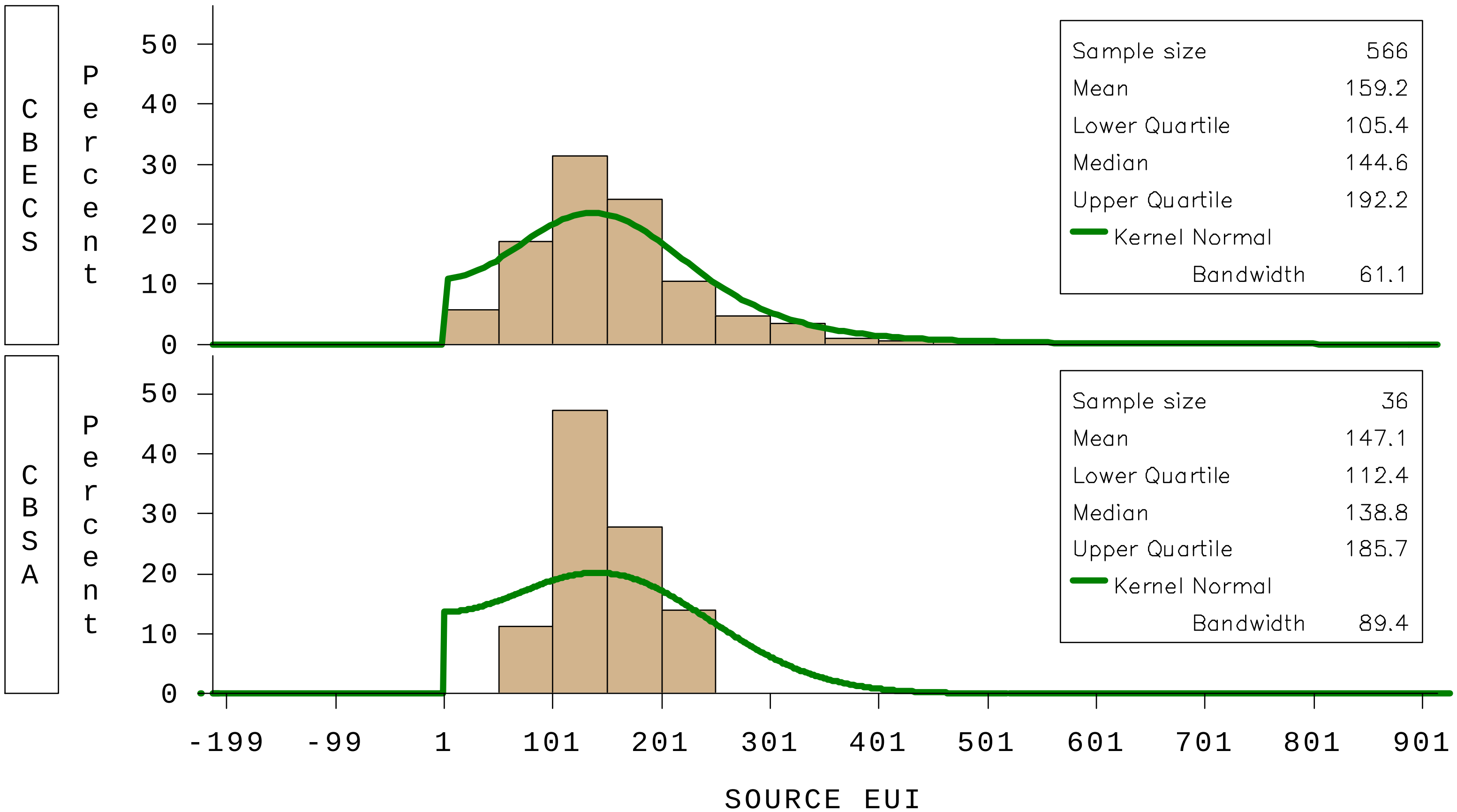
[47] Note that the values of some variables for some CBSA facilities were imputed and that the CBSA source energy use intensities reflect different weather years. See Section 3.

Appendix Figure 5.2. Distribution of Source EUI for CBECS and CBSA Retail[48]



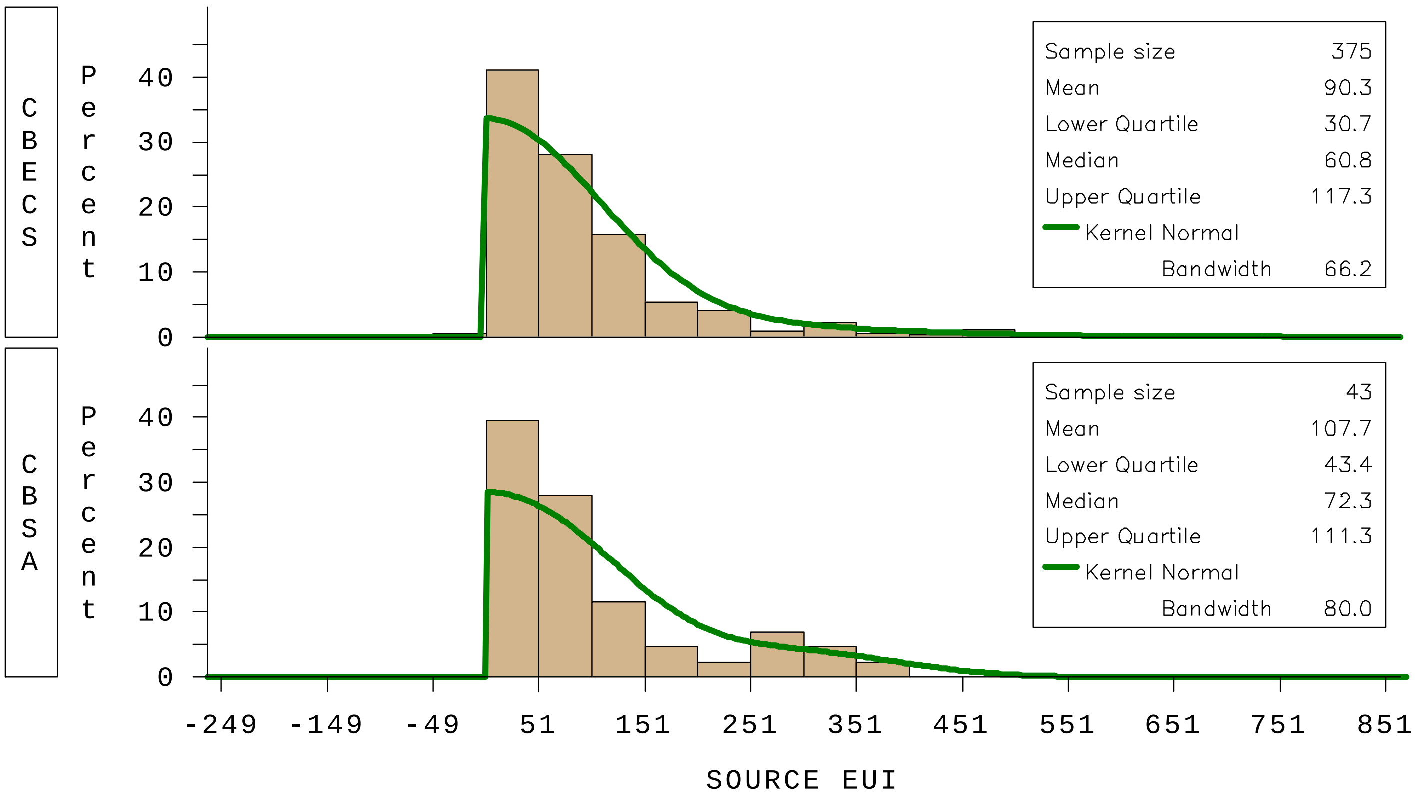
[48] See footnote 47.

Appendix Figure 5.3. Distribution of Source EUI for CBECS and CBSA Schools[49]



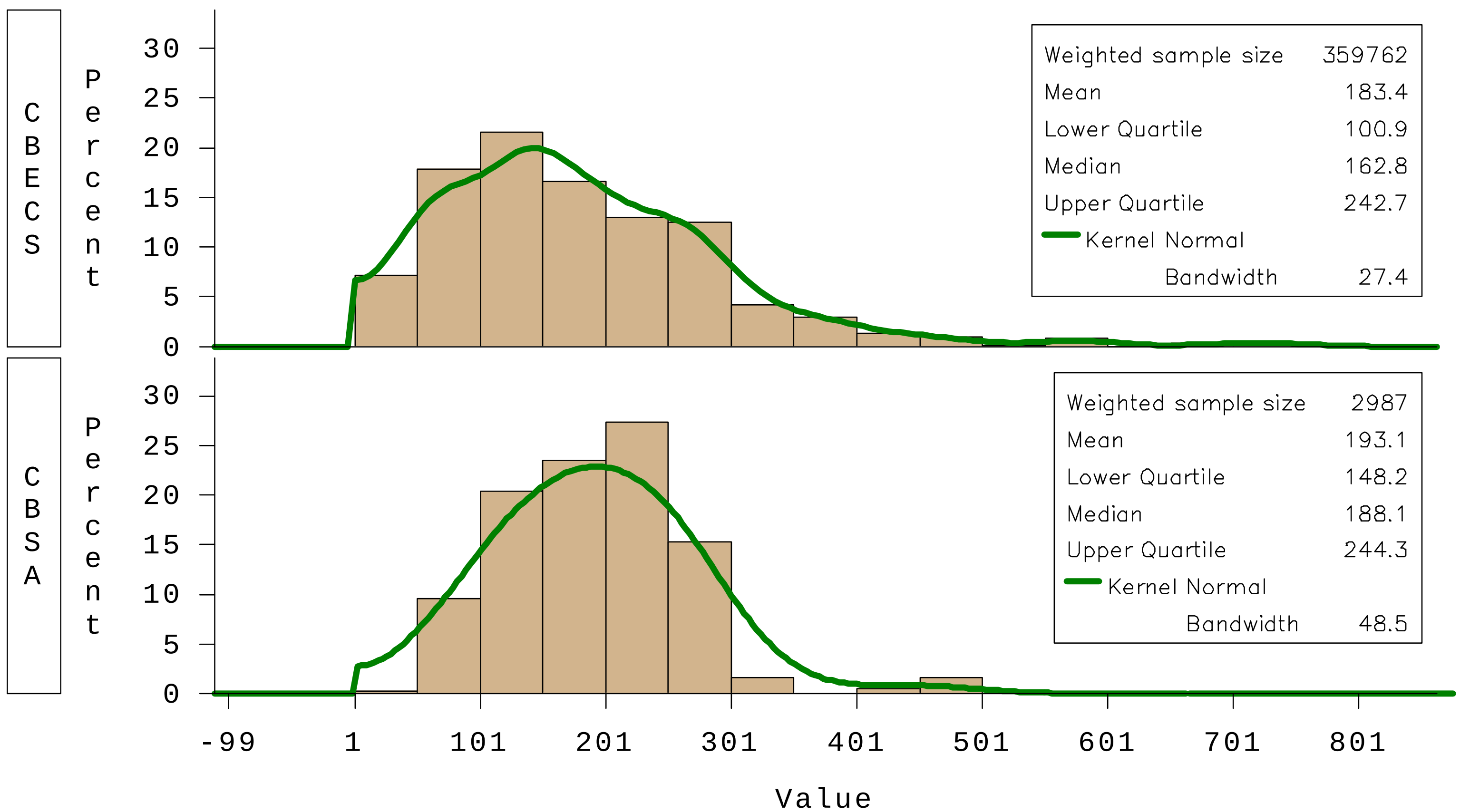
49 See footnote 47.

Appendix Figure 5.4. Distribution of Source EUI for CBECS and CBSA Warehouses[50]



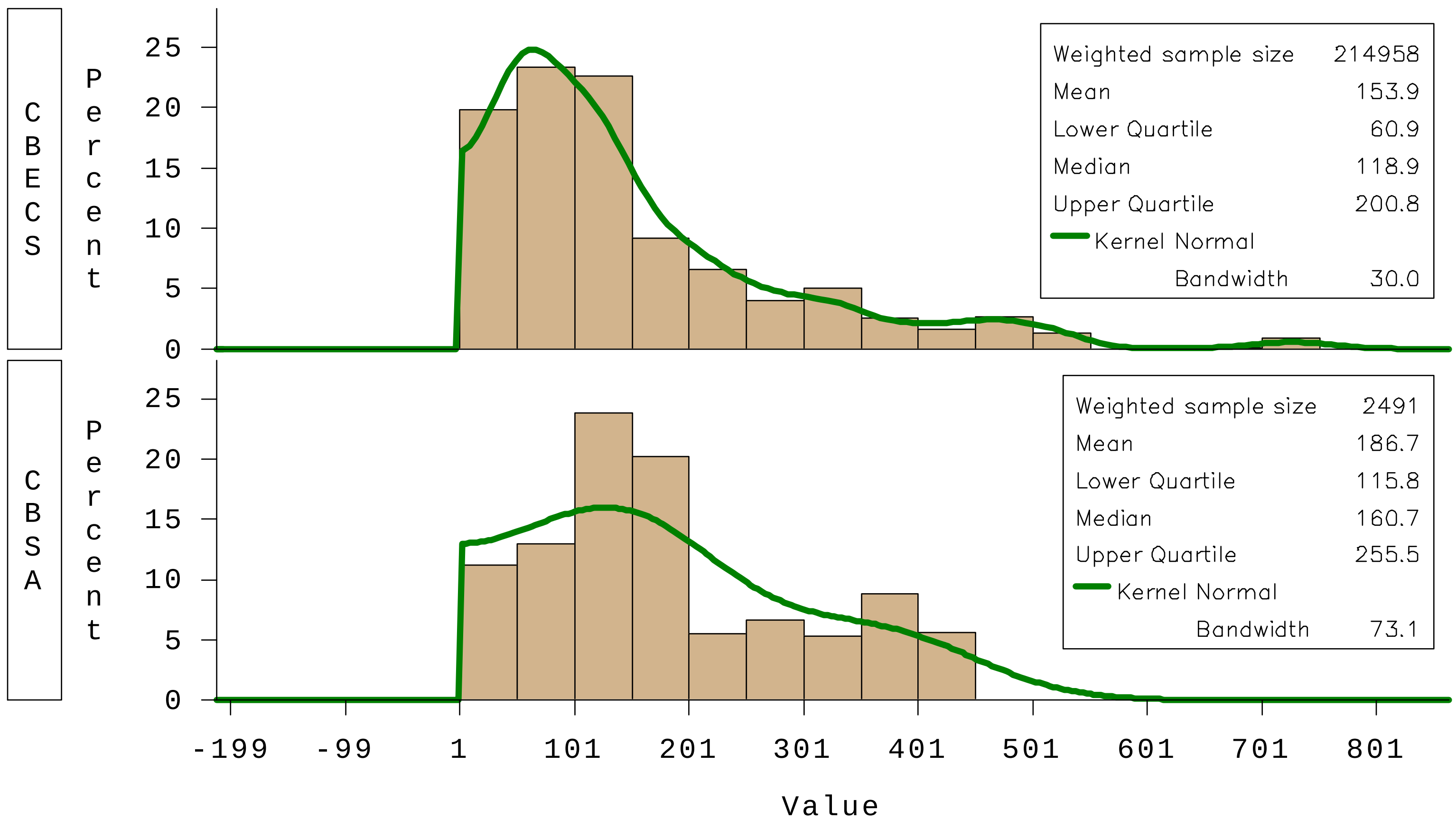
[50] See footnote 47.

Appendix Figure 5.5. Population Weighted Distribution of Source EUI for CBECS and CBSA Offices[51]



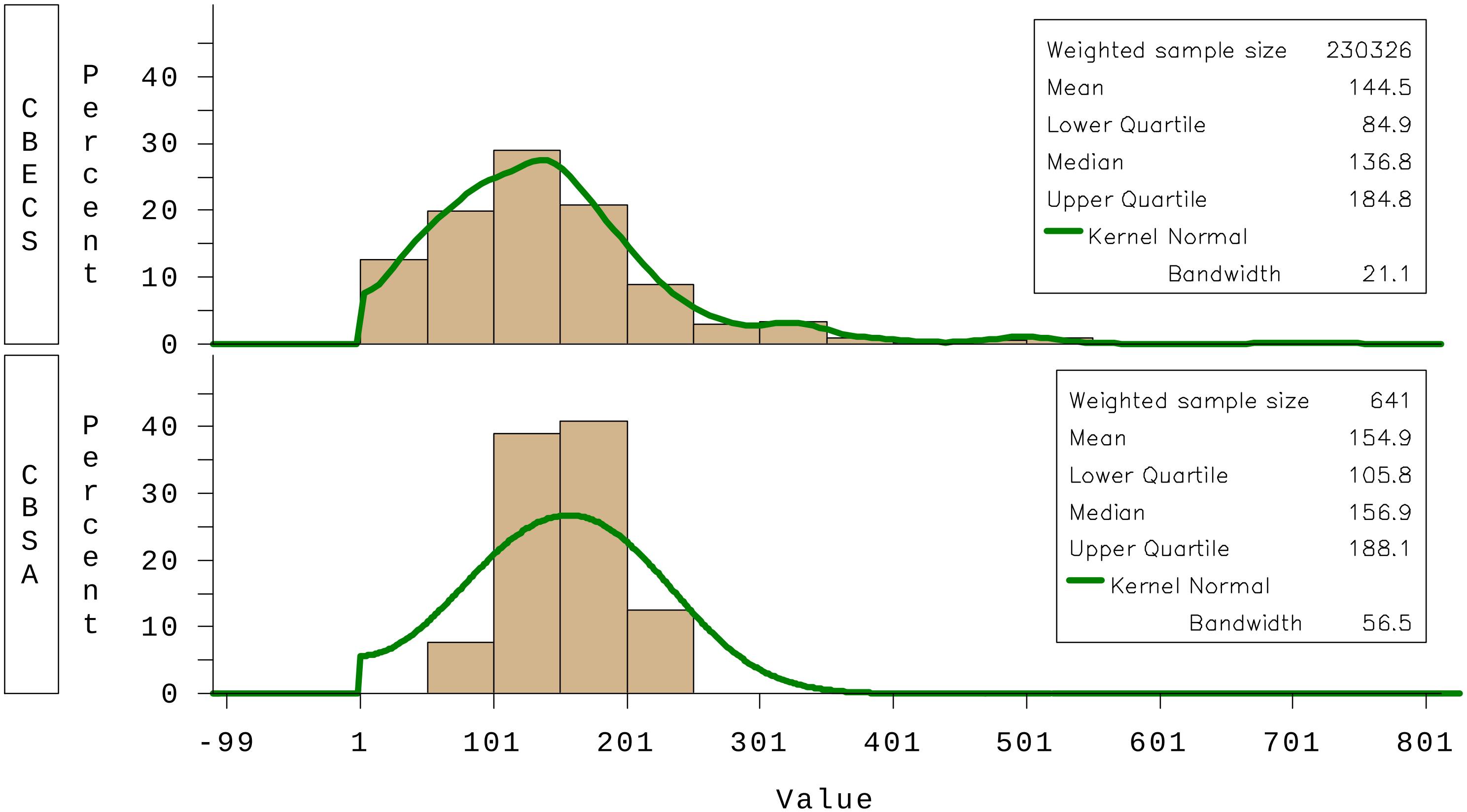
[51] See footnote 47.

Appendix Figure 5.6. Population Weighted Distribution of Source EUI for CBECS and CBSA Retail[52]



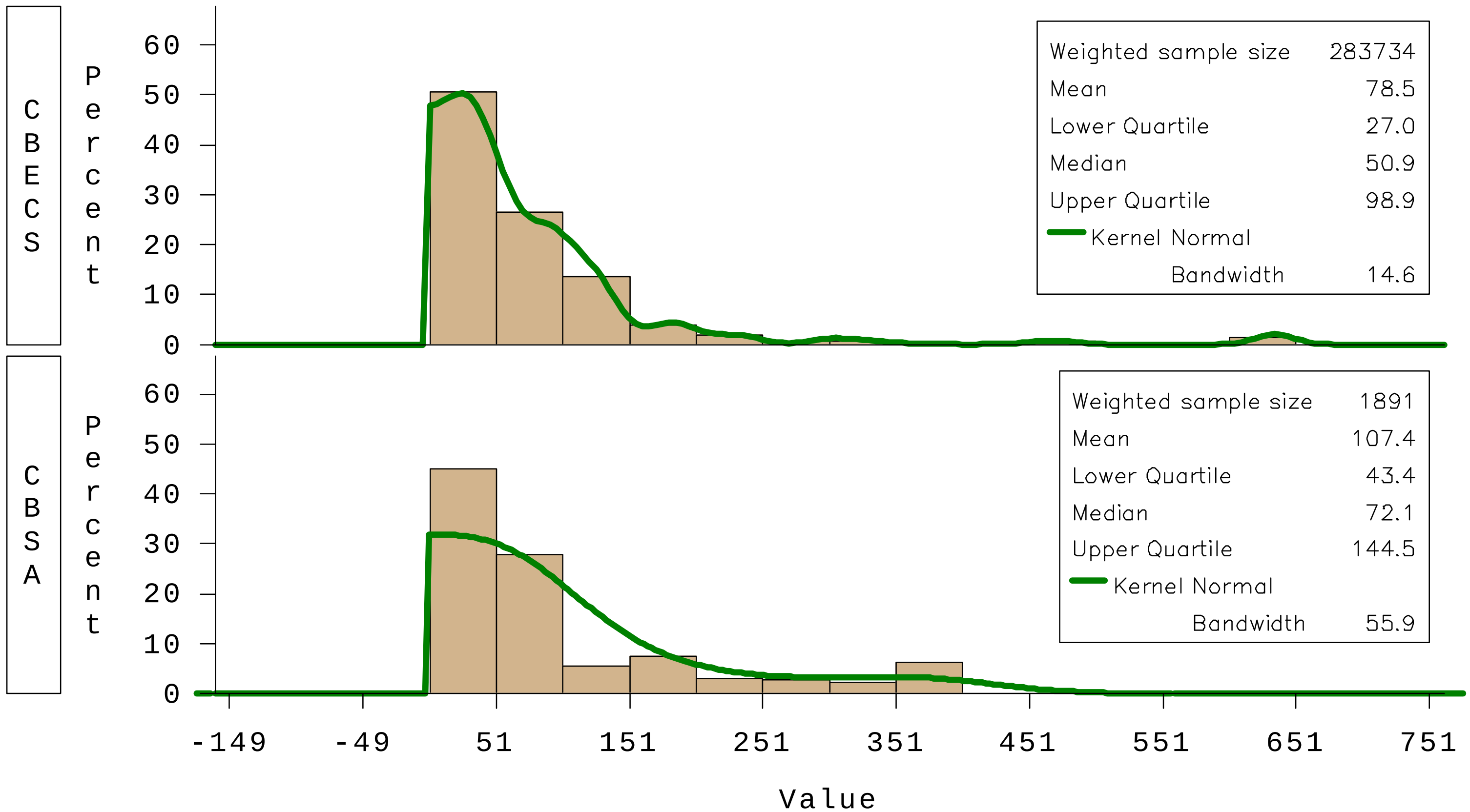
[52] See footnote 47.

Appendix Figure 5.7. Population Weighted Distribution of Source EUI for CBECS and CBSA Schools[53]



[53] See footnote 47.

Appendix Figure 5.8. Population Weighted Distribution of Source EUI for CBECS and CBSA Warehouses[54]



[54] See footnote 47.