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Is the BPD Nationally Representative?

A Comparison of the Building Performance Database to the Commercial Buildings Energy Consumption Survey

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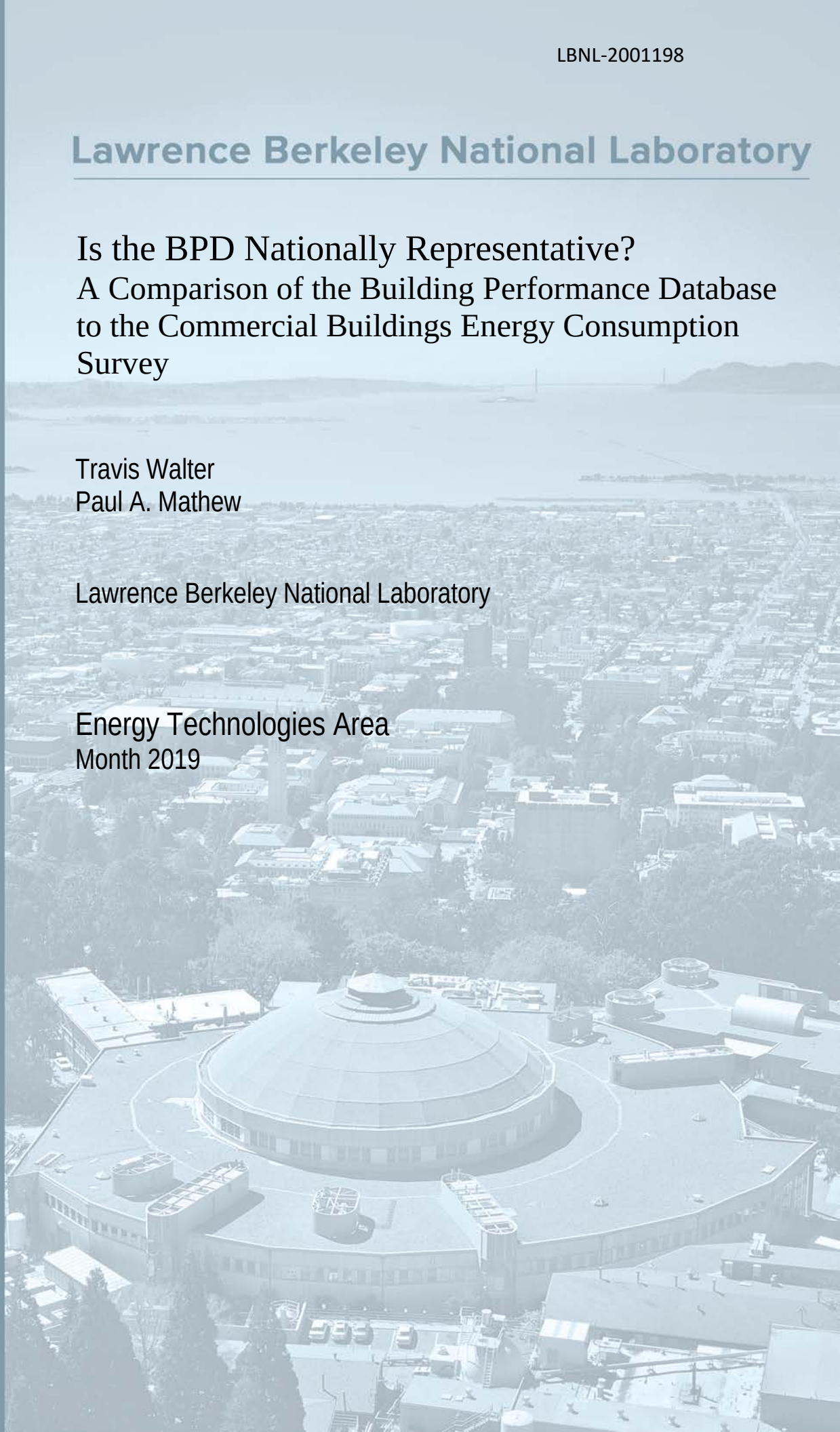

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Abstract

The Building Performance Database (BPD) contains building characteristics and energy use data that can be used to benchmark buildings against their peers. However, the BPD contains data from any source that was willing to contribute data, regardless of whether that dataset is representative of the national building stock. This report explores the representativeness of the BPD. Namely, we compared the BPD to the Commercial Buildings Energy Consumption Survey (CBECS), which was designed to be a nationally representative sample of buildings. We divided the datasets into subgroups based on building type and location, we focused on three key variables (floor area, site energy use intensity, and source energy use intensity), and we compared their statistical properties in the BPD to the CBECS. We found that while the BPD contains significantly more buildings with larger floor areas, the BPD is reasonably representative in terms of site and source energy use intensity and does not appear to have a systemic bias towards energy efficient buildings.

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Introduction

Building energy data is becoming more prevalent and provides opportunities for benchmarking. Benchmarking is an effective way to compare the energy efficiency of a building to its peers, and various benchmarking methods and tools have been developed over the last two decades (see, for example, [18], [17], [11], [10], and [8]). It is often the first step in assessing the efficiency opportunity in a building and is required in ASHRAE Standard 211[6] for commercial building energy audits. Many cities now have mandatory benchmarking laws requiring buildings meeting certain criteria (e.g., size or type) to disclose energy and characteristics data[7]. The Building Performance Database (BPD)[15] is the largest collection of energy data from real buildings, and can be used for benchmarking. The BPD can be accessed via the website[16] or the application programming interface (API)[13]. With over 13,000 website users and over 60 API users, the most frequent application of the BPD is to compare the energy use intensity (EUI) of a given building to a customized set of peer buildings (e.g., medium-sized retail buildings in a given state or climate zone). For other applications (e.g., building stock analysis), it is important for the supporting analyses to be based on a dataset that is representative of the actual building stock. Otherwise, the resulting conclusions may be biased towards a particular geographic region or type of building.

The BPD is a compilation of about 70 different datasets of different dataset sizes, building sizes, building types, and locations. The datasets are from a variety of sources from both the private and public sectors. Some datasets contain only a certain type of building (e.g., schools or hotels), some are from energy efficiency programs, and others are from city benchmarking ordinances. Some datasets contains hundreds of buildings, while others contain over ten thousand. Due to this variability in data sources, there is no reason to expect the BPD to be representative of the entire building stock. Despite the large number of buildings in the BPD (roughly 231,000 commercial buildings and 778,000 residential buildings), this represents only a small fraction (roughly 4% commercial and 0.6% residential) of the total number of buildings in the United States.

On the other hand, the Commercial Buildings Energy Consumption Survey (CBECS)[2] is a dataset that was constructed with the specific aim of being a representative sample of the national building stock. For this reason, we elected to compare the BPD to the CBECS as a means of evaluating how representative the BPD is of the building stock. That is, we assumed that if the BPD is representative of the CBECS, then the BPD is representative of the entire building stock.

In a previous paper[9], we compared the BPD to the CBECS. We found that the BPD had a somewhat similar distribution to the CBECS with respect to location: the BPD over-represented the West and Northeast census regions and under-represented the South and Midwest census regions, but not to a particularly large degree. With respect to building type, the BPD significantly over-represented Education, Office, and Retail buildings and under-represented many other types. With respect to site EUI, the BPD matched the CBECS quite closely for Retail buildings but differed significantly for Office buildings. However, this previous work contained a significant limitation: it counted each CBECS record equally, i.e., it did not use the weighting factors in the CBECS dataset to appropriately account for the number of buildings each record is meant to represent. In this paper, we resolve this limitation by properly utilizing the CBECS weighting factors.

Data

The BPD contains measured annual energy consumption data, in addition to several other data fields (building type, location, floor area, lighting, heating, and cooling types, etc.). For the full list of BPD fields, see the API documentation[12]. The data are manually converted into a standardized format using the Building Energy Data Exchange Specification (BEDES)[14], then are automatically checked for quality and consistency. The large majority of buildings (roughly 90%) have data for energy use, building type, floor area, and location, but very few buildings (roughly 5%) have information on assets like lighting, heating, and cooling types.

Likewise, the 2012 CBECS microdata[1] contain measured energy use, building type, location, floor area, and many fields relating to asset details. In addition, the dataset contains the "Final full sample building weight" field (labeled as "FINALWT") that is used to quantify how many buildings each record in the dataset represents (see [5] and [3] for more information about weights and sampling). In the remainder of this document, we use N_R to denote the number of records in a dataset and N to denote the number of buildings those records represent. For the CBECS, the number of buildings is the sum of the weights of the records in question. For the BPD, the number of buildings is equal to the number of records (since each record is measured data for an actual building).

For this study, the BPD building types and locations were mapped so as to match the building types and locations in the CBECS dataset. Namely, we used the "Principal building activity" (labeled as "PBA") field to represent building type, and we used the "Census division"

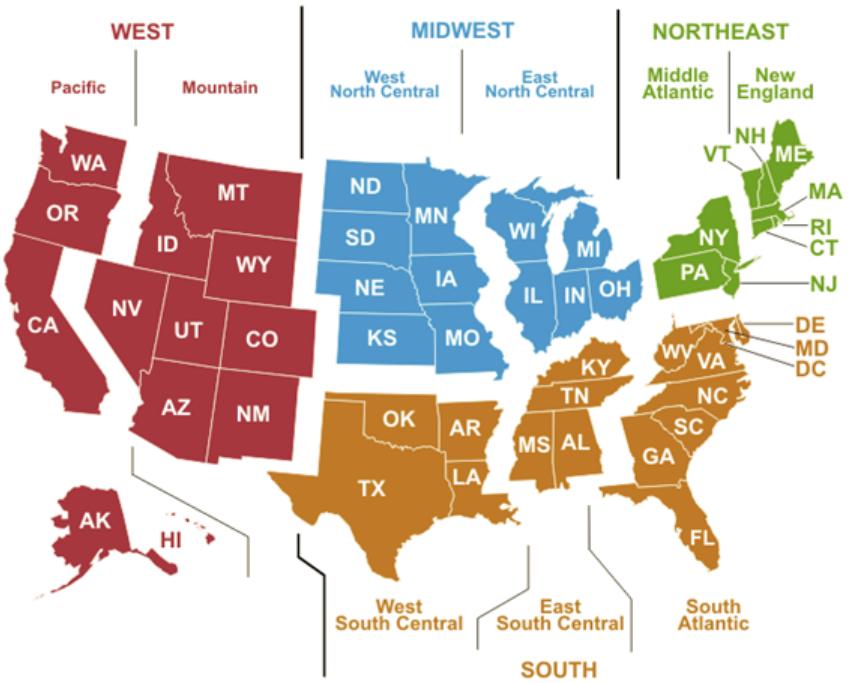

Figure 1: Map of the 9 census divisions used in the CBECS dataset.

(labeled as "CENDIV") field to represent location (see Figure 1). BPD records that did not have data for building type or location, or had types or locations that did not correspond to any CBECS types or locations, were excluded from the analysis.

Methods

When comparing BPD buildings to CBECS buildings, we first split the datasets into subgroups corresponding to buildings only of a particular type and located in a particular census division because this is the level at which comparisons are typically done and at which they are most relevant. We also note that the data can be useful if it is representative for a particular building type in a particular location, even though it is not representative for other types in other locations.

While the BPD and CBECS datasets contain data on many building assets (heating, cooling, lighting, etc.), we decided to only compare three key quantities: floor area, site EUI and source EUI. Since so few of the buildings in the BPD have data for other fields, we were not able to assess whether the BPD is representative with respect to these other fields.

In this paper, we focus only on commercial buildings, and not on residential buildings.

While there does exist a nationally representative database for residential buildings, namely, the Residential Energy Consumption Survey (RECS)[4], we do not expect the residential buildings in the BPD to be representative of the RECS. This is primarily due to the extreme bias in the BPD caused by collecting a very large number of residential buildings from a very specific geographic region.

We compared the BPD to the CBECS in three main parts:

1. We first compared the distributions of the two datasets with respect to building type and location. This helps us identify building types or locations that are over- or under-represented.

2. Next, we divided the dataset into building type and location subgroups and compared distributions of three key variables (floor area, site EUI, and source EUI) for each subgroup. We compared these distributions by overlaying histograms and by comparing their quartiles. This helps us identify subgroups that contain typically higher or lower values of key variables.

3. Lastly, we constructed scatterplots showing the agreement of BPD and CBECS quartiles for all building type and location subgroups. This helps draw conclusions about the overall agreement between the two datasets over all building type and location subgroups, with respect to each quartile of each variable.

Results

Figure 2 shows the percentage of buildings in each of the census divisions. The BPD significantly over-represents the Middle Atlantic and Pacific divisions, and significantly under-represents the West South Central division. All other divisions are represented relatively closely.

Figure 3 shows the percentage of buildings of each of the building types. The BPD highly over-represents Office, Education, Food sales, and Lodging buildings. The BPD highly under-represents several other building types (e.g., Non-refrigerated warehouse, Public assembly, and Service).

Figures 4 and 5 are examples of the 540 histograms we have included in the appendix: one for each of the 20 building types, 9 census divisions, and 3 variables (floor area, site EUI, and source EUI).

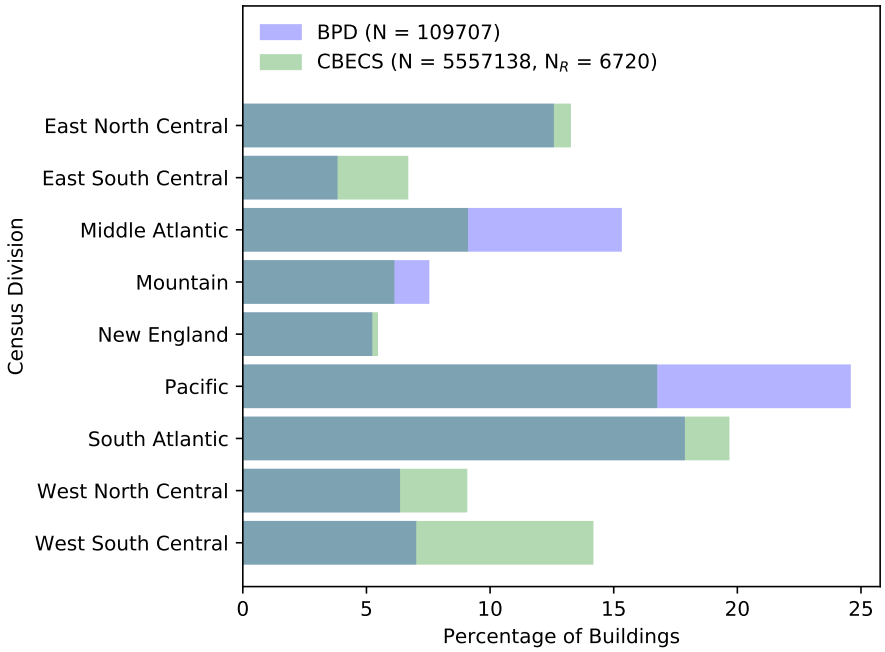

Figure 2: Histogram of census division in the BPD and CBECS datasets. In the legend, N is the number of buildings and N_R is the number of records.

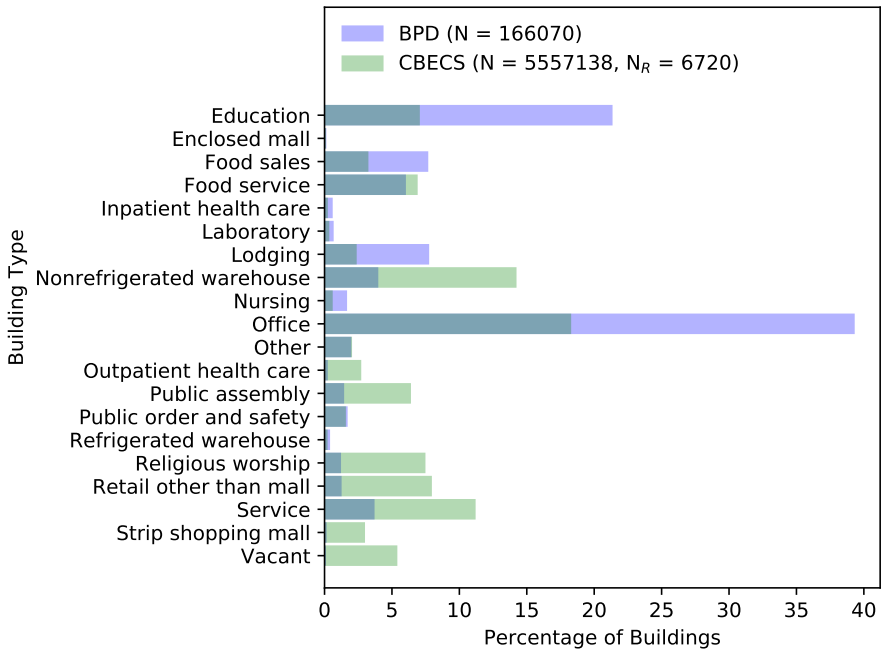

Figure 3: Histogram of building type in the BPD and CBECS datasets. In the legend, N is the number of buildings and N_R is the number of records.

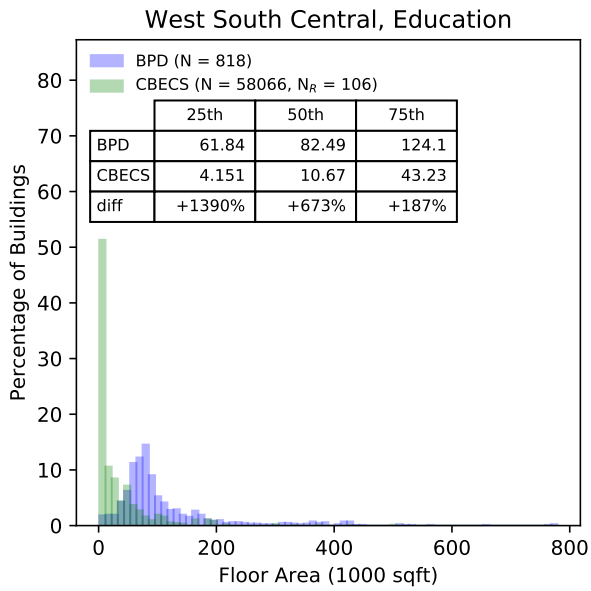

Figure 4: Histogram of floor area for Education buildings in the West South Central census division. In the legend, N is the number of buildings and N_R is the number of records. The table shows the 25th, 50th, and 75th percentiles for BPD and CBECS, and the difference between BPD and CBECS relative to CBECS.

Figure 4 shows the percentage of buildings with each floor area for Education buildings in the West South Central census division, and shows the percentiles for each dataset. The BPD contains significantly larger buildings (e.g., the 25th percentile in the BPD is nearly 15 times as large as in the CBECS). In addition, the shape of the BPD distribution is significantly different than that of the CBECS distribution (i.e., the CBECS distribution is steadily decreasing while the BPD distribution's peak is shifted towards larger areas).

Figure 5 shows the percentage of buildings with each site EUI for Office buildings in the Pacific census division, and shows the percentiles for each dataset. The distributions have very similar shapes, and despite the BPD's 25th percentile being 48% higher than that of CBECS, the 50th and 75th percentiles are within 4%.

Overall, with exceptions for some building type and census division subgroups, the area histograms show two major trends:

1. Both the BPD and CBECS datasets have similar histograms shapes: nearly all buildings have very small floor areas and very few buildings have larger areas. This histogram shape is nearly always true in the CBECS, and is mostly true in the BPD. Most of the cases in which this is not true is when the particular building type and

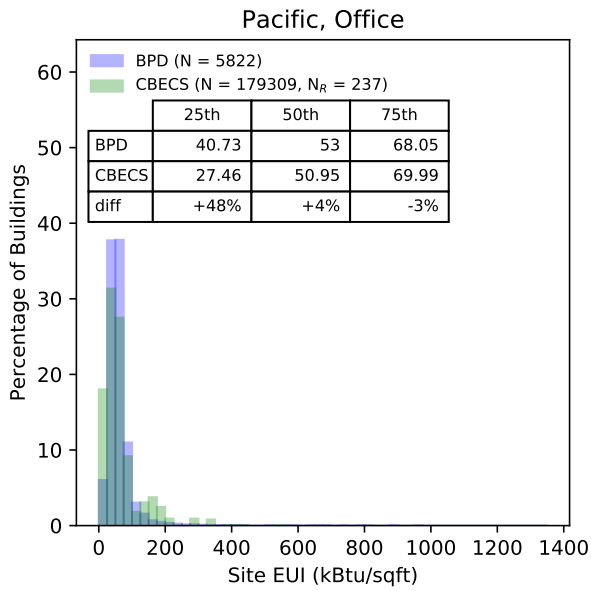

Figure 5: Histogram of site EUI for Office buildings in the Pacific census division. In the legend, N is the number of buildings and N_R is the number of records. The table shows the 25th, 50th, and 75th percentiles for BPD and CBECS, and the difference between BPD and CBECS relative to CBECS.

census division subgroup contains relatively few records.

2. The BPD consistently contains buildings with larger floor areas, with BPD quartiles often exceeding those of CBECS by several hundred percent. These differences tend to be largest for the 25th percentile, smaller for the 50th percentile, and smaller yet for the 75th percentile.

Likewise, with exceptions for some building type and census division subgroups, the site and source EUI histograms show two major trends:

1. There is significant variation in the shape of the histograms for different building type and census division combinations. This is true for both site EUI and source EUI and for both the BPD and CBECS datasets. In cases where there are a substantial number of records, the histogram shapes tend to be more consistently log-normal, and tend to agree better between the BPD and the CBECS.

2. There is significantly less difference between the BPD and CBECS quartiles for site and source EUI than for floor area. The differences are typically on the order of tens of percents, rather than hundreds. In addition, these differences tend to be both positive

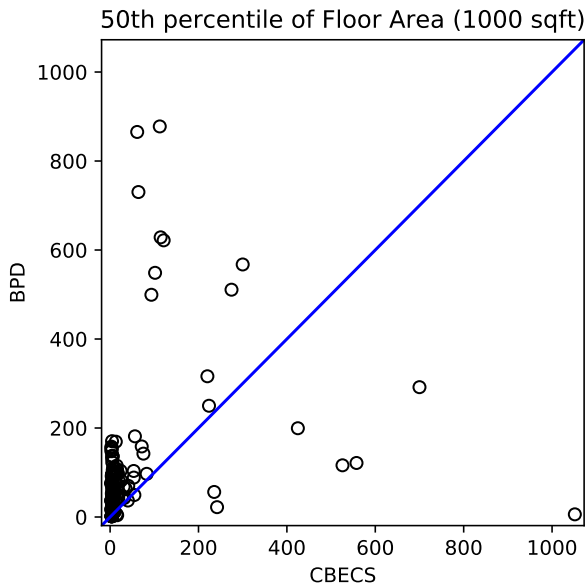

Figure 6: Scatterplot of the 50th percentile of floor area for the BPD and CBECS datasets. Each circle represents one combination of building type and census division. The blue line indicates all values where the BPD and CBECS percentiles are equal.

and negative (i.e., the BPD has both higher and lower EUI quartiles), rather than just positive (i.e., the BPD typically has higher floor area quartiles).

Figures 6 and 7 are examples of the 9 scatterplots we have included in the appendix: one for each of the 3 quartiles and 3 variables (floor area, site EUI, and source EUI).

Figure 6 shows a scatterplot of the 50th percentile of floor area for each dataset and for each building type and census division subgroup. Some subgroups are scattered particularly far from the blue line, indicating major differences between the BPD and CBECS quartile in the subgroup. The majority of the circles lie above the blue line, indicating that in most subgroups the BPD quartile is larger than the CBECS quartile (i.e., the BPD tends to have larger buildings than the CBECS). The scatterplots for the 25th and 75th percentiles of floor area show nearly the same shape and same trends (i.e., high scatter and most circles above the blue line).

Figure 7 shows a scatterplot of the 50th percentile of site EUI for each dataset and for each building type and census division subgroup. Some subgroups are scattered far from the blue line, but the degree of scatter is less than with floor area. This indicates smaller differences between the BPD and CBECS quartiles. There are roughly as many circles above the blue line as below, indicating the BPD quartiles are larger than the corresponding CBECS

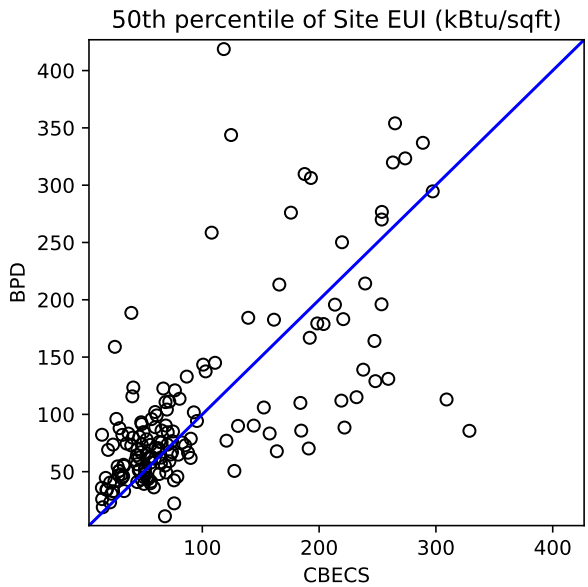

Figure 7: Scatterplot of the 50th percentile of site EUI for the BPD and CBECS datasets with one circle representing each combination of building type and census division. The blue line indicates all values where the BPD and CBECS percentiles are equal.

quartiles roughly as often (i.e., the BPD does not consistently over- or under-represent the 50th percentile of site EUI). The scatterplots for the 25th and 75th percentiles of site EUI show nearly the same shape and same trends (i.e., moderate scatter and as many circles above the blue line as below).

Conclusion

This report analyzed the representativeness of the BPD relative to the national building stock, by comparing the BPD to the CBECS, which was designed to be a nationally representative sample of buildings. We found that while the BPD contains significantly more buildings with larger floor areas, the BPD is reasonably representative in terms of site and source EUI and does not appear to have a systemic bias (i.e., the BPD does not inherently have a self-selection bias toward more efficient buildings). The degree of representativeness varies by building type and location and the appendix contains comparisons of 180 combinations of building types and census divisions.

We encourage BPD users to refer to the appendix to decide whether the BPD adequately represents the particular building types and locations relevant to their analysis. Future

BPD data collection efforts will target the under-represented building types and locations identified in this report.

We reiterate that the BPD is not a national statistical sample and is not appropriate for the type of applications that require rigorous statistical sampling (e.g., estimates of national or regional energy use). However, the BPD can be used effectively for analyzing general trends and comparing buildings to customized peer groups for purposes of screening efficiency potential.

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Appendix

Floor area histograms

The following 20 pages contain histograms of floor area for each building type and census division. In the legend, N is the number of buildings and N_R is the number of records. The table shows the 25th, 50th, and 75th percentiles for BPD and CBECS, and the difference between BPD and CBECS relative to CBECS. In some cases, there are too few buildings for meaningful calculations of the percentiles, so "nan" (not a number) is shown instead.

Building Type = Education

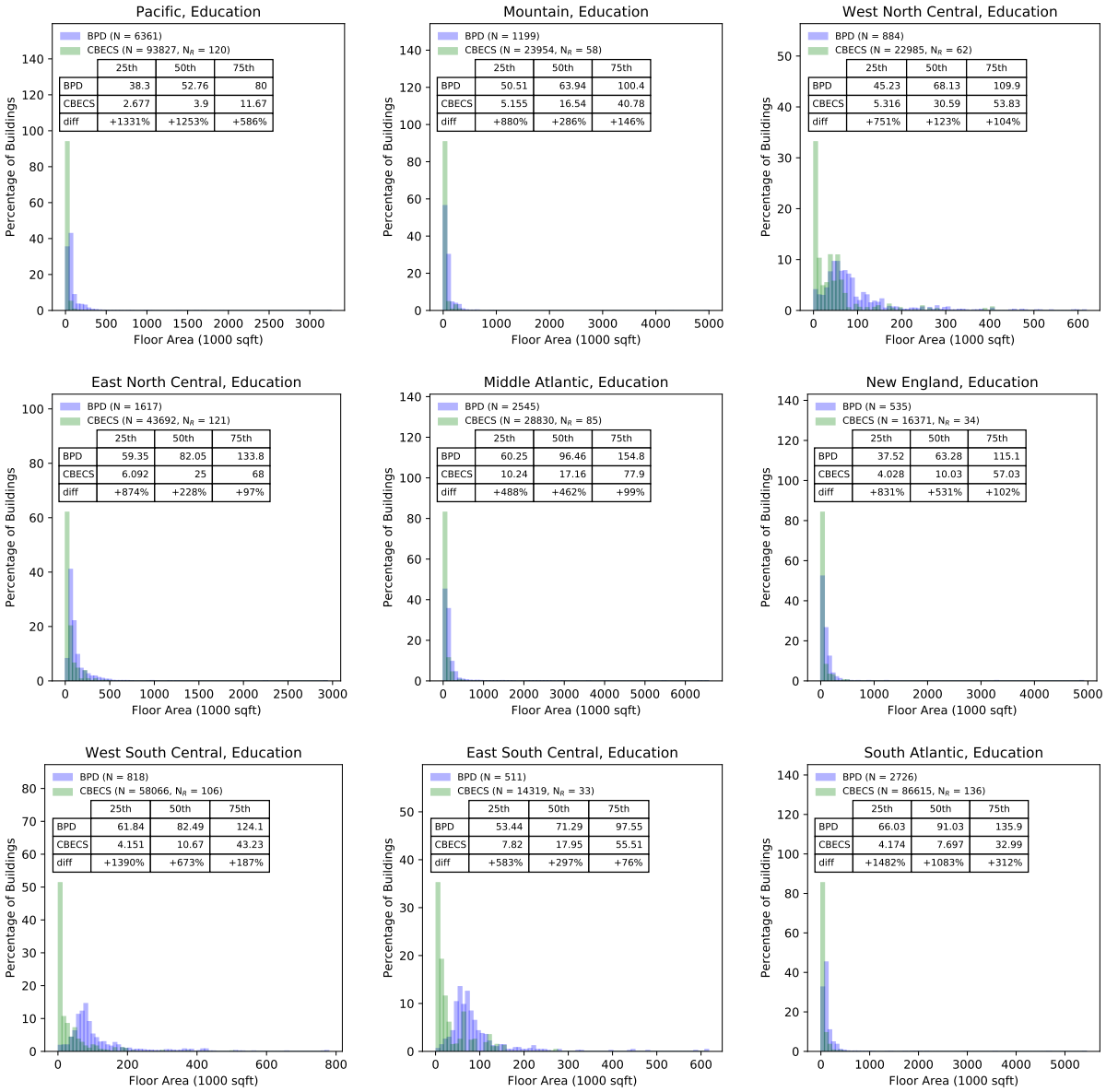


Figure 8: Histograms of floor area for Education buildings in each census division.

Building Type = Enclosed mall

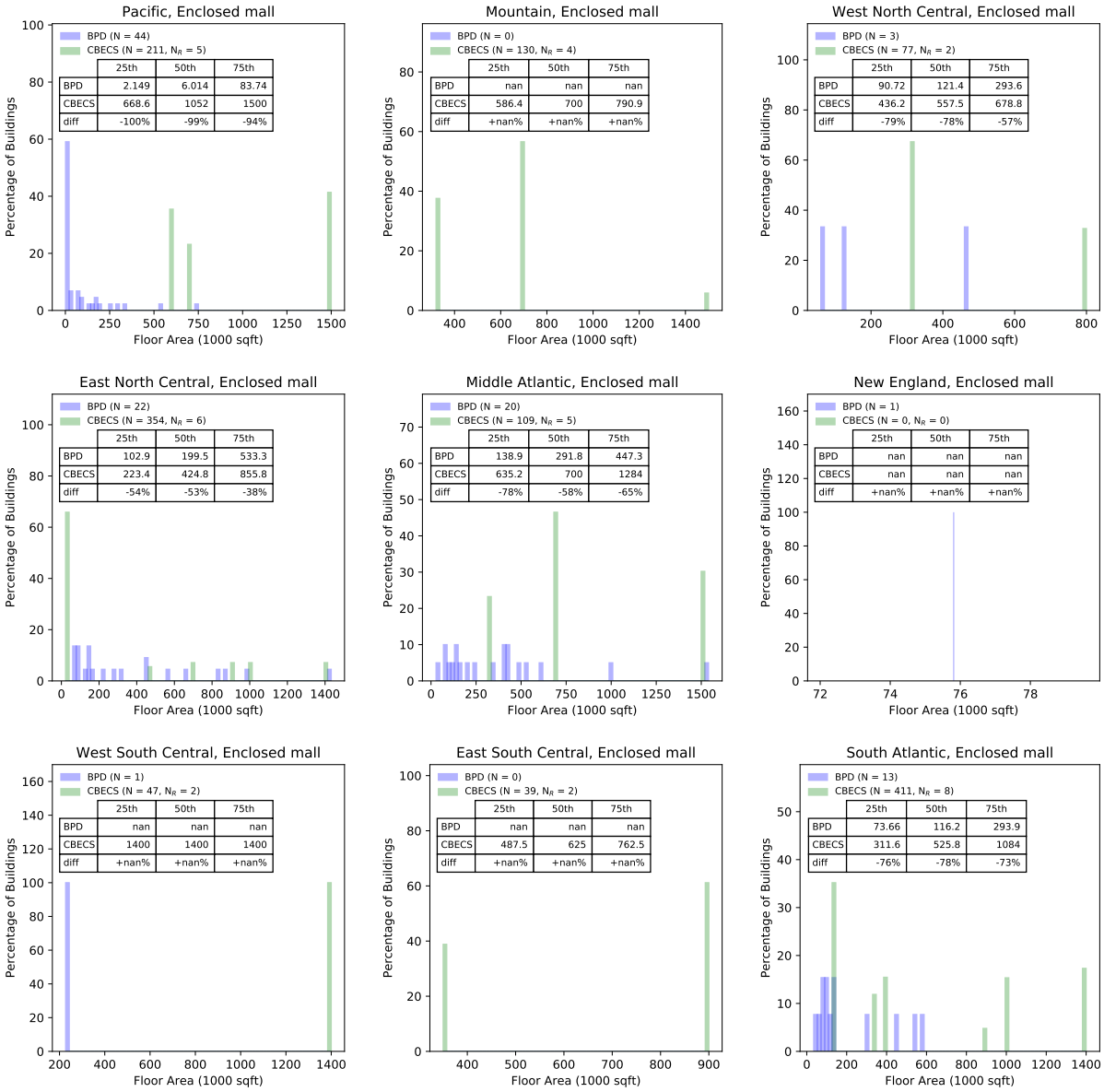


Figure 9: Histograms of floor area for Enclosed mall buildings in each census division.

Building Type = Food sales

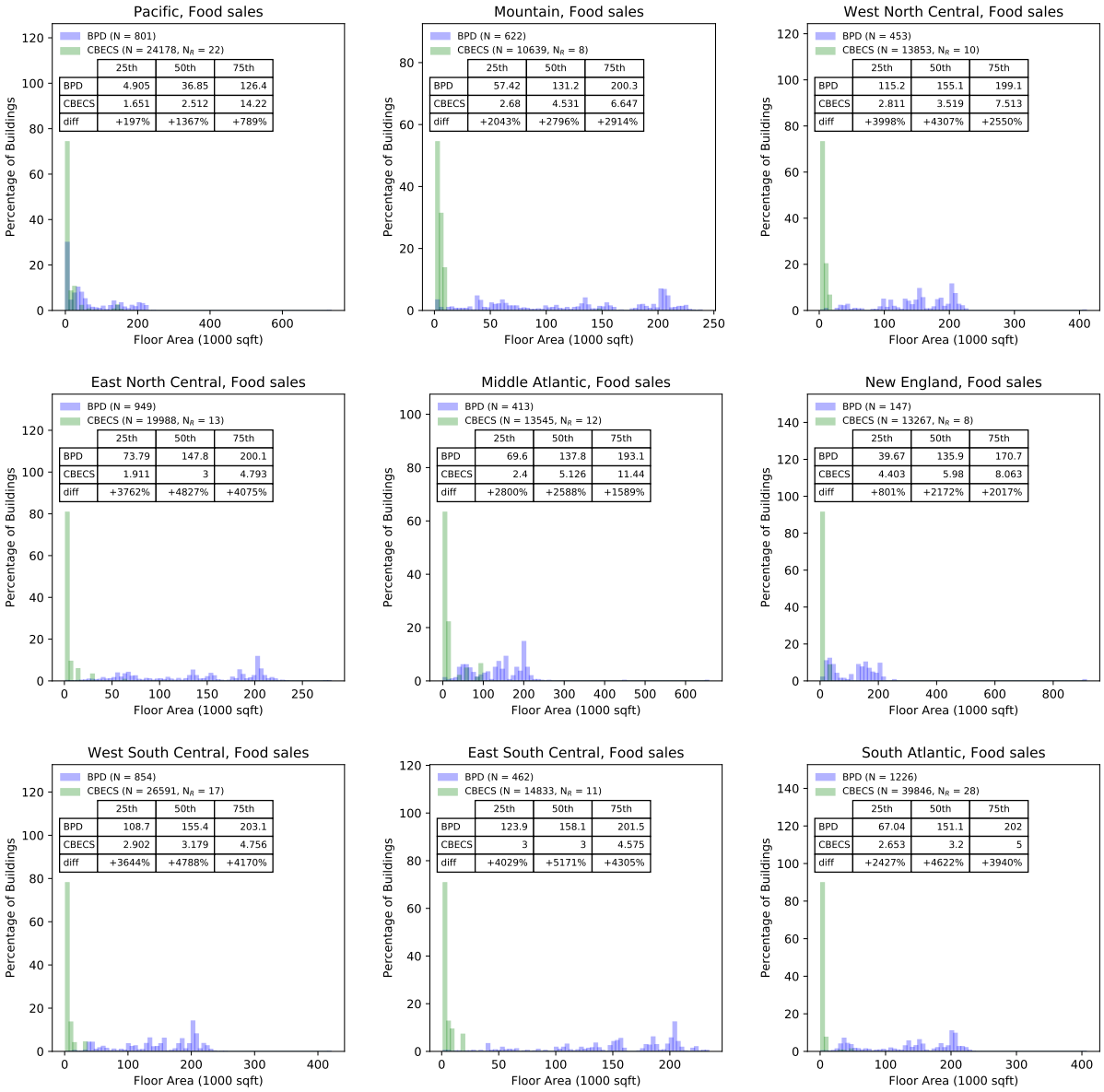


Figure 10: Histograms of floor area for Food sales buildings in each census division.

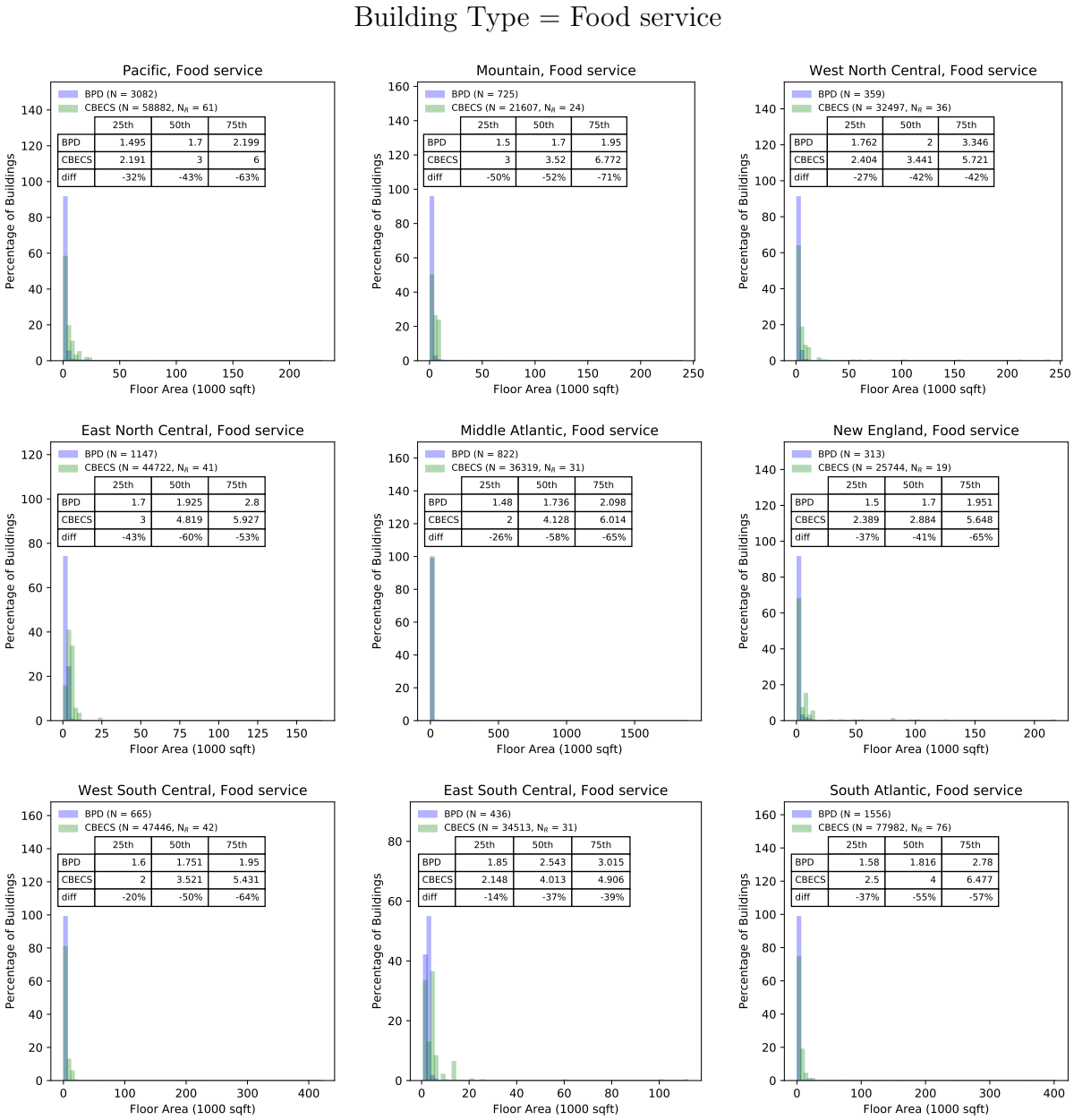


Figure 11: Histograms of floor area for Food service buildings in each census division.

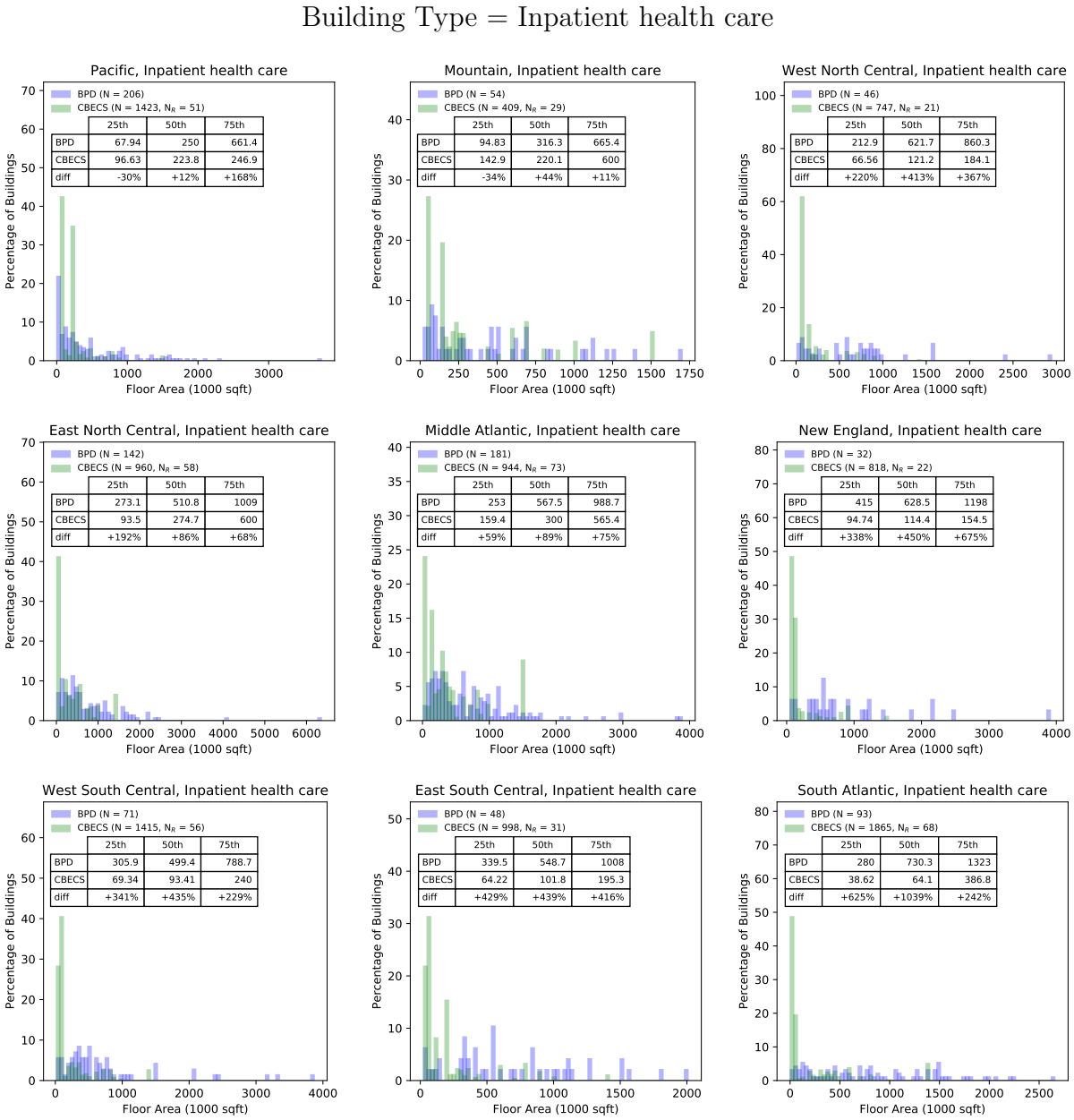


Figure 12: Histograms of floor area for Inpatient health care buildings in each census division.

Building Type = Laboratory

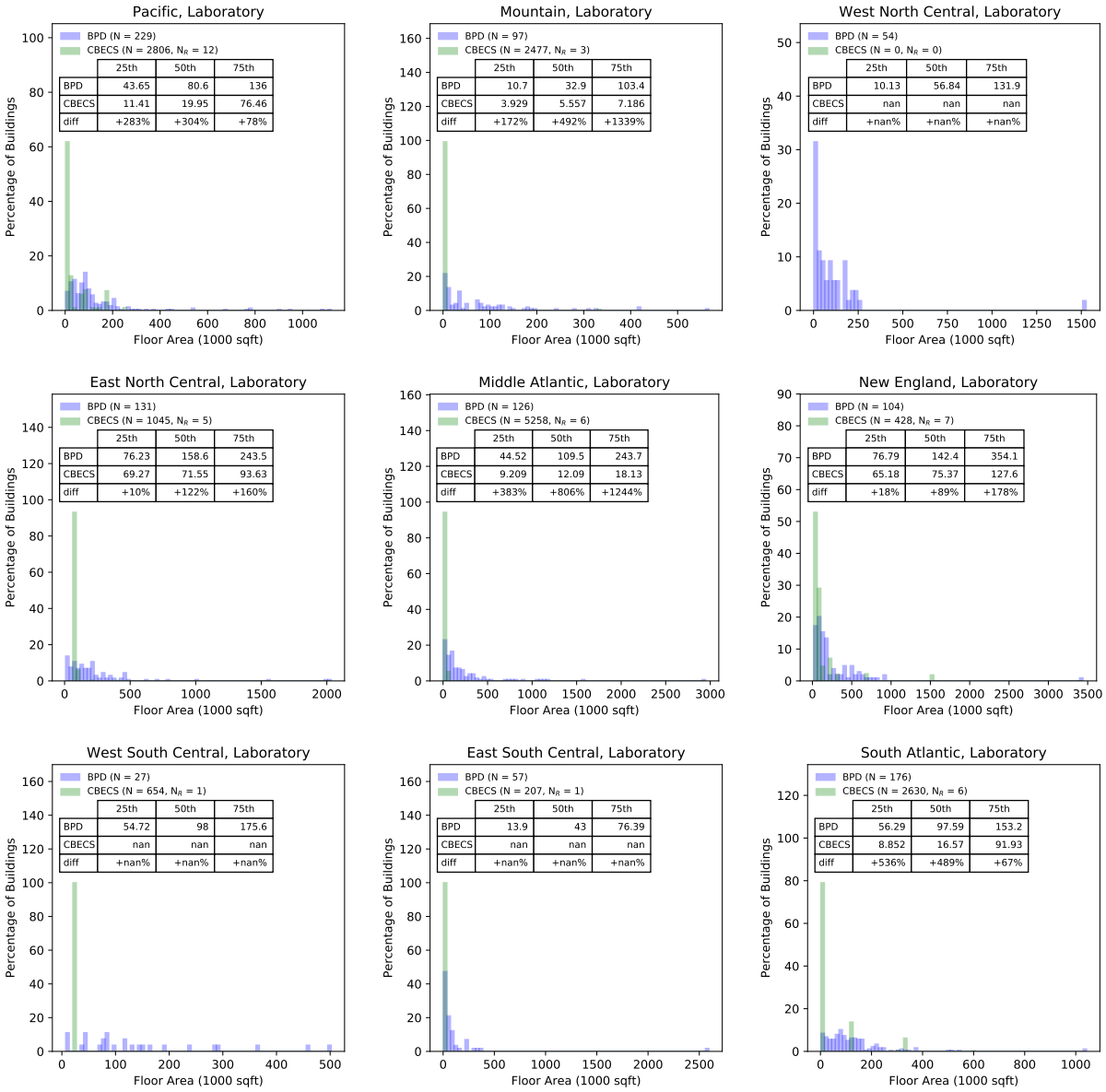


Figure 13: Histograms of floor area for Laboratory buildings in each census division.

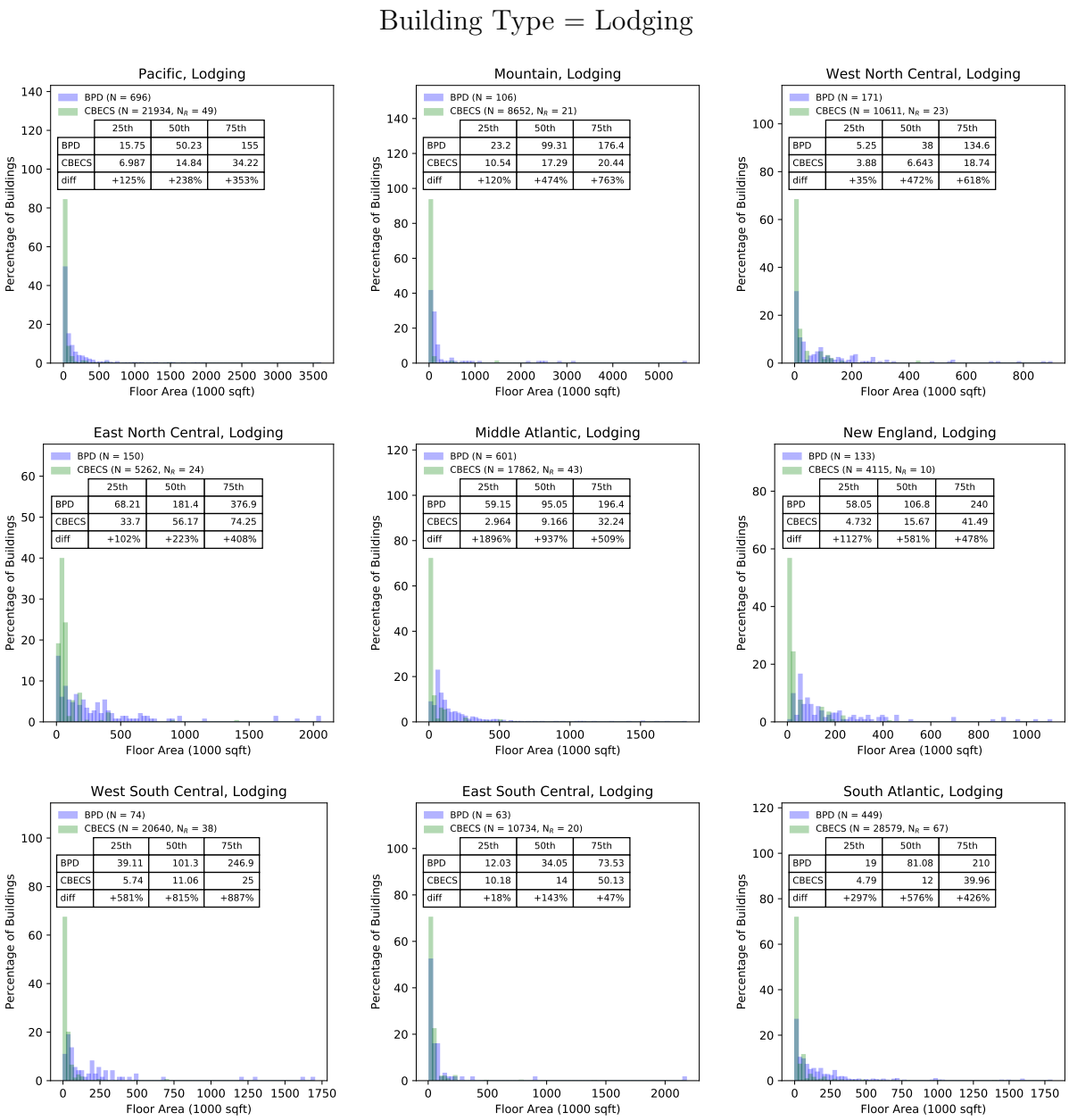


Figure 14: Histograms of floor area for Lodging buildings in each census division.

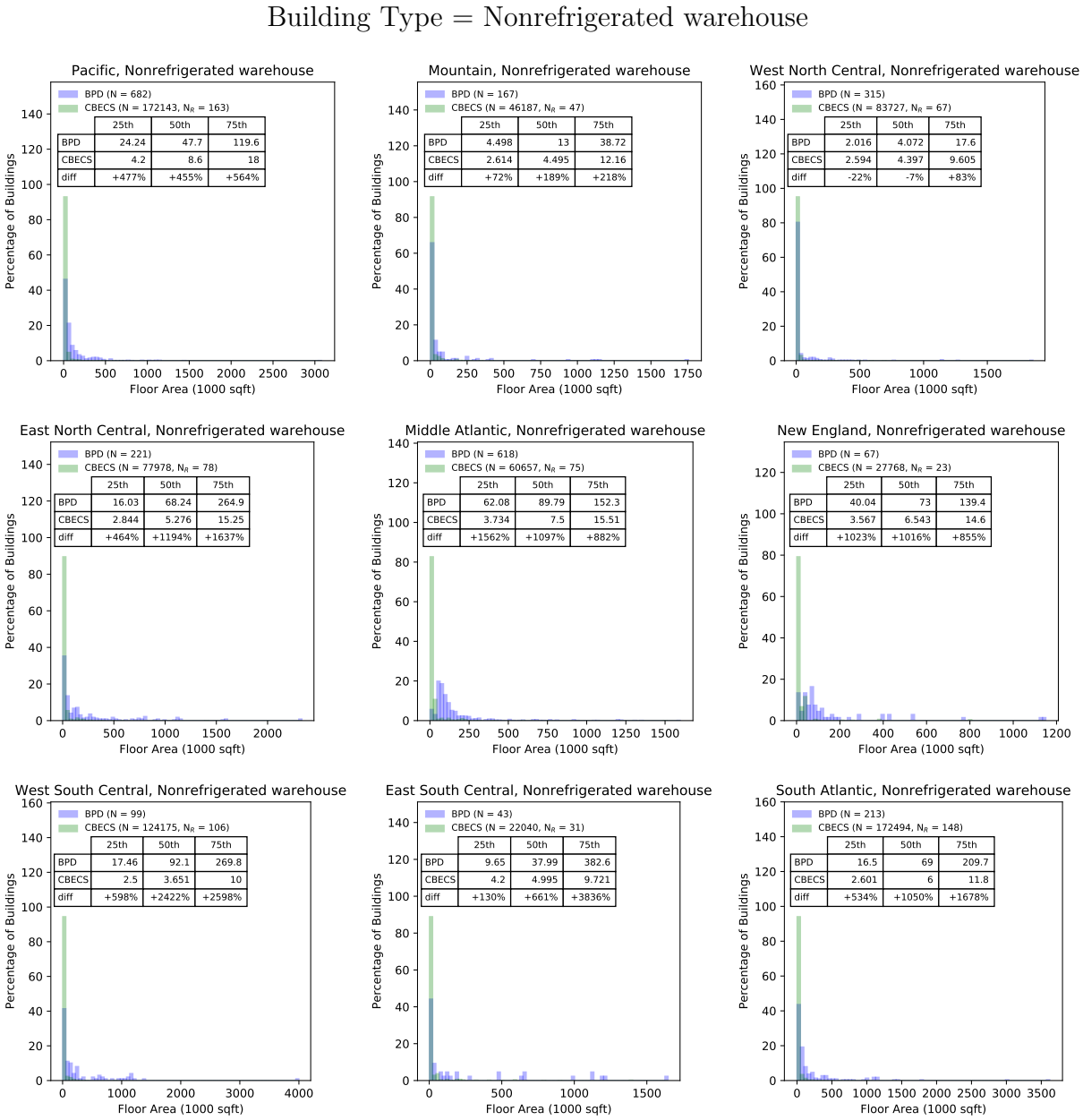


Figure 15: Histograms of floor area for Nonrefrigerated warehouse buildings in each census division.

Building Type = Nursing

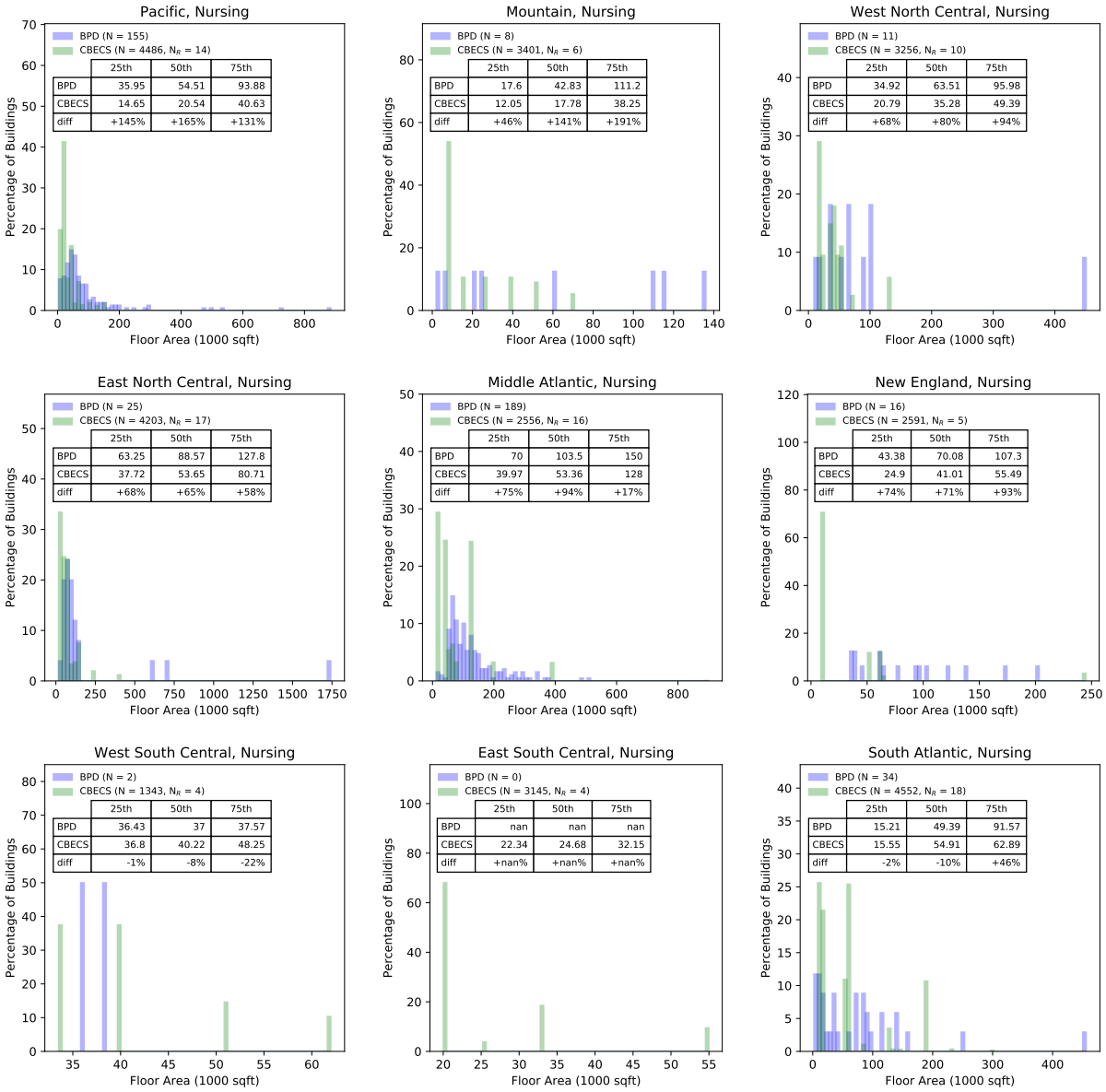
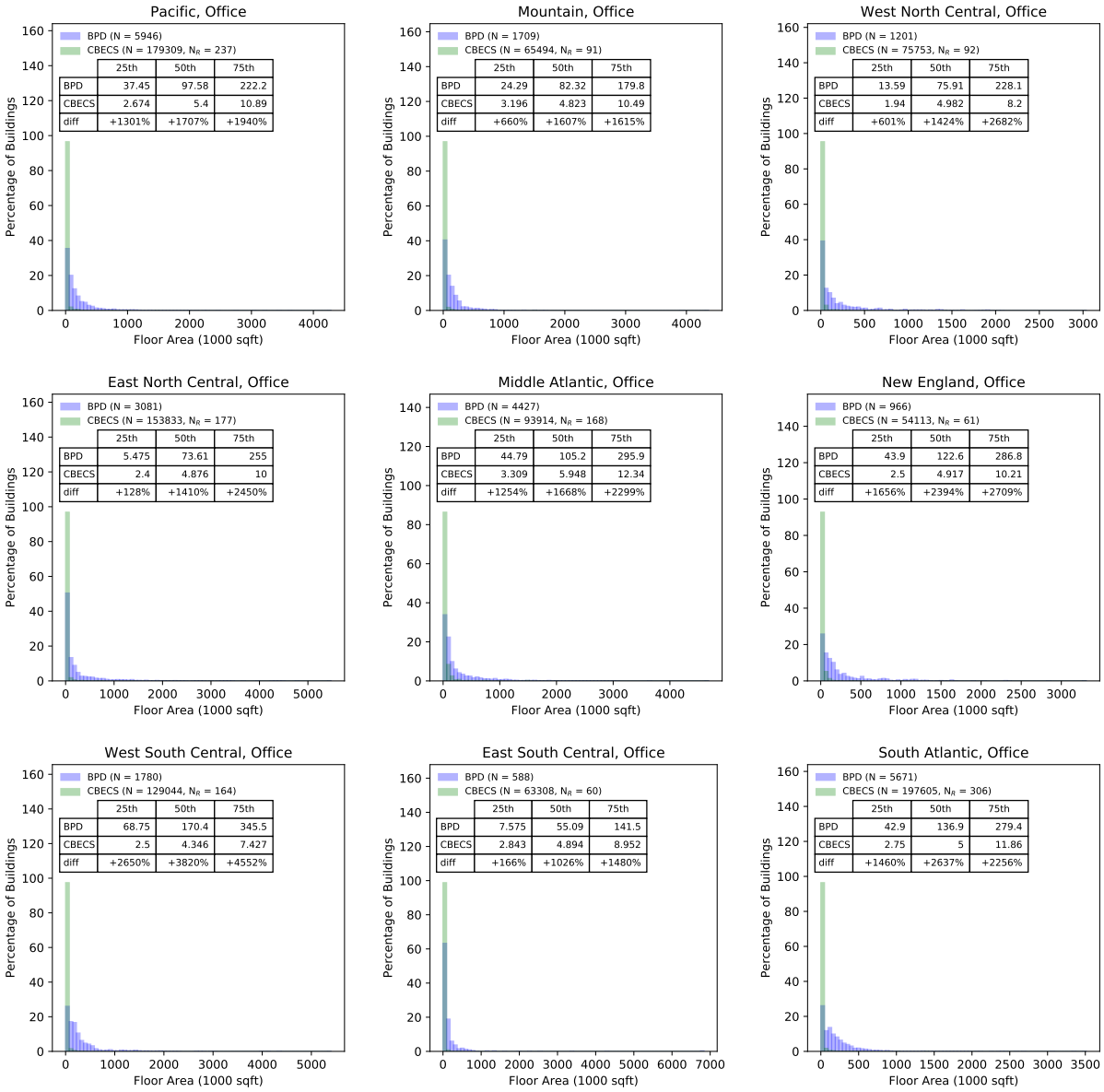


Figure 16: Histograms of floor area for Nursing buildings in each census division.

Building Type = Office



	25th	50th	75th
BPD	37.45	97.58	222.2
CBECS	2.674	5.4	10.89
diff	+1301%	+1707%	+1940%

	25th	50th	75th
BPD	24.29	82.32	179.8
CBECS	3.196	4.823	10.49
diff	+660%	+1607%	+1615%

	25th	50th	75th
BPD	13.59	75.91	228.1
CBECS	1.94	4.982	8.2
diff	+601%	+1424%	+2682%

	25th	50th	75th
BPD	5.475	73.61	255
CBECS	2.4	4.876	10
diff	+128%	+1410%	+2450%

	25th	50th	75th
BPD	44.79	105.2	295.9
CBECS	3.309	5.948	12.34
diff	+1254%	+1668%	+2299%

	25th	50th	75th
BPD	43.9	122.6	286.8
CBECS	2.5	4.917	10.21
diff	+1656%	+2394%	+2709%

	25th	50th	75th
BPD	68.75	170.4	345.5
CBECS	2.5	4.346	7.427
diff	+2650%	+3820%	+4552%

	25th	50th	75th
BPD	7.575	55.09	141.5
CBECS	2.843	4.894	8.952
diff	+166%	+1026%	+1480%

	25th	50th	75th
BPD	42.9	136.9	279.4
CBECS	2.75	5	11.86
diff	+1460%	+2637%	+2256%

Figure 17: Histograms of floor area for Office buildings in each census division.

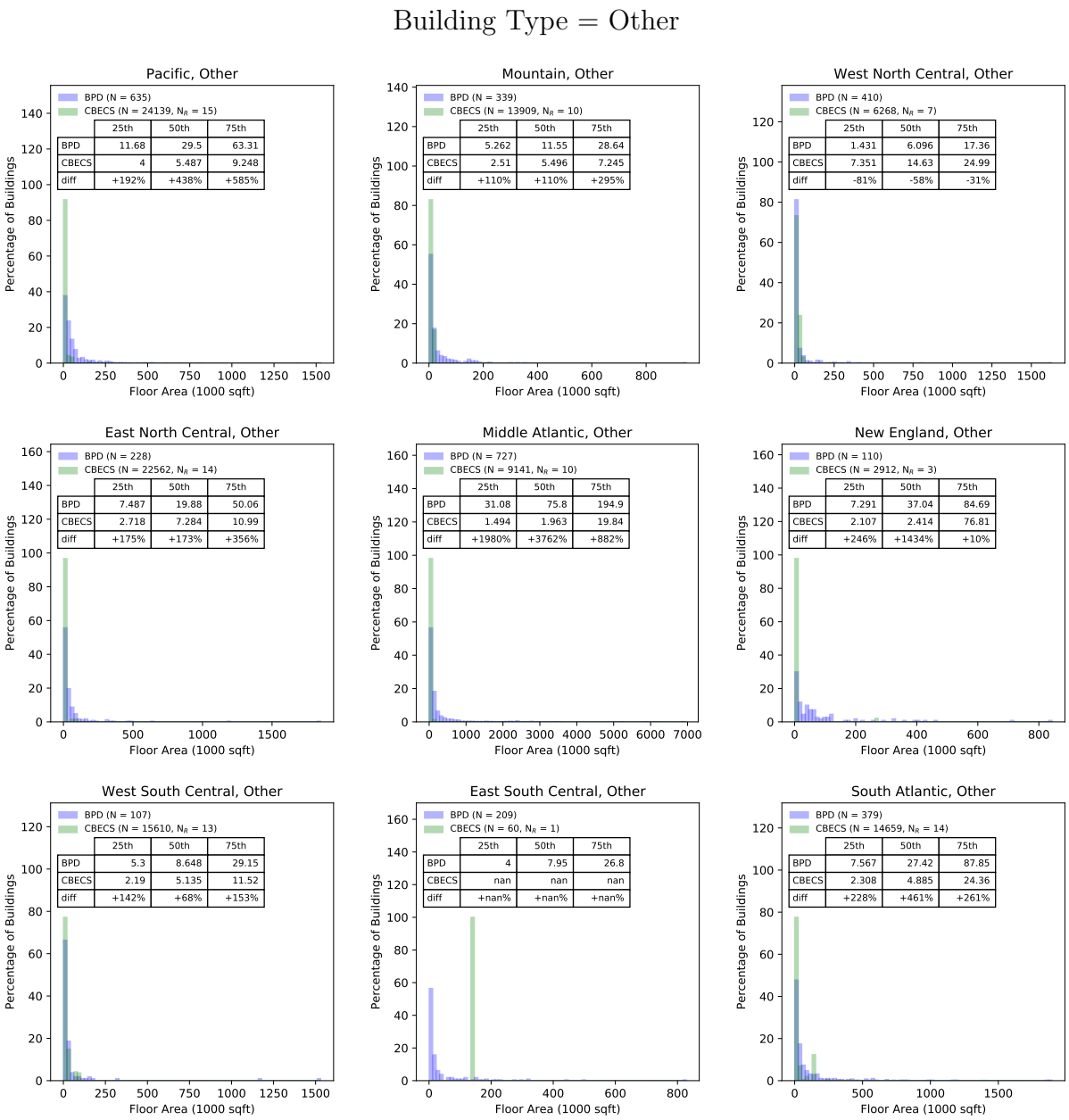


Figure 18: Histograms of floor area for Other buildings in each census division.

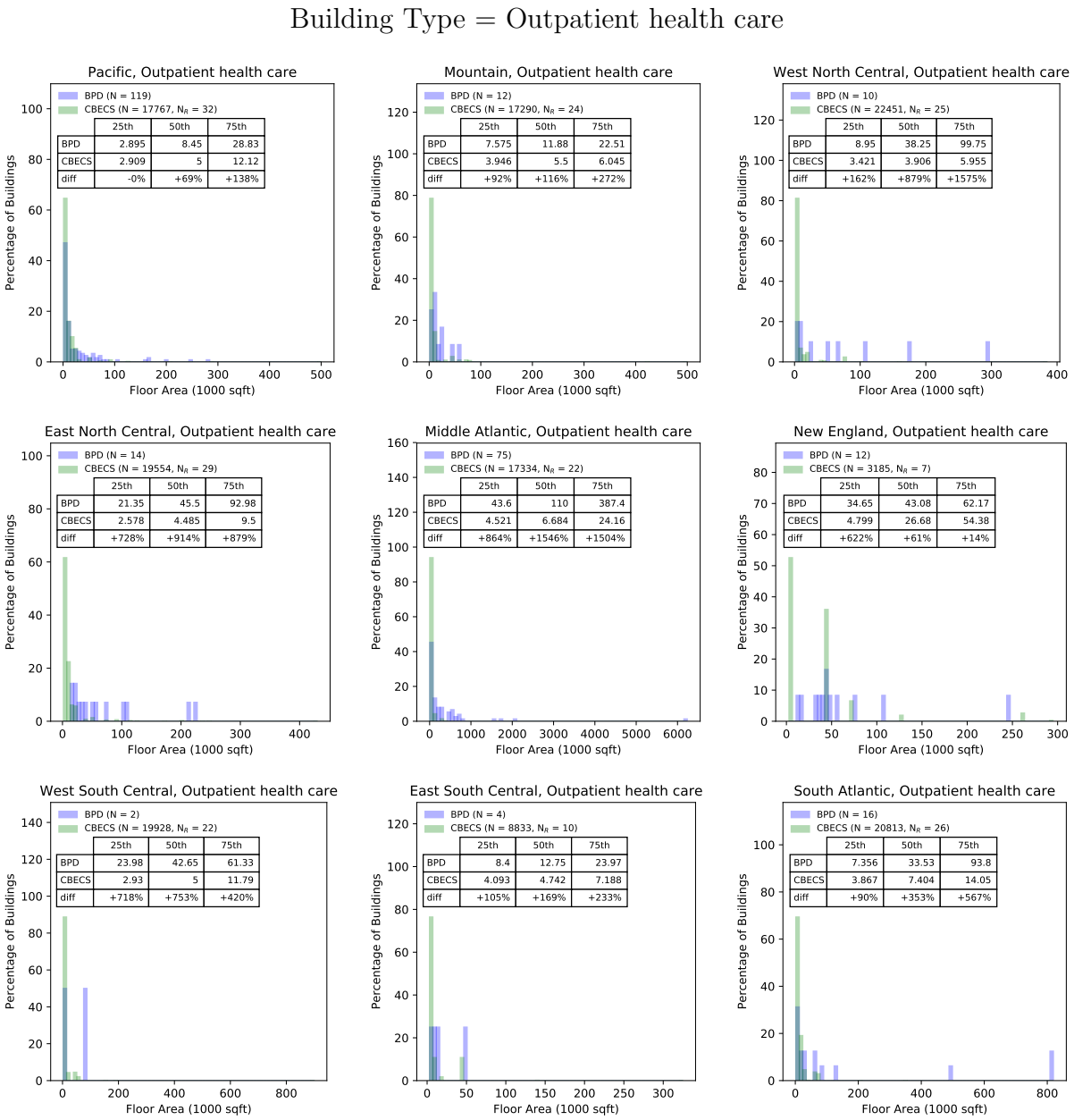


Figure 19: Histograms of floor area for Outpatient health care buildings in each census division.

Building Type = Public assembly

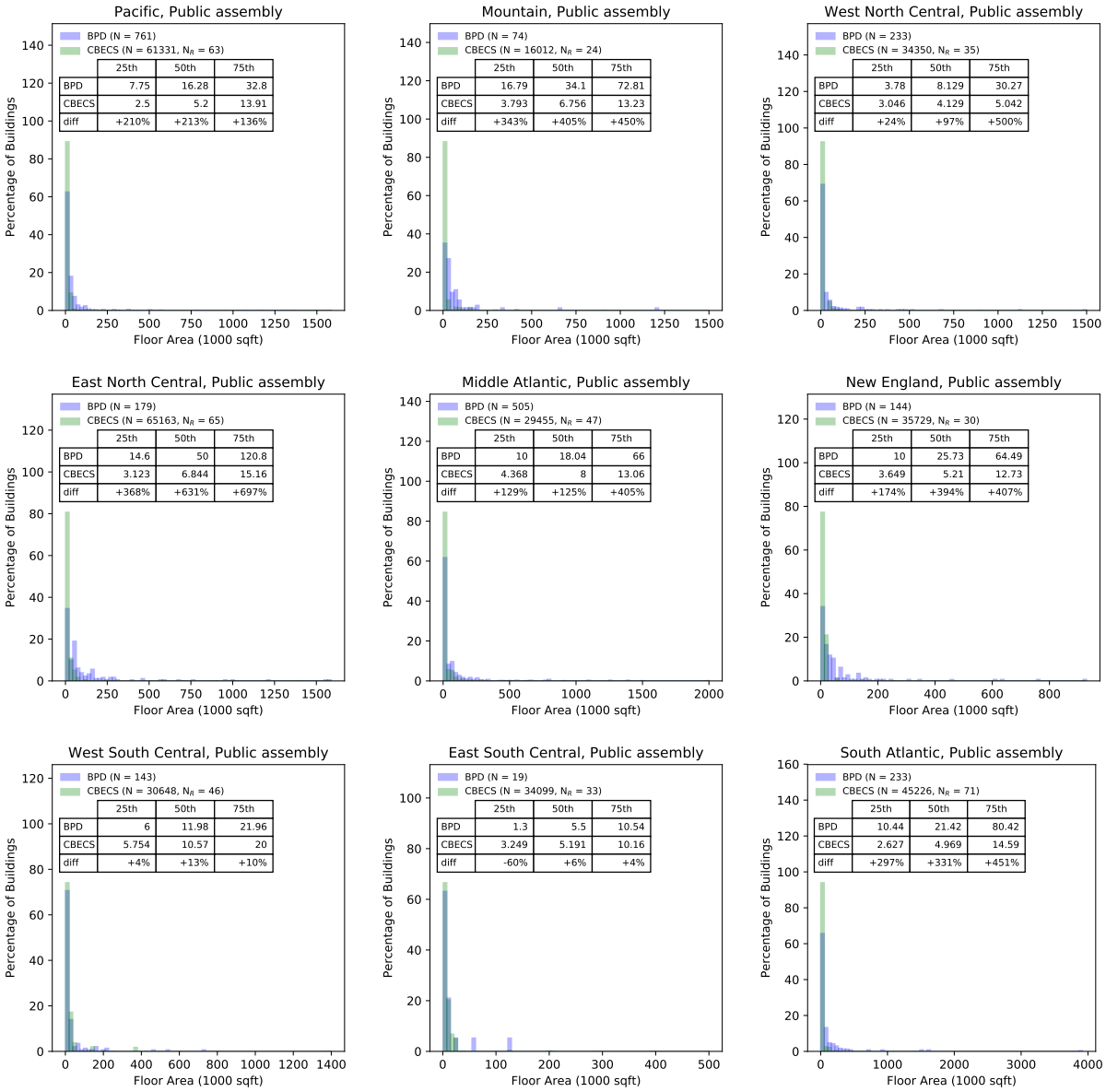


Figure 20: Histograms of floor area for Public assembly buildings in each census division.

Building Type = Public order and safety

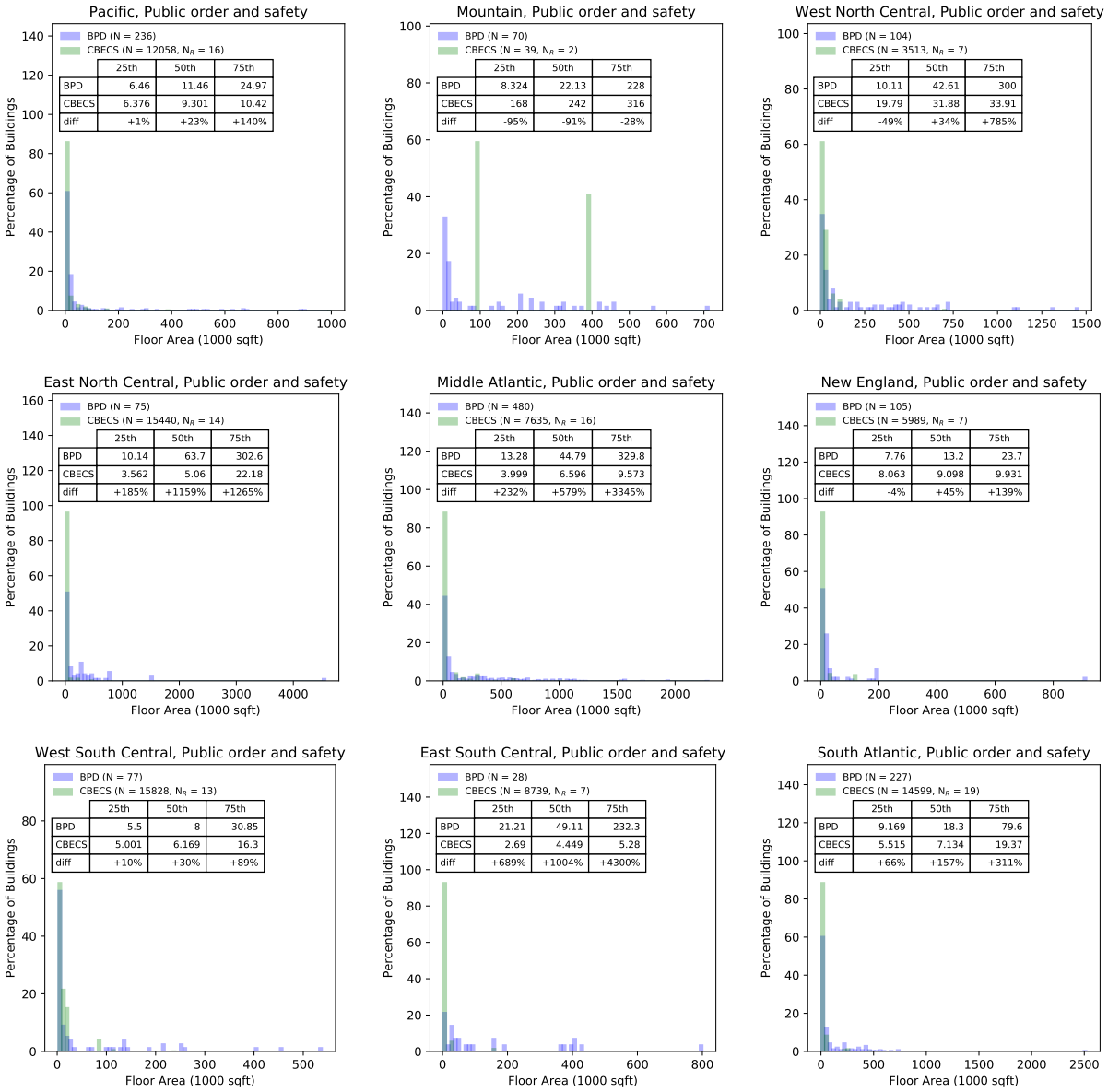


Figure 21: Histograms of floor area for Public order and safety buildings in each census division.

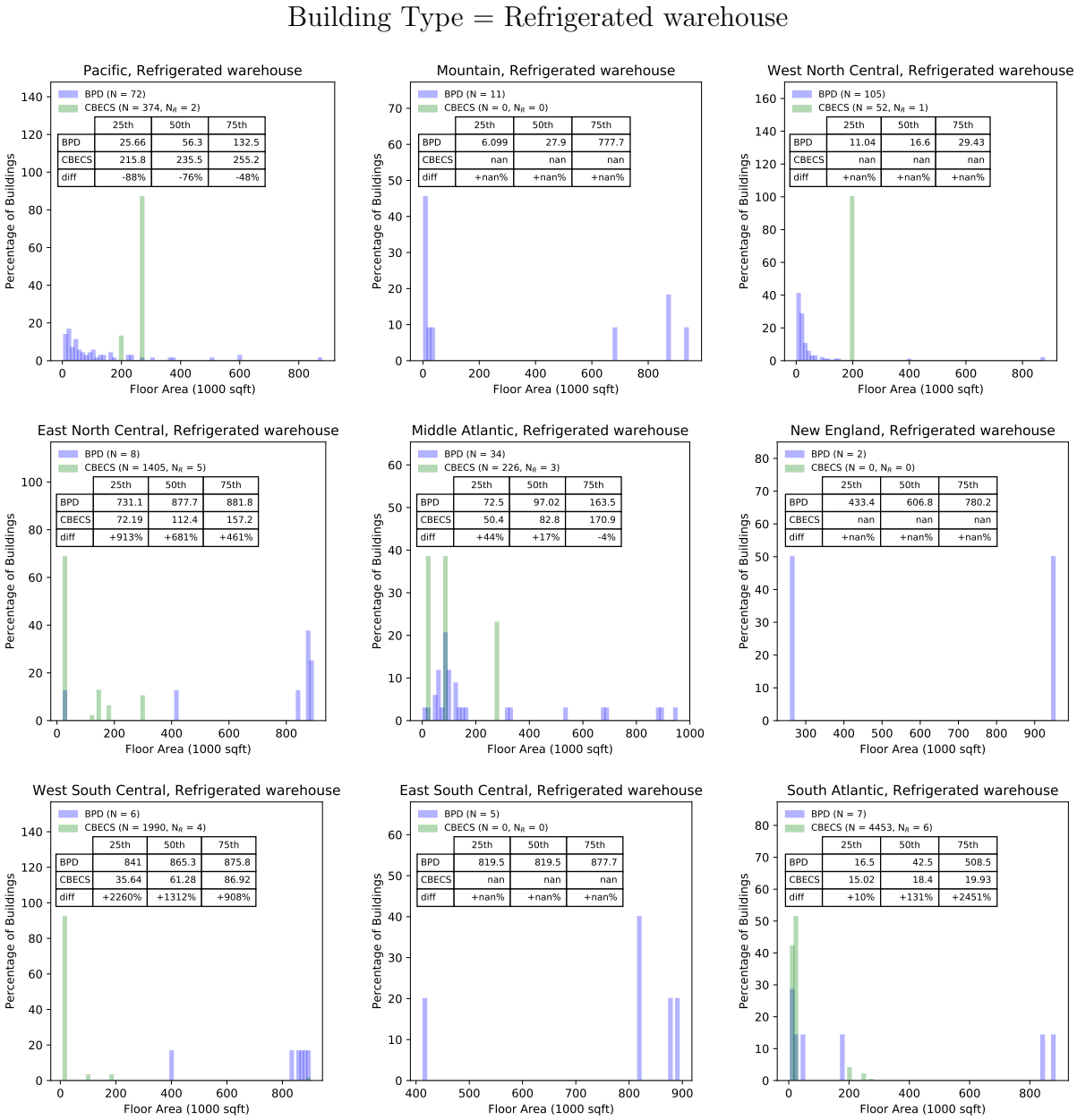


Figure 22: Histograms of floor area for Refrigerated warehouse buildings in each census division.

Building Type = Religious worship

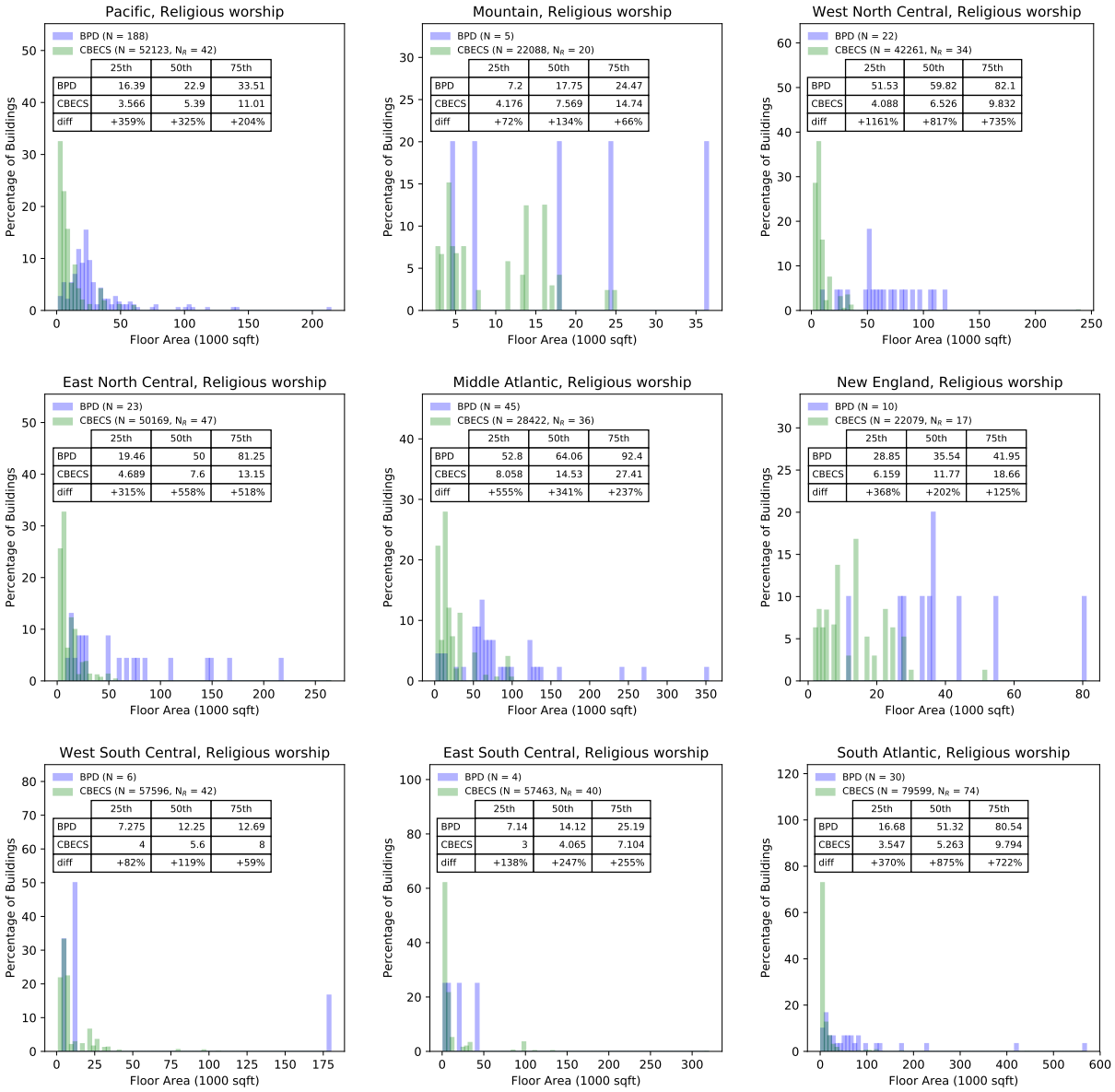


Figure 23: Histograms of floor area for Religious worship buildings in each census division.

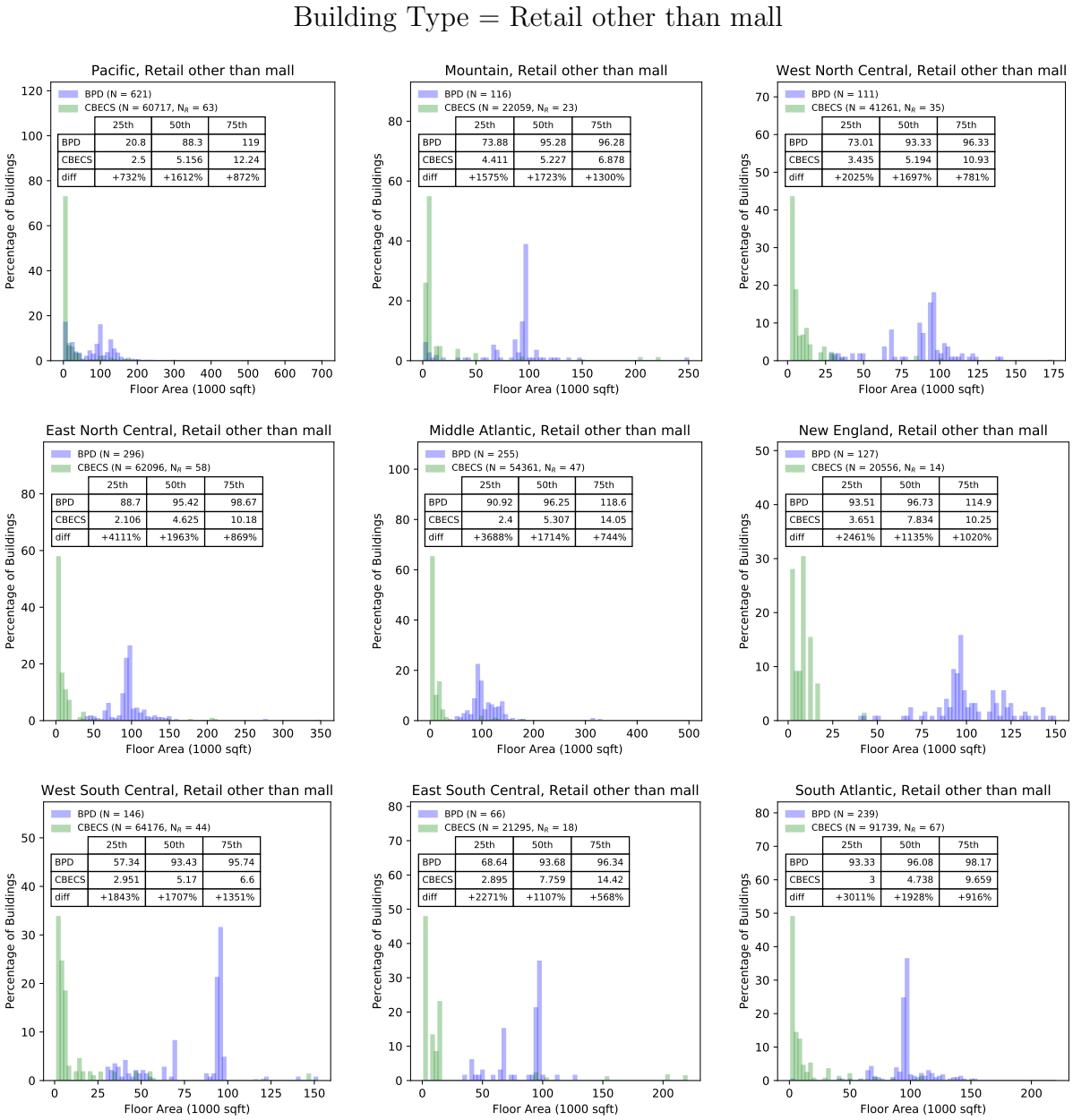


Figure 24: Histograms of floor area for Retail other than mall buildings in each census division.

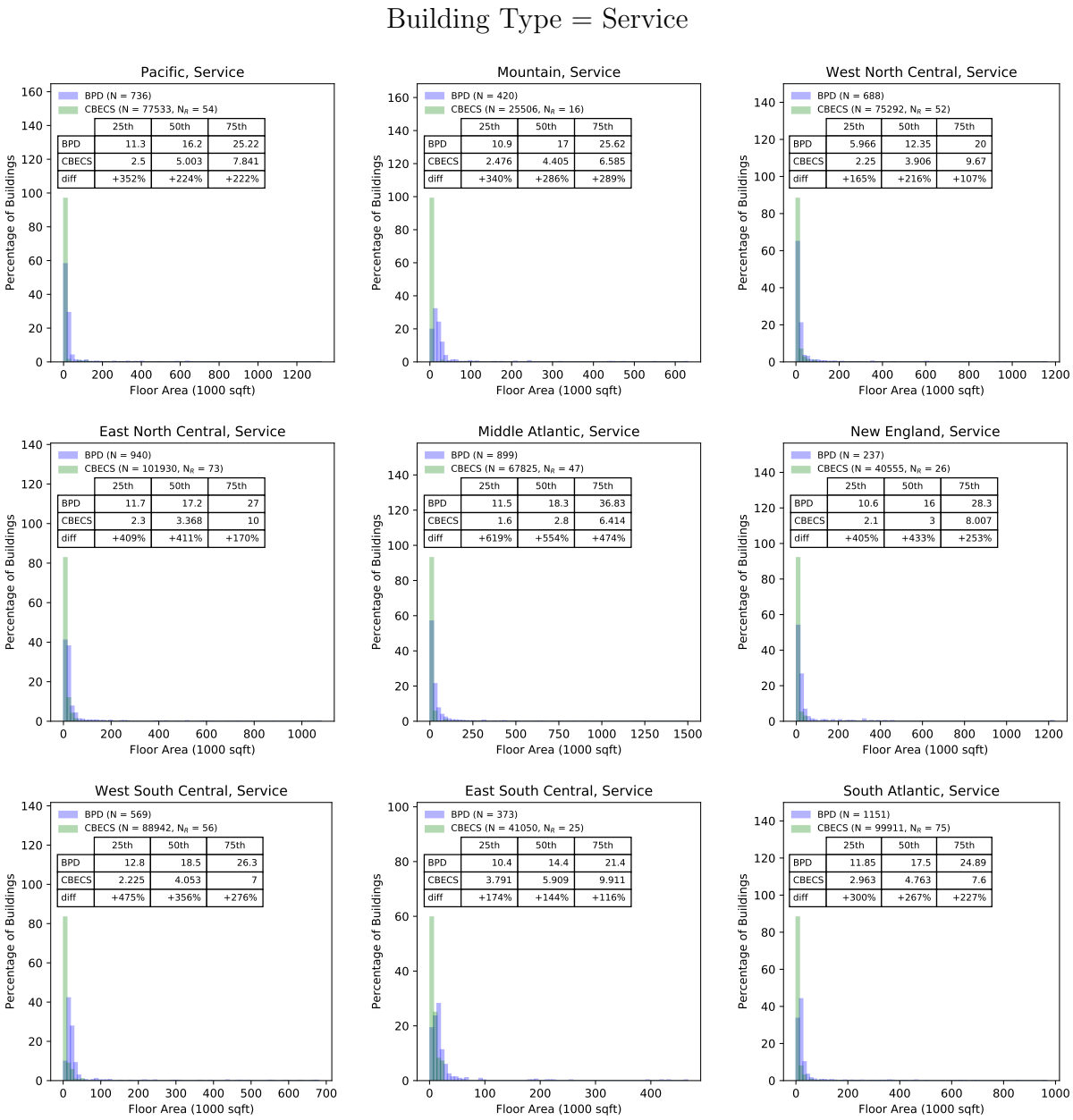


Figure 25: Histograms of floor area for Service buildings in each census division.

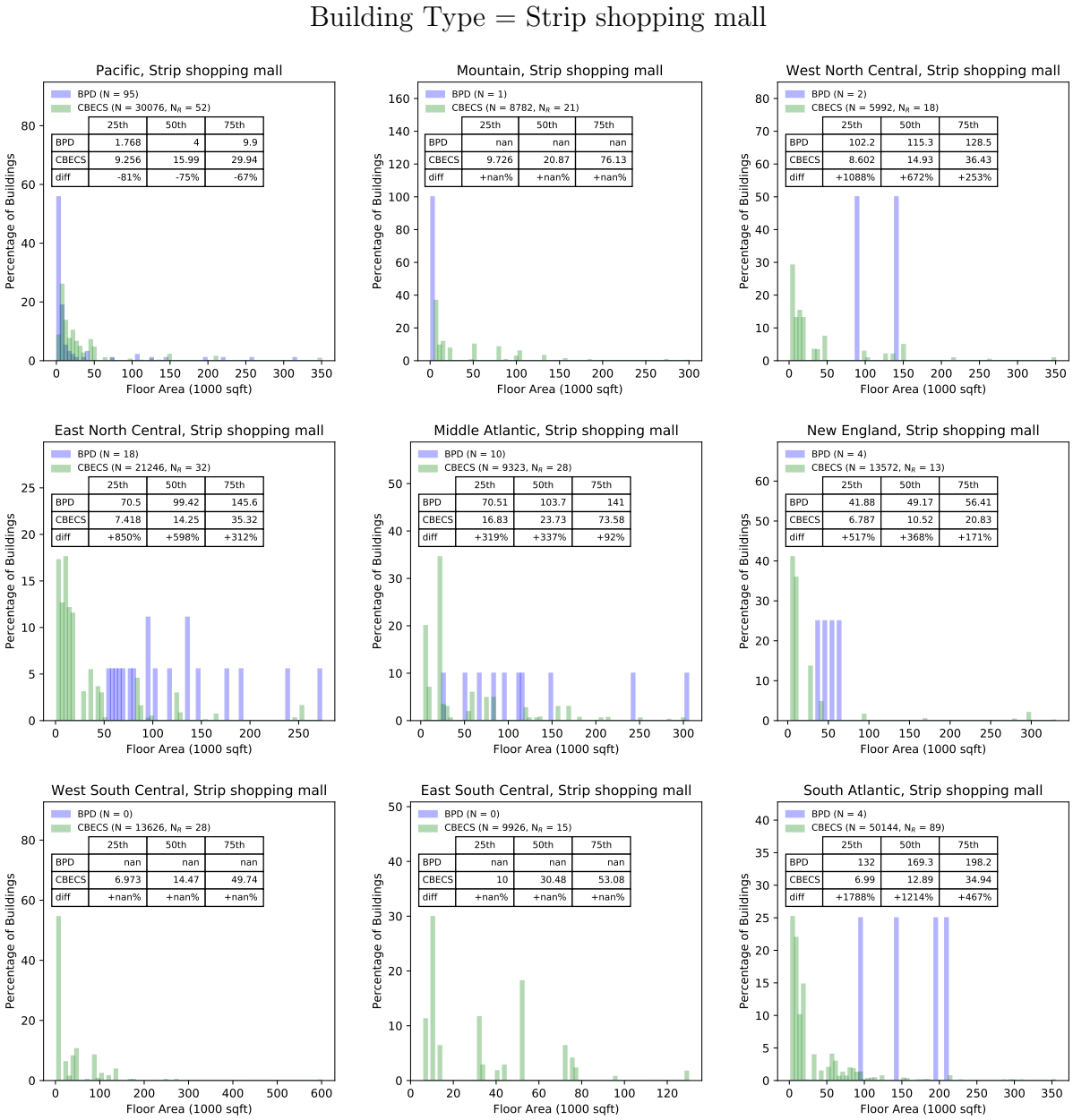


Figure 26: Histograms of floor area for Strip shopping mall buildings in each census division.

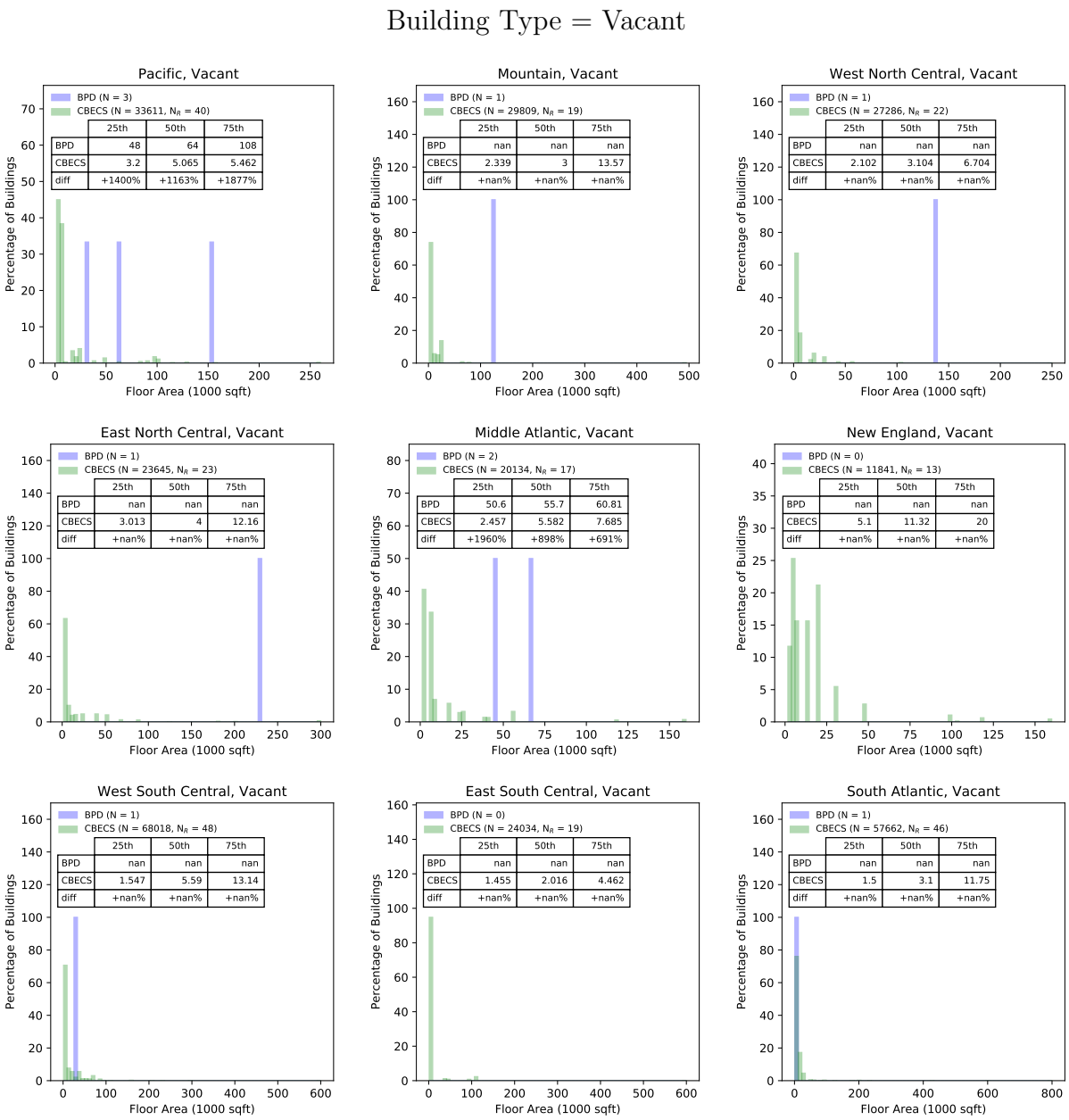


Figure 27: Histograms of floor area for Vacant buildings in each census division.

Site EUI histograms

The following 20 pages contain histograms of site EUI for each building type and census division. In the legend, N is the number of buildings and N_R is the number of records. The table shows the 25th, 50th, and 75th percentiles for BPD and CBECS, and the difference between BPD and CBECS relative to CBECS. In some cases, there are too few buildings for meaningful calculations of the percentiles, so "nan" (not a number) is shown instead.

Building Type = Education

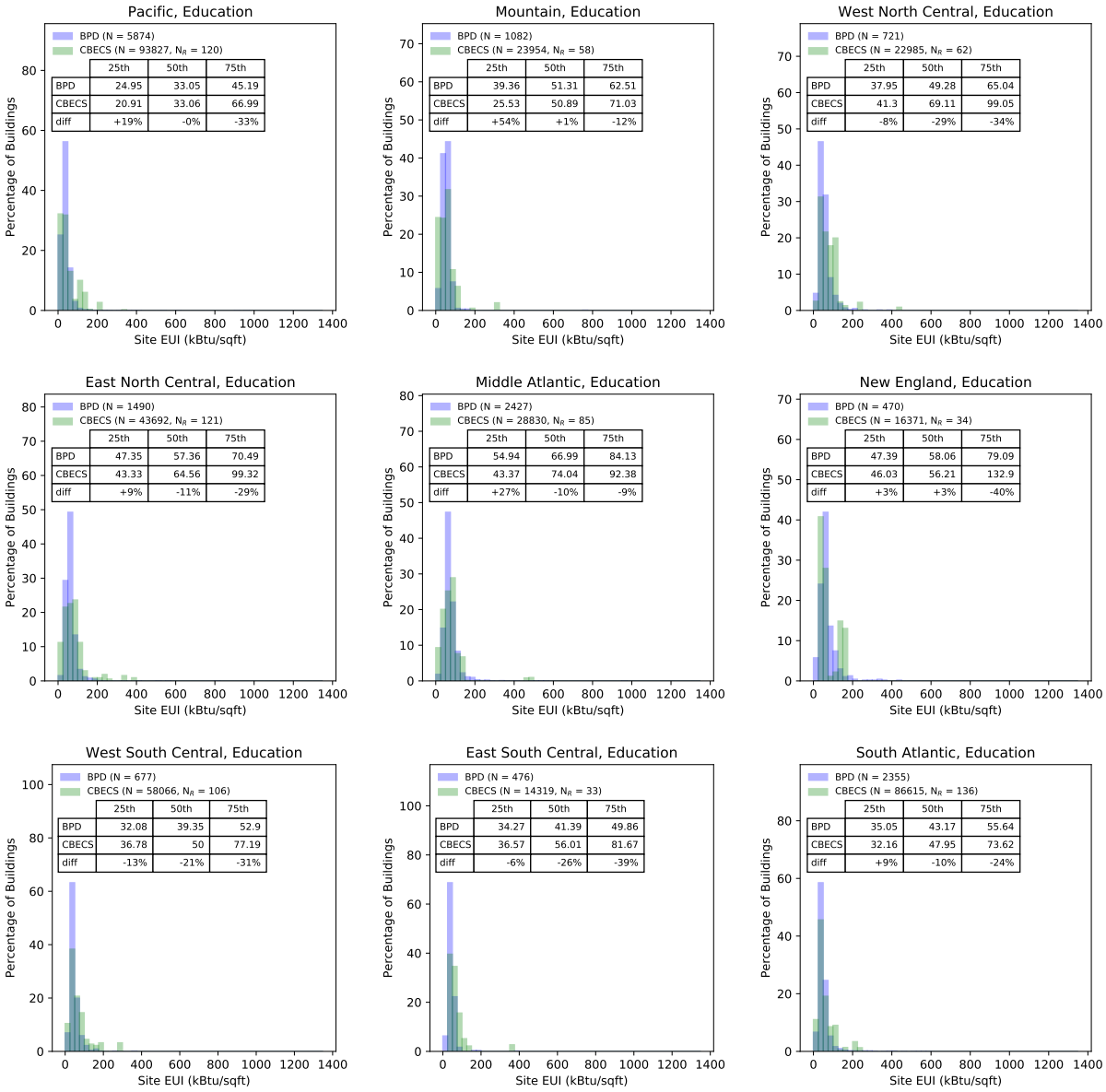


Figure 28: Histograms of site EUI for Education buildings in each census division.

Building Type = Enclosed mall

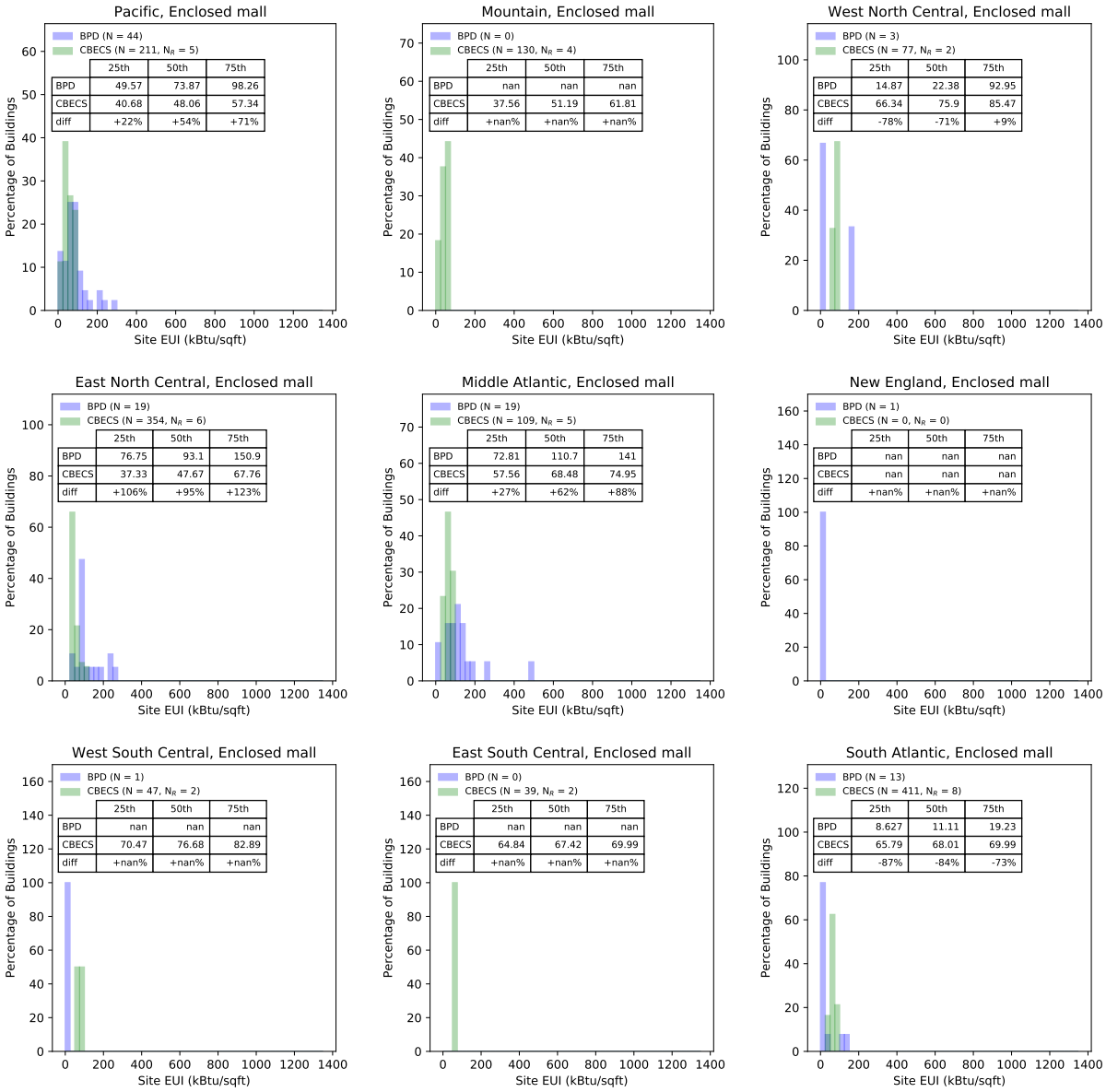


Figure 29: Histograms of site EUI for Enclosed mall buildings in each census division.

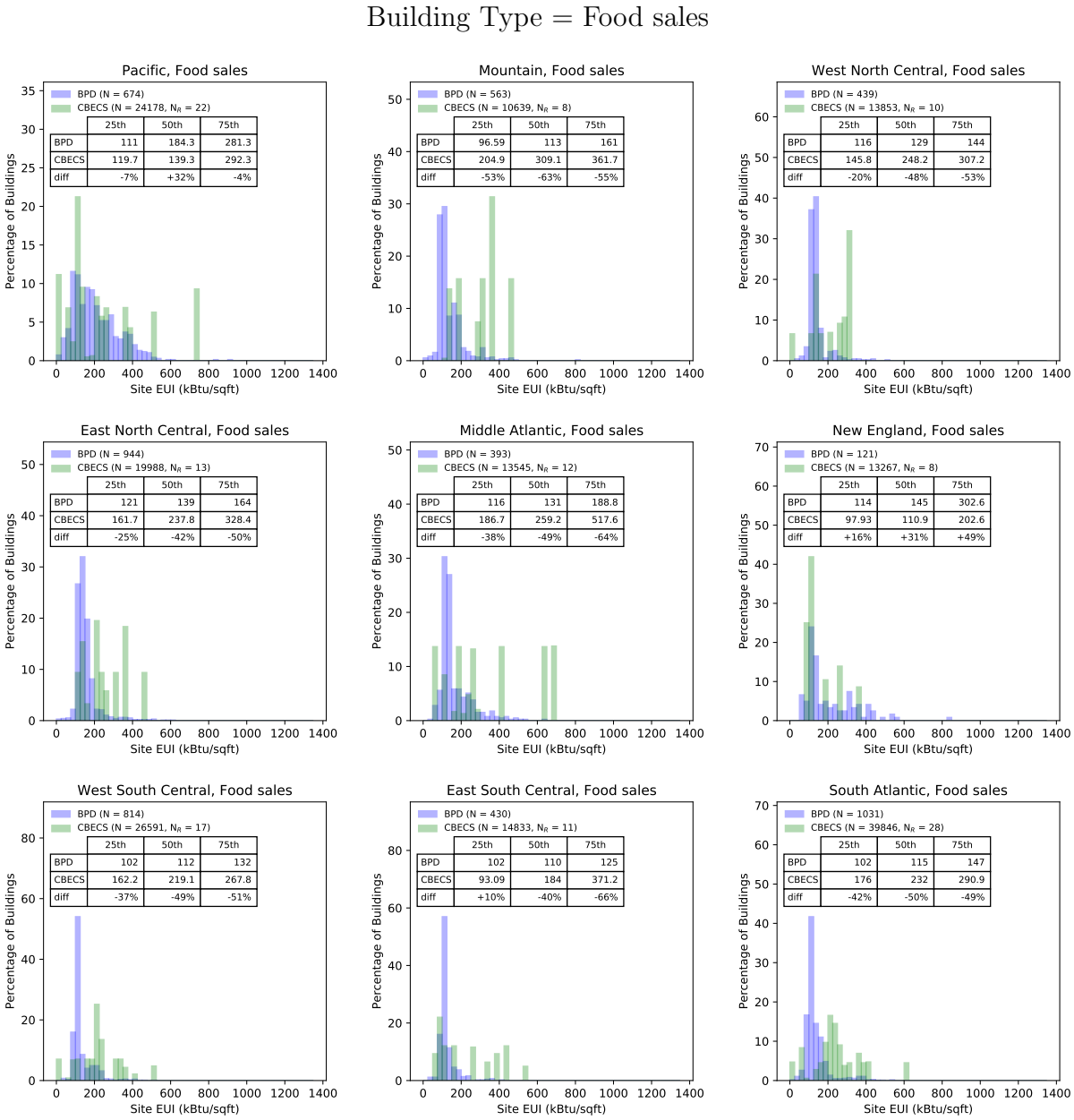


Figure 30: Histograms of site EUI for Food sales buildings in each census division.

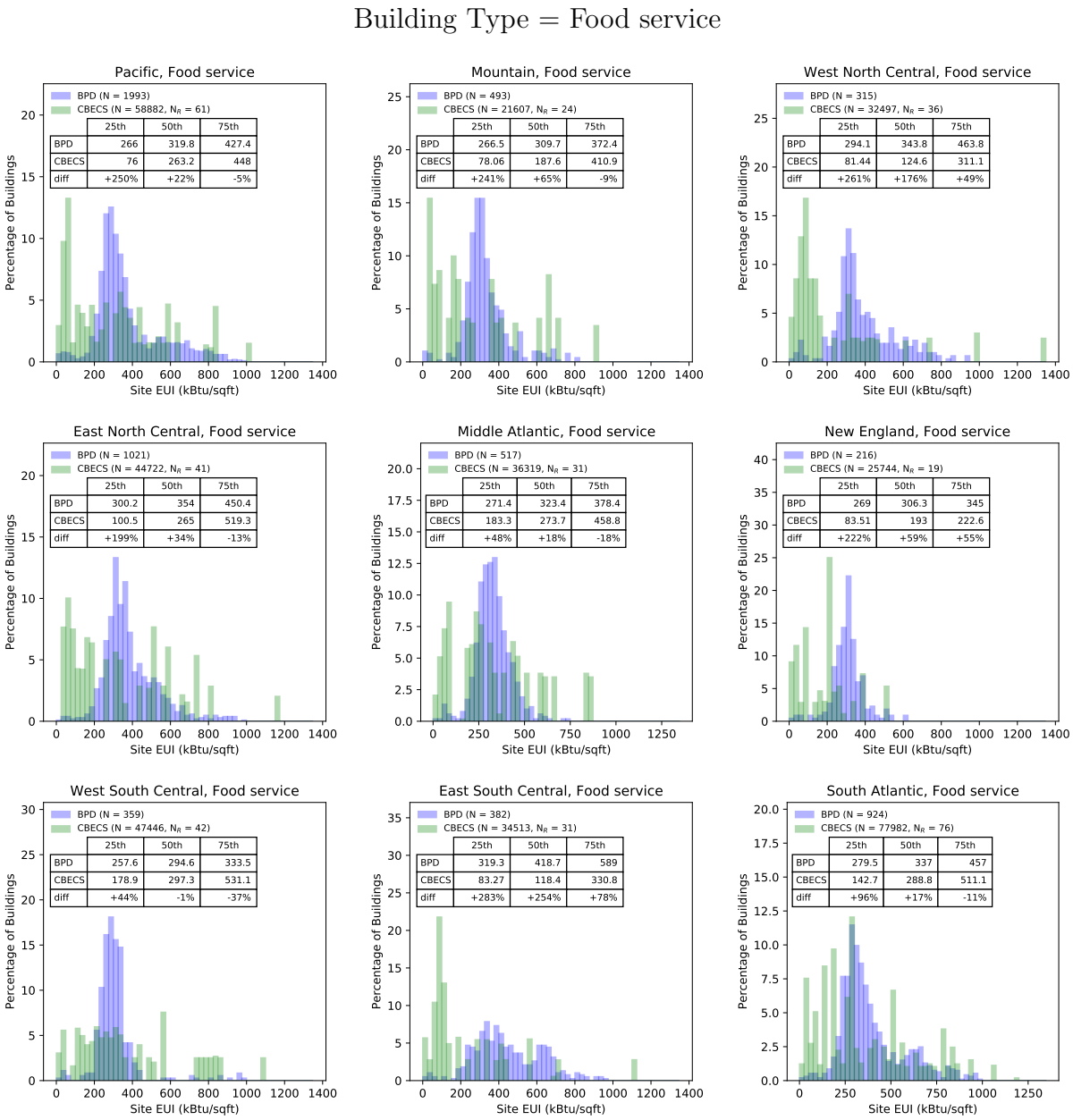


Figure 31: Histograms of site EUI for Food service buildings in each census division.

Building Type = Inpatient health care

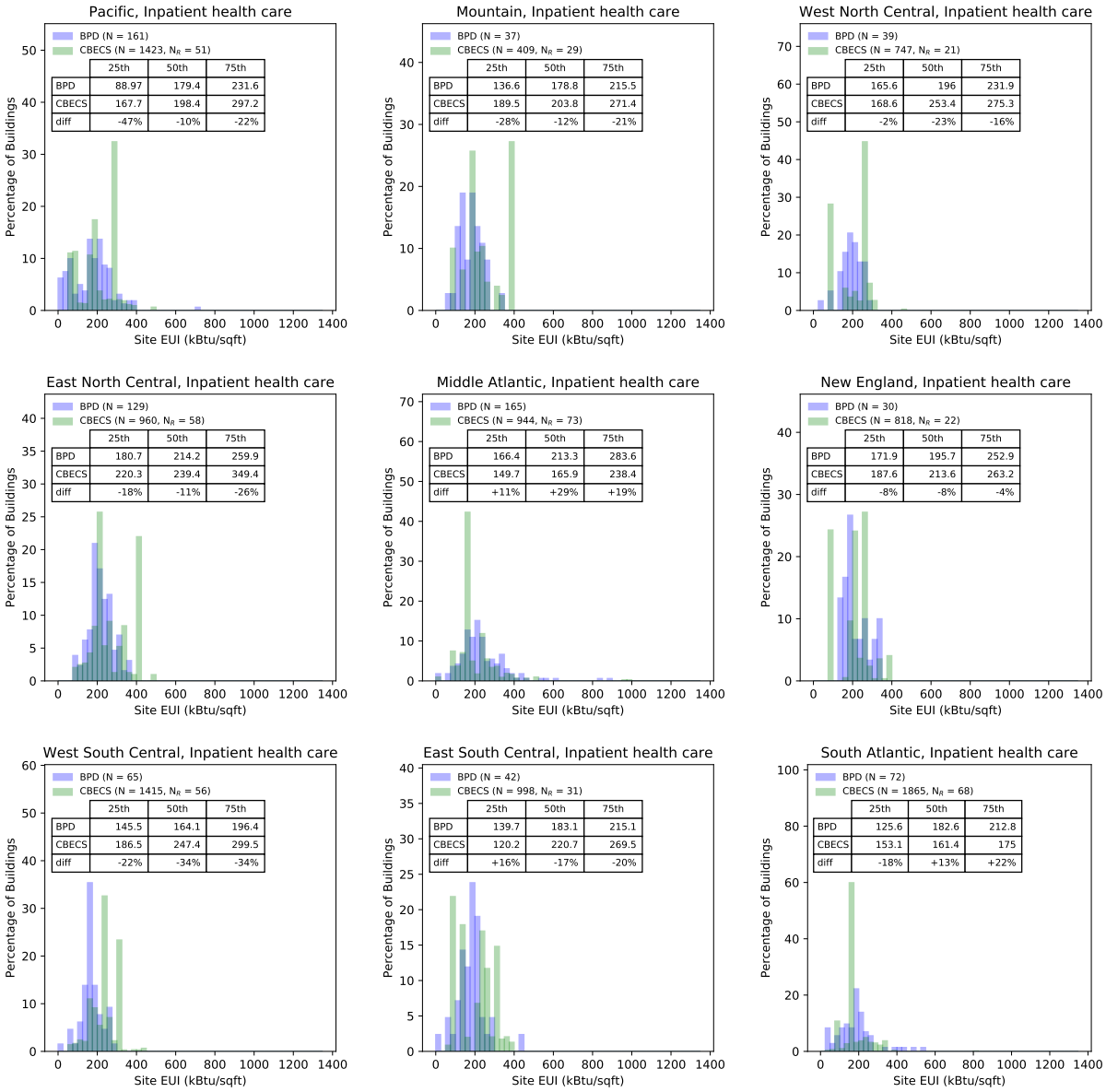


Figure 32: Histograms of site EUI for Inpatient health care buildings in each census division.

Building Type = Laboratory

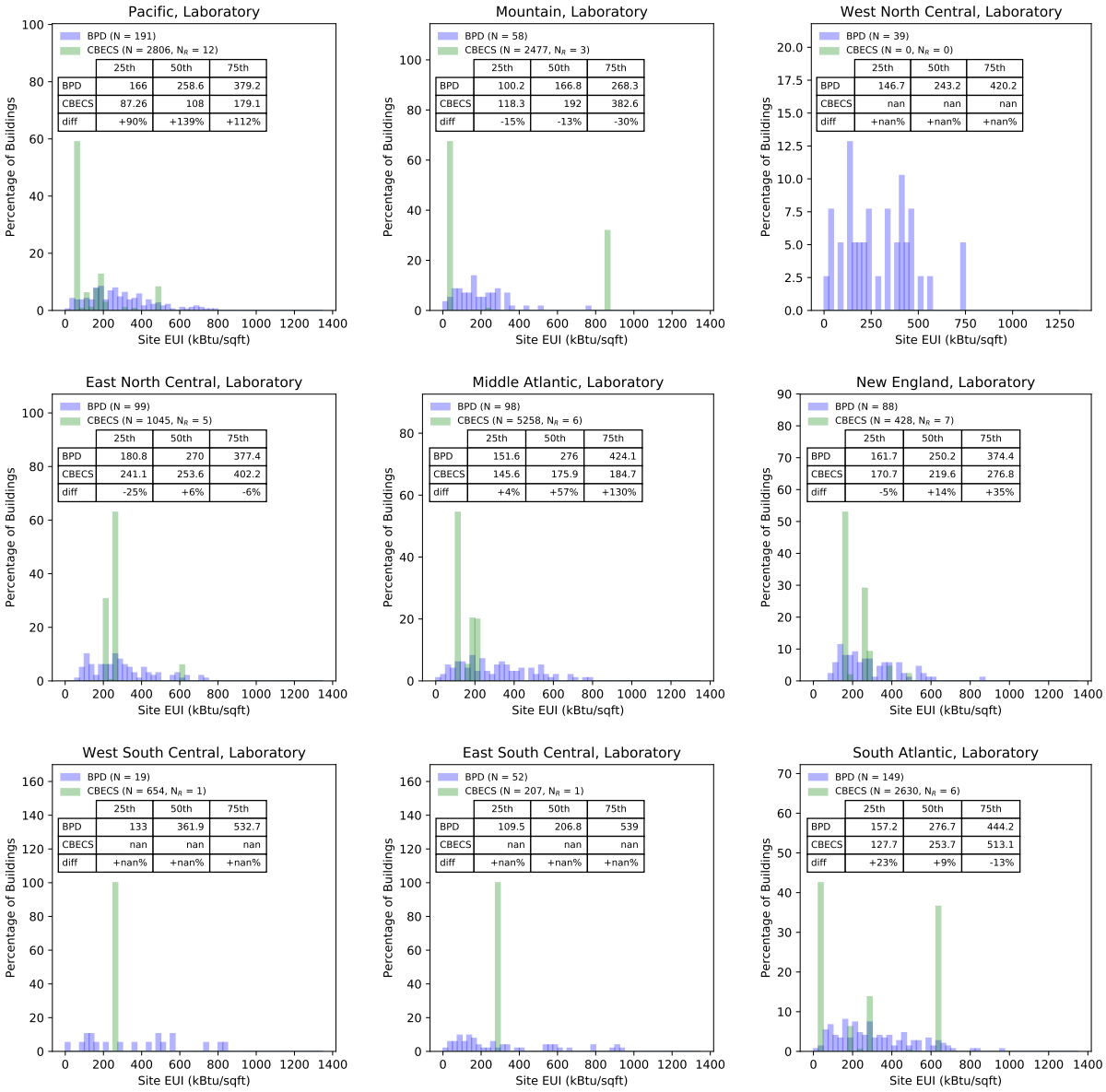


Figure 33: Histograms of site EUI for Laboratory buildings in each census division.

Building Type = Lodging

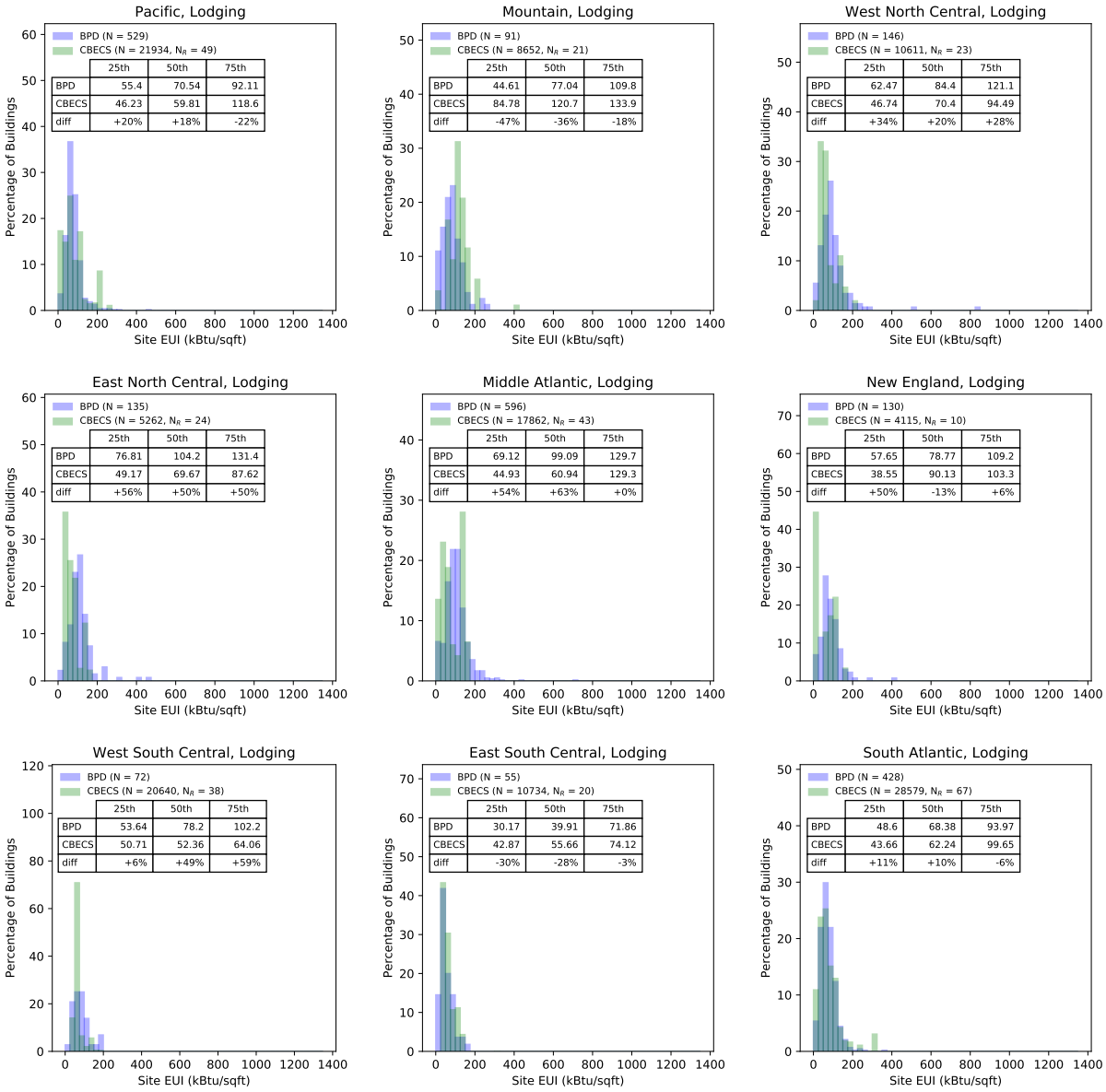


Figure 34: Histograms of site EUI for Lodging buildings in each census division.

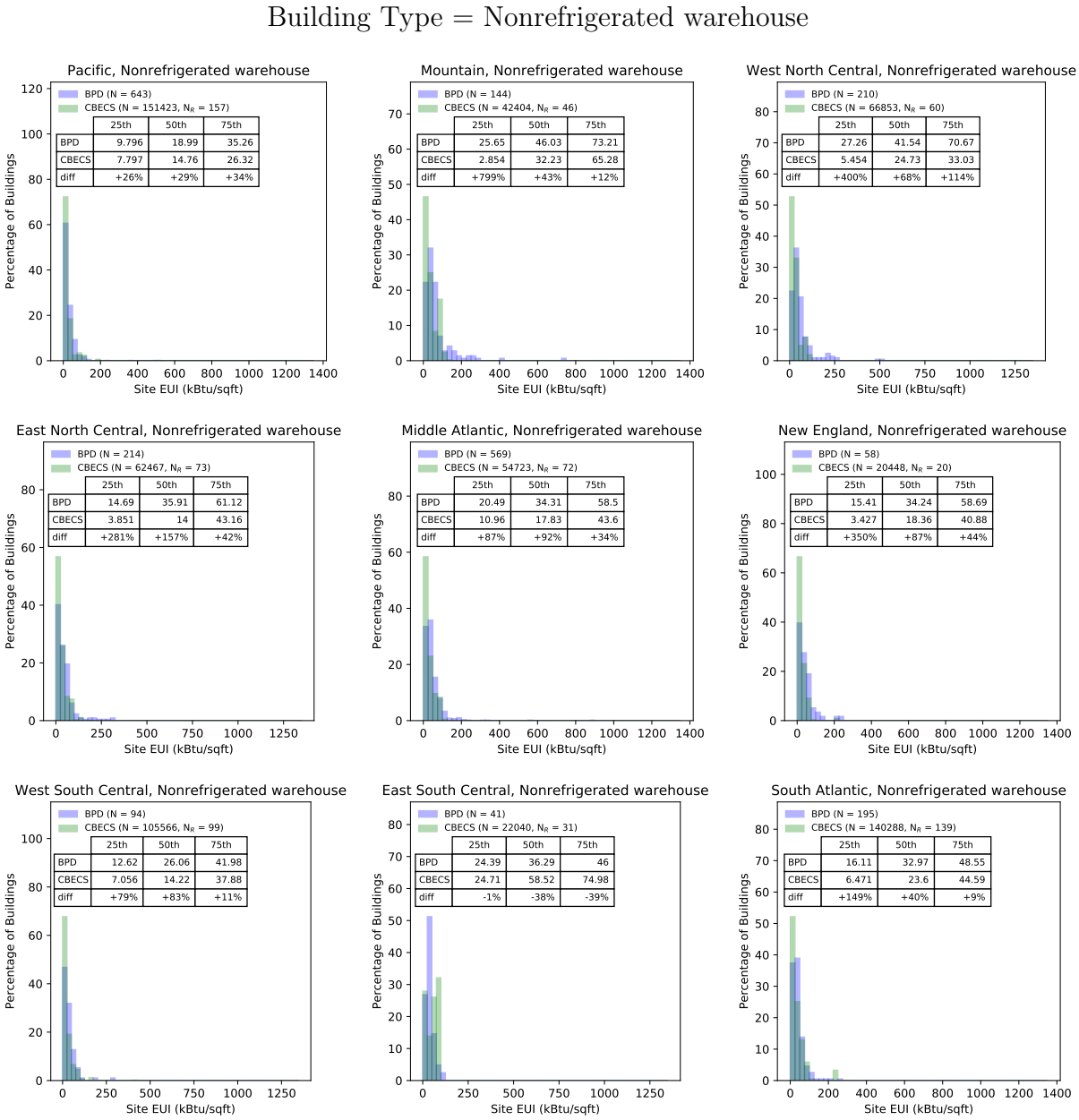


Figure 35: Histograms of site EUI for Nonrefrigerated warehouse buildings in each census division.

Building Type = Nursing

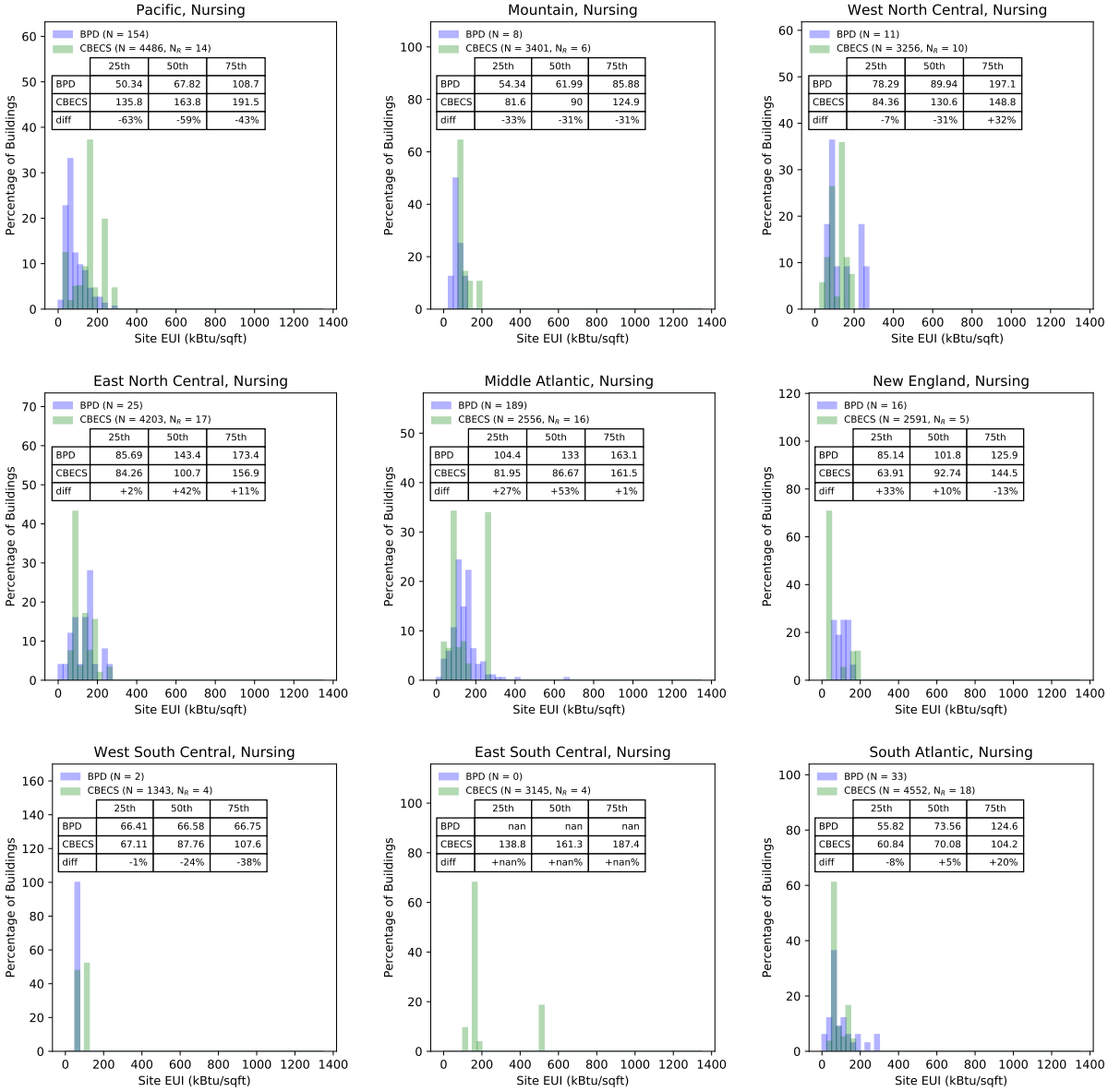


Figure 36: Histograms of site EUI for Nursing buildings in each census division.

Building Type = Office

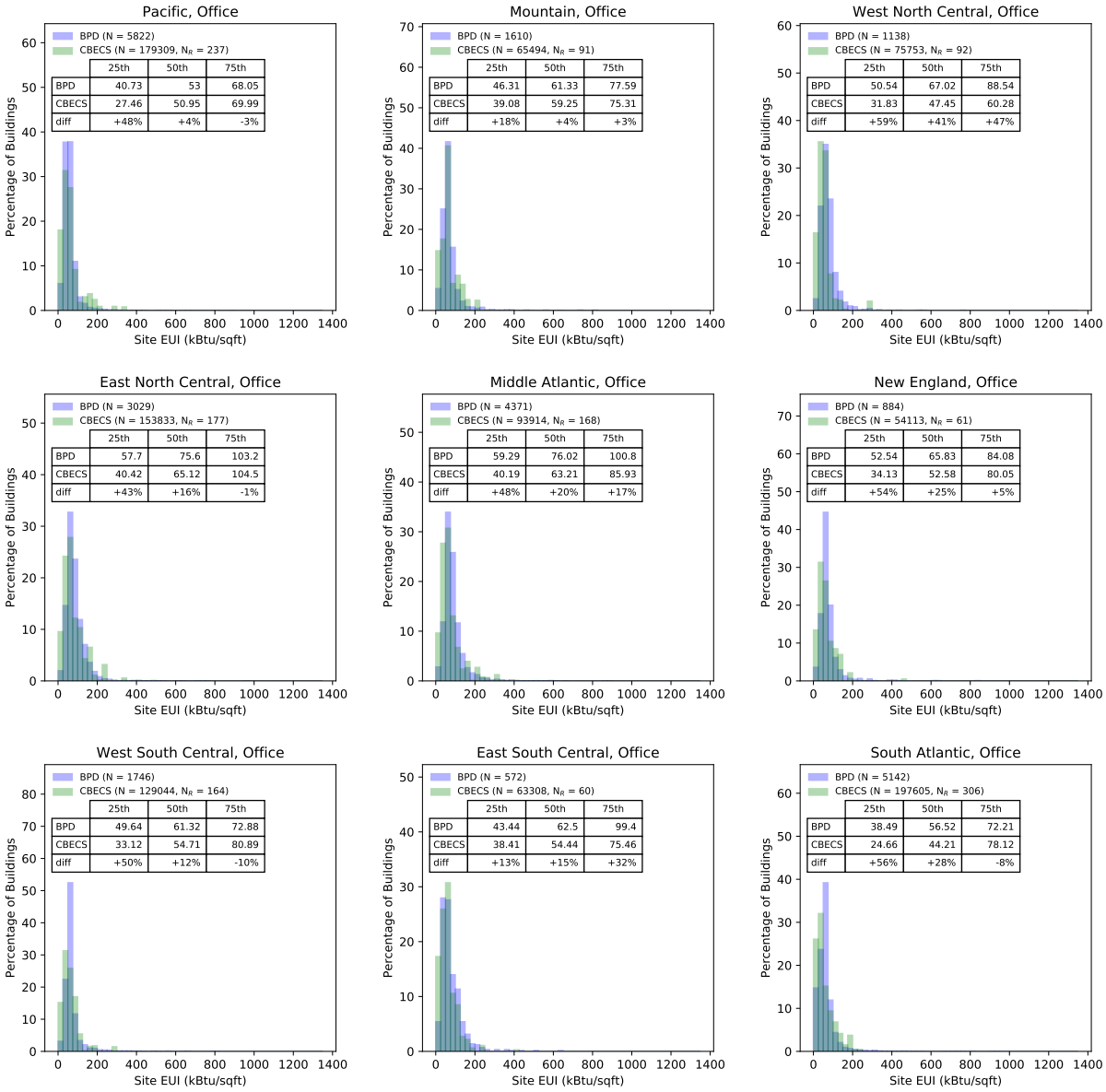


Figure 37: Histograms of site EUI for Office buildings in each census division.

Building Type = Other

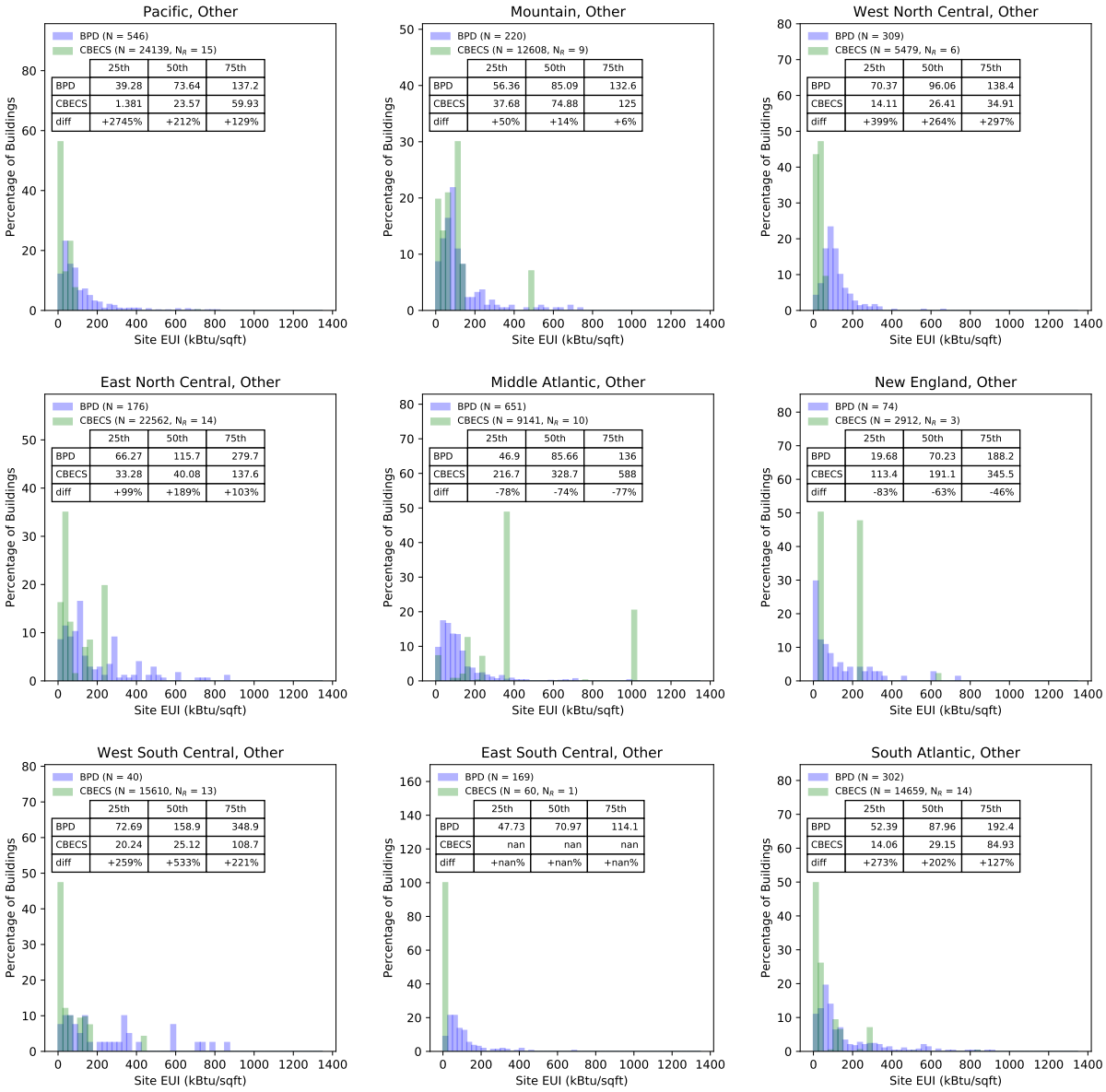


Figure 38: Histograms of site EUI for Other buildings in each census division.

Building Type = Outpatient health care

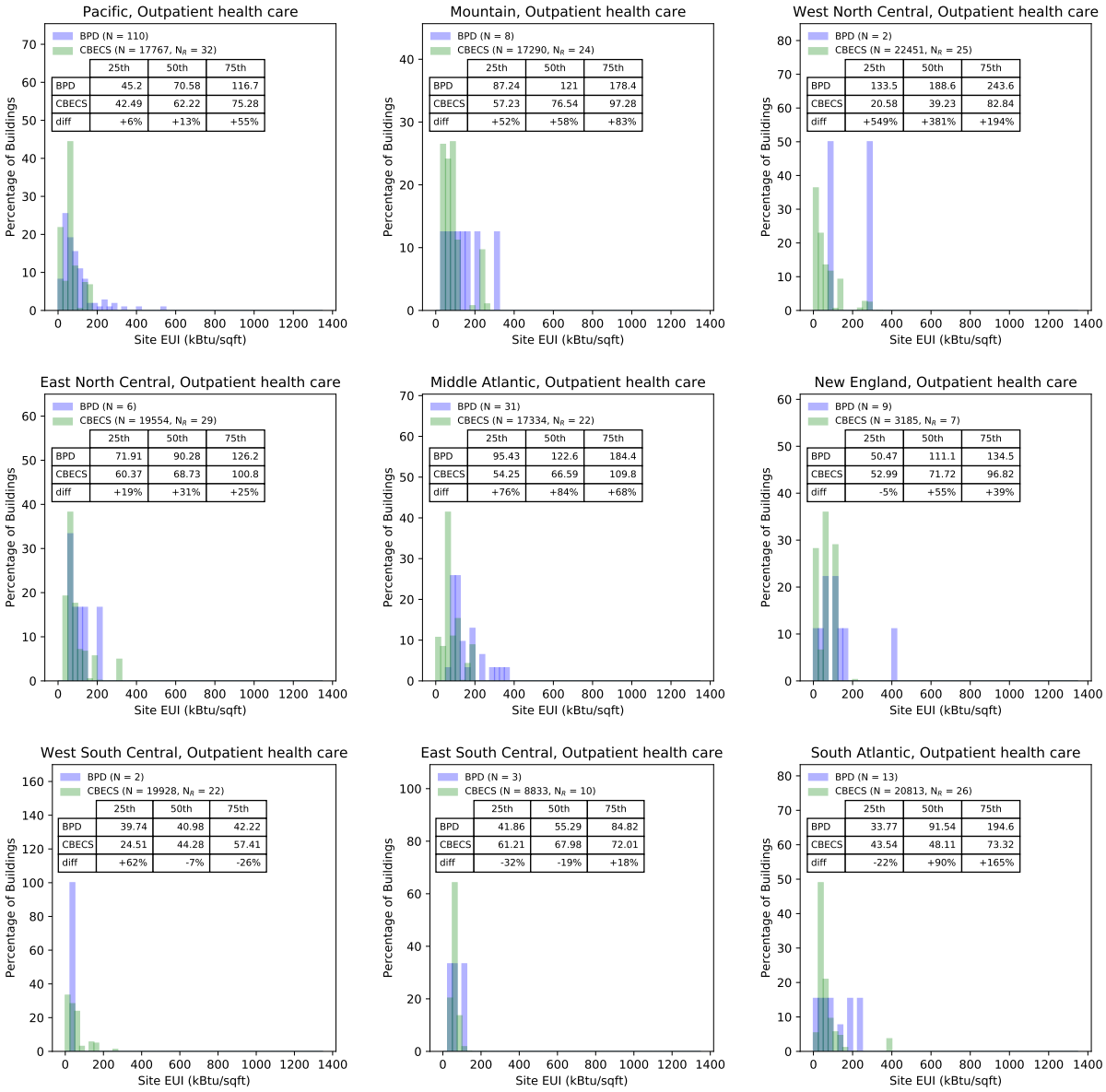


Figure 39: Histograms of site EUI for Outpatient health care buildings in each census division.

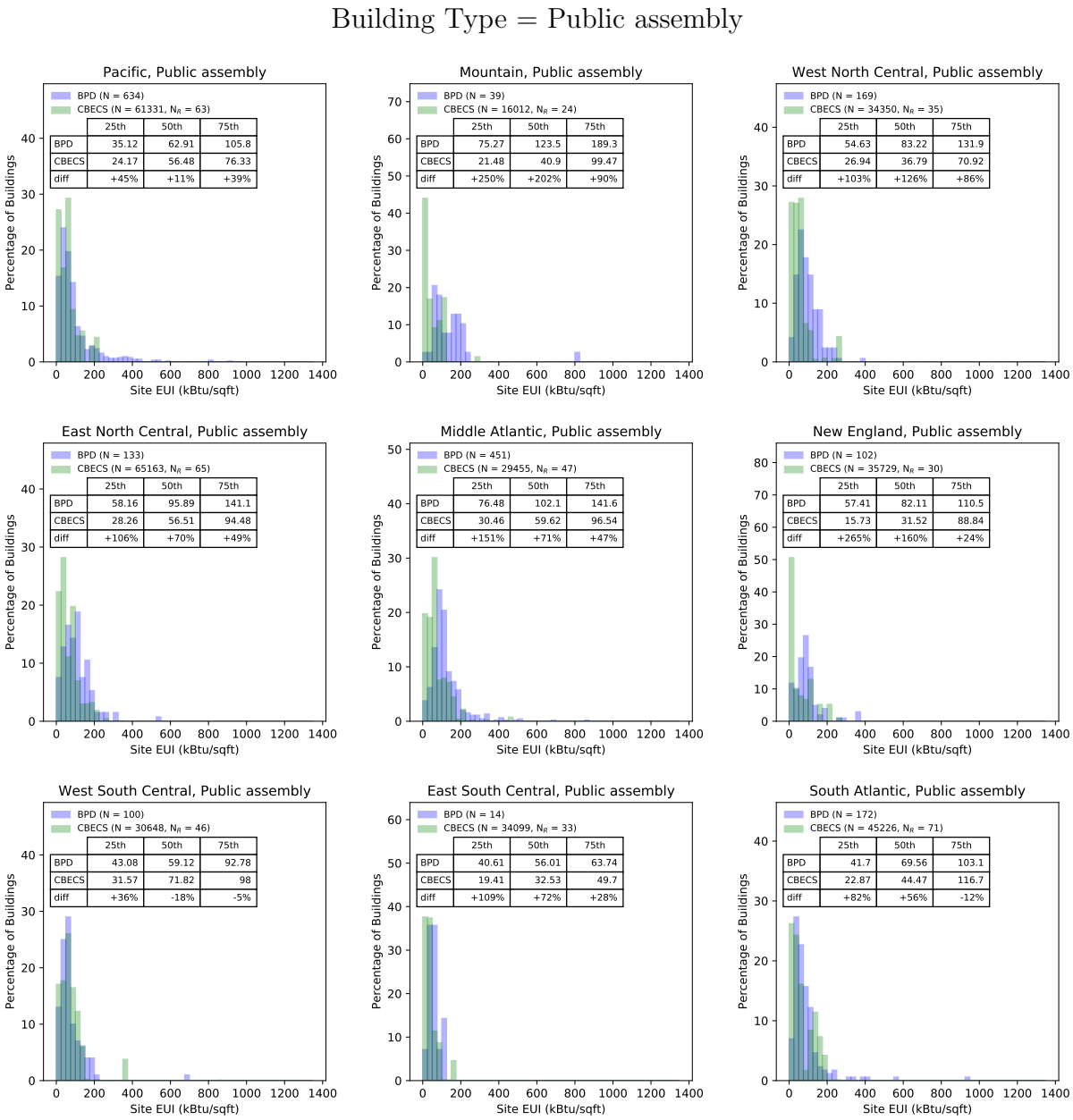


Figure 40: Histograms of site EUI for Public assembly buildings in each census division.

Building Type = Public order and safety

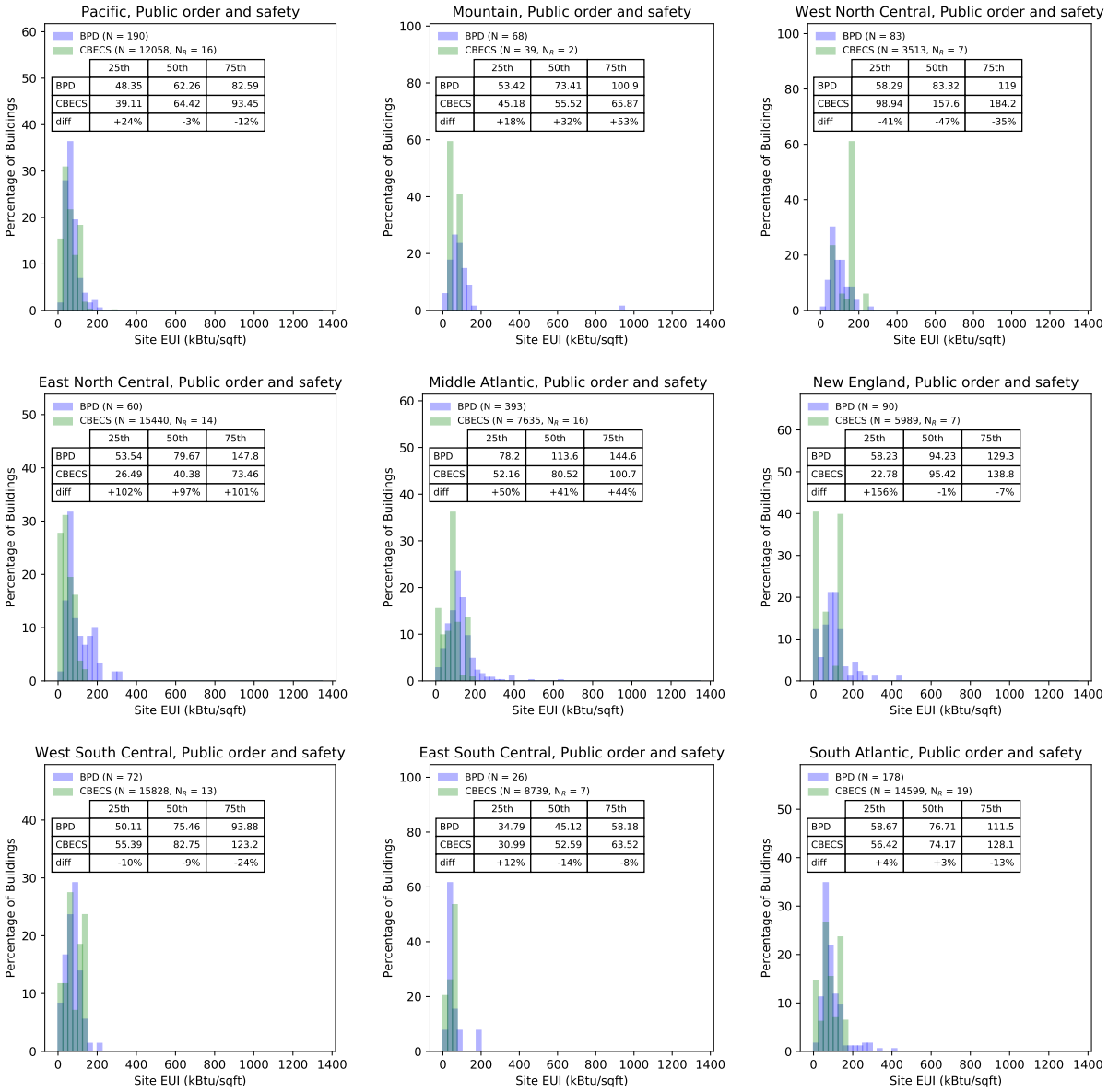


Figure 41: Histograms of site EUI for Public order and safety buildings in each census division.

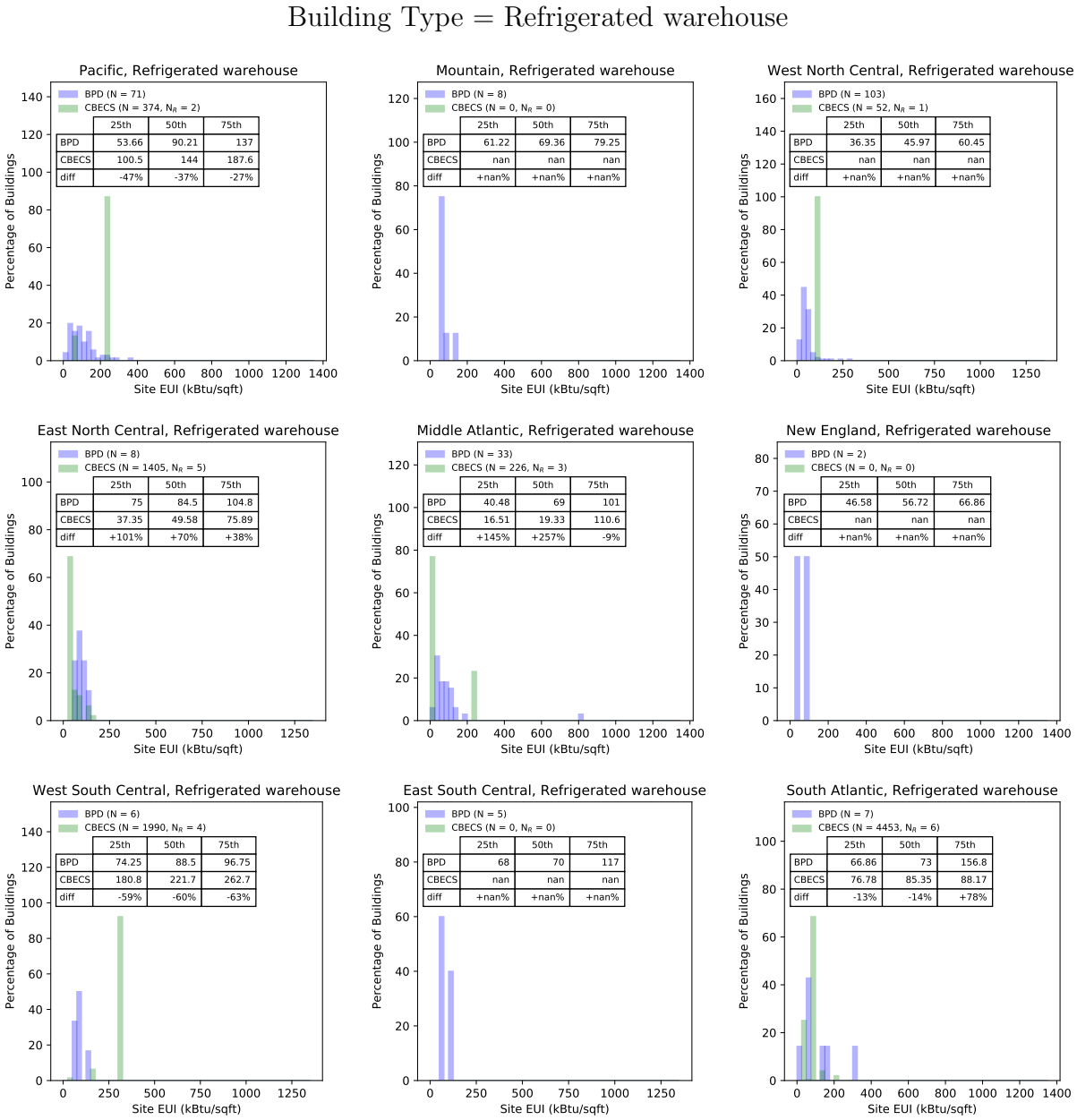


Figure 42: Histograms of site EUI for Refrigerated warehouse buildings in each census division.

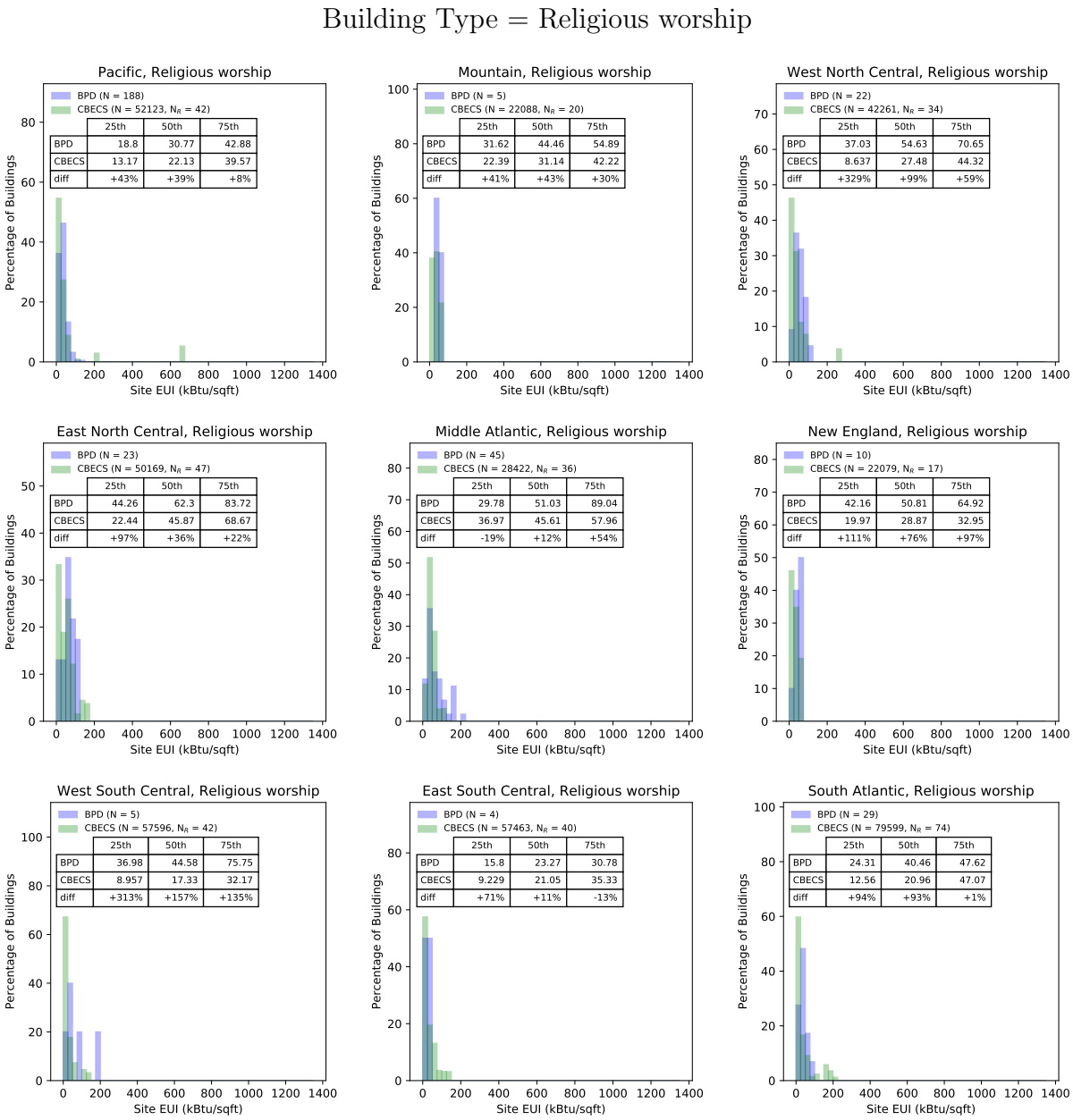


Figure 43: Histograms of site EUI for Religious worship buildings in each census division.

Building Type = Retail other than mall

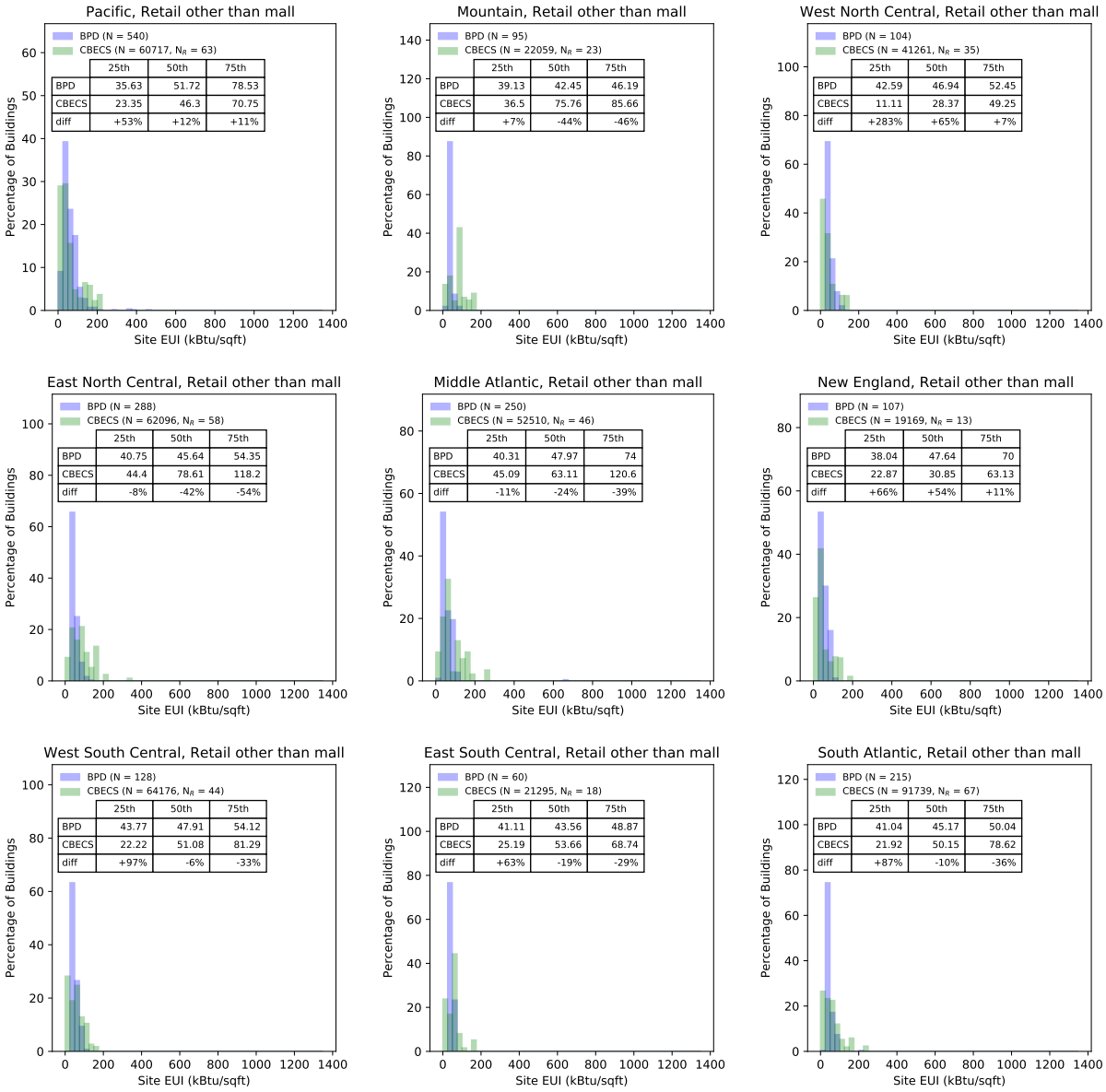


Figure 44: Histograms of site EUI for Retail other than mall buildings in each census division.

Building Type = Service

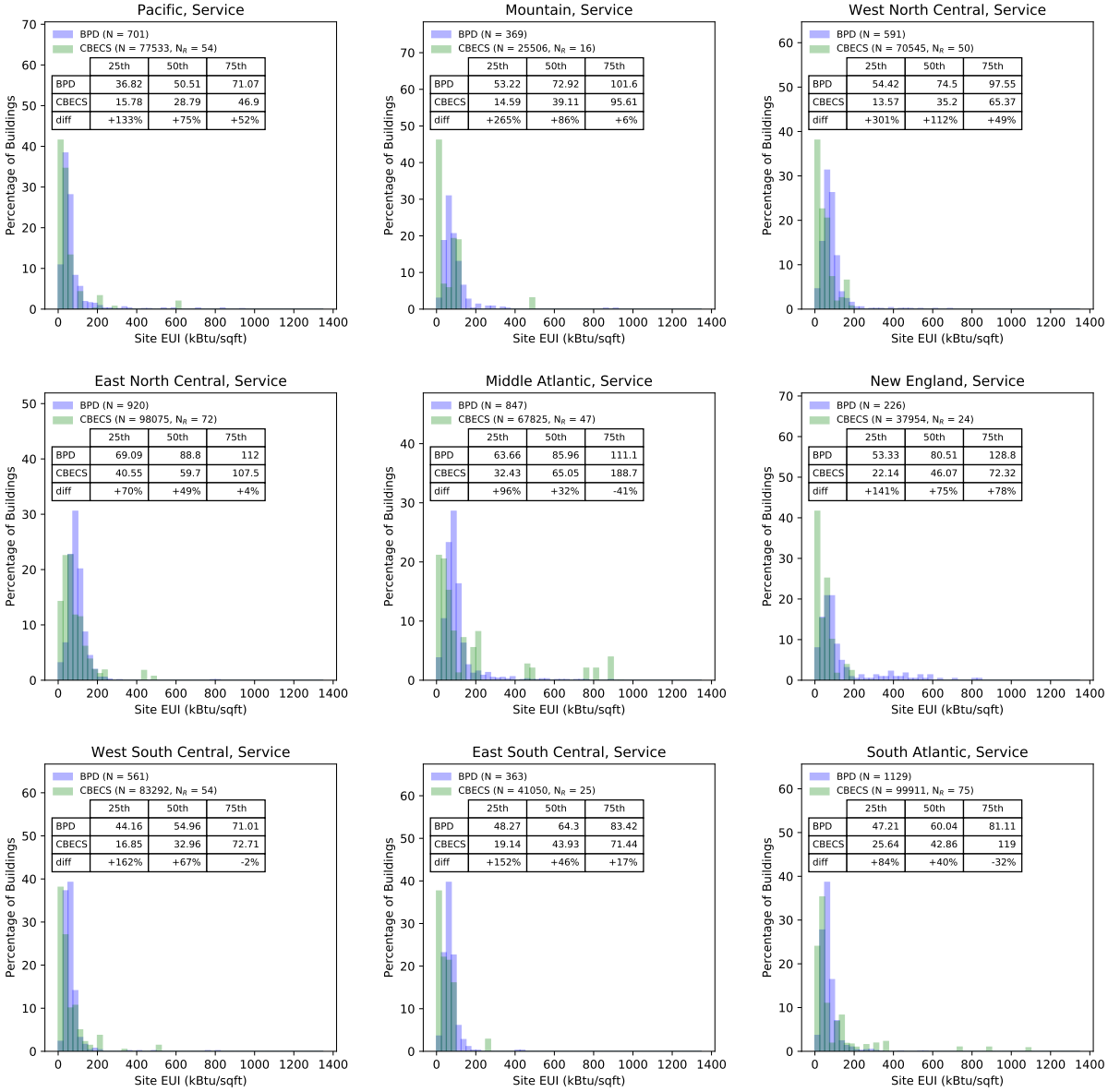


Figure 45: Histograms of site EUI for Service buildings in each census division.

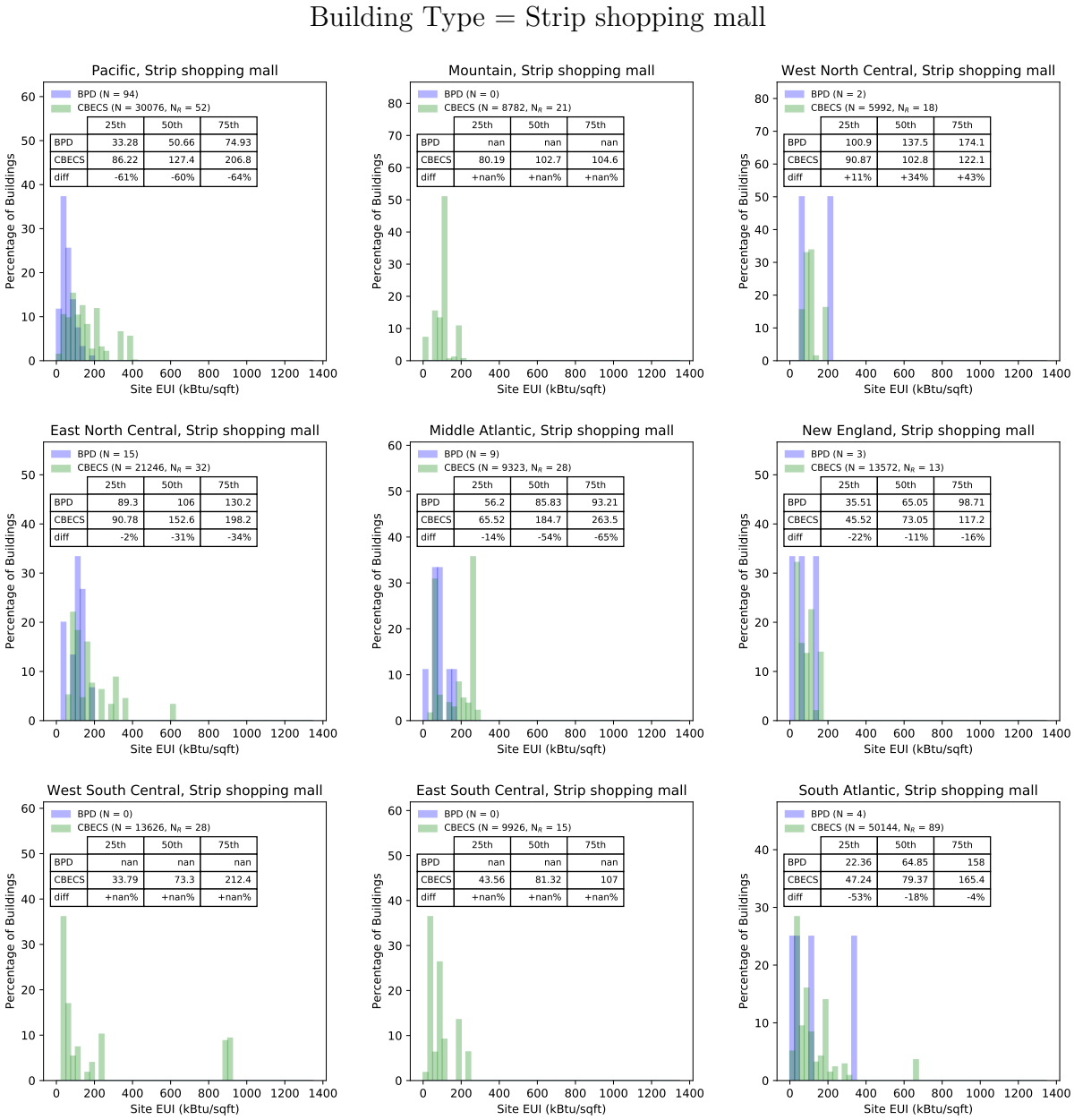


Figure 46: Histograms of site EUI for Strip shopping mall buildings in each census division.

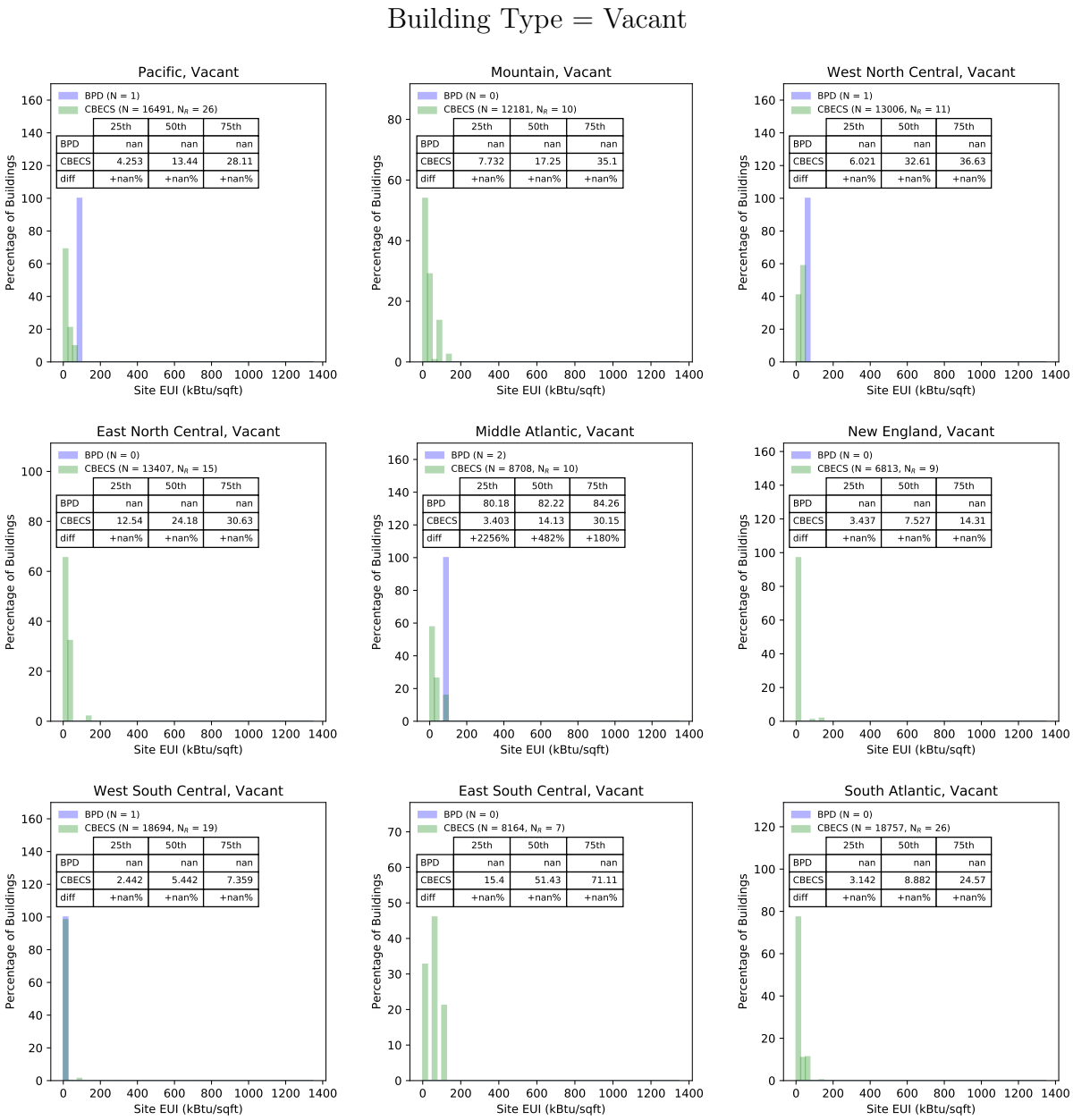


Figure 47: Histograms of site EUI for Vacant buildings in each census division.

Source EUI histograms

The following 20 pages contain histograms of source EUI for each building type and census division. In the legend, N is the number of buildings and N_R is the number of records. The table shows the 25th, 50th, and 75th percentiles for BPD and CBECS, and the difference between BPD and CBECS relative to CBECS. In some cases, there are too few buildings for meaningful calculations of the percentiles, so "nan" (not a number) is shown instead.

Building Type = Education

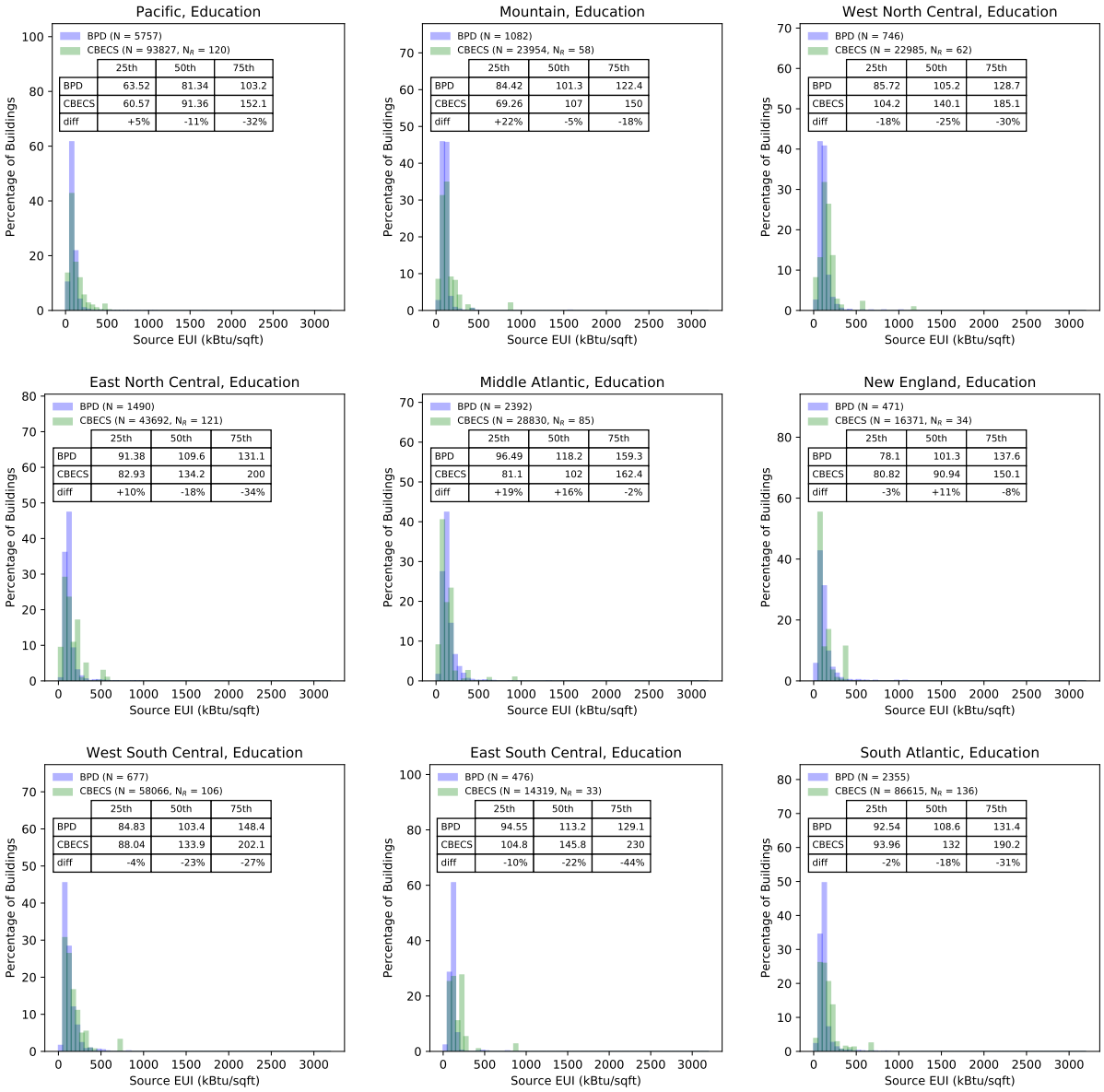


Figure 48: Histograms of source EUI for Education buildings in each census division.

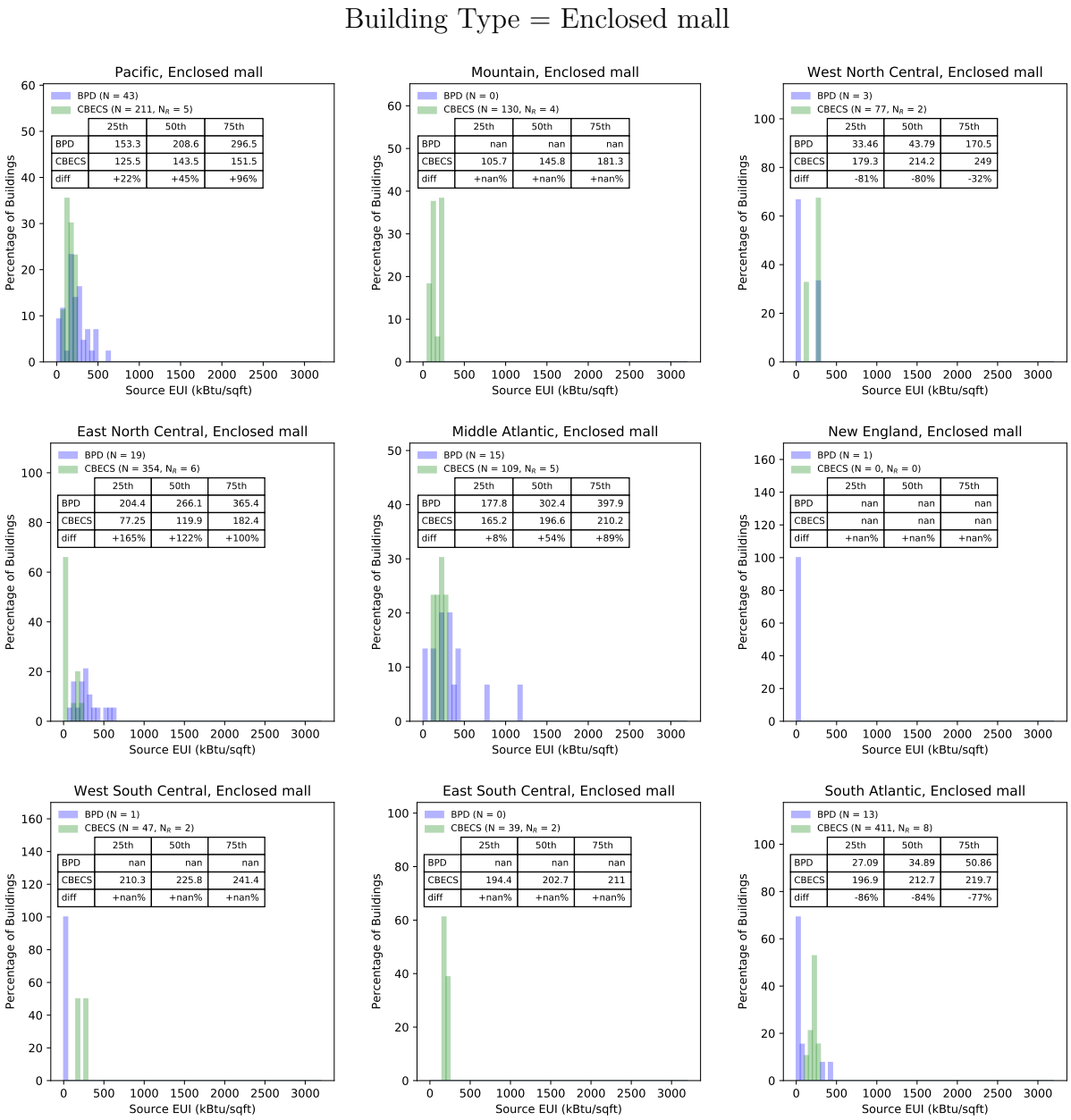


Figure 49: Histograms of source EUI for Enclosed mall buildings in each census division.

Building Type = Food sales

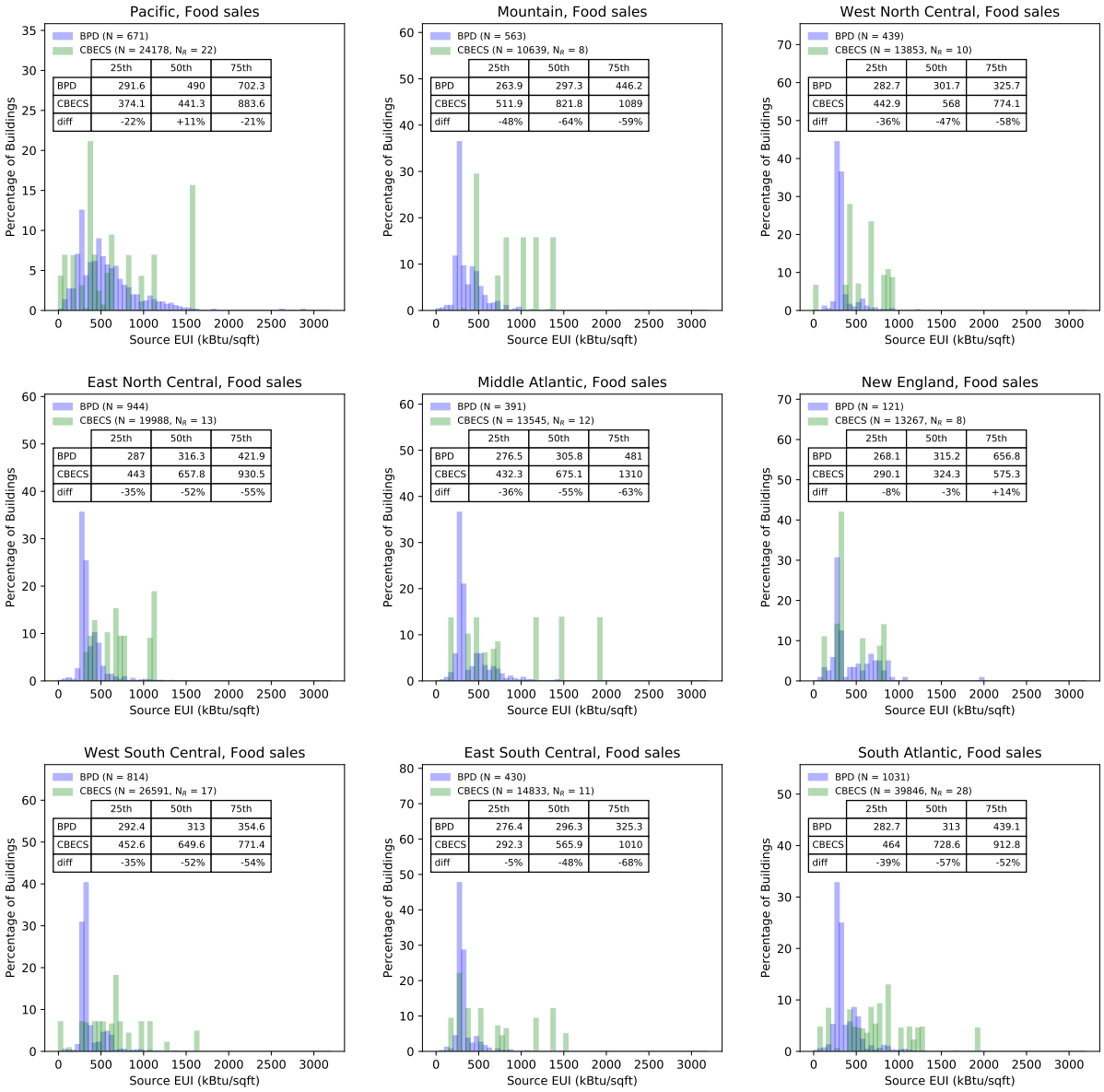


Figure 50: Histograms of source EUI for Food sales buildings in each census division.

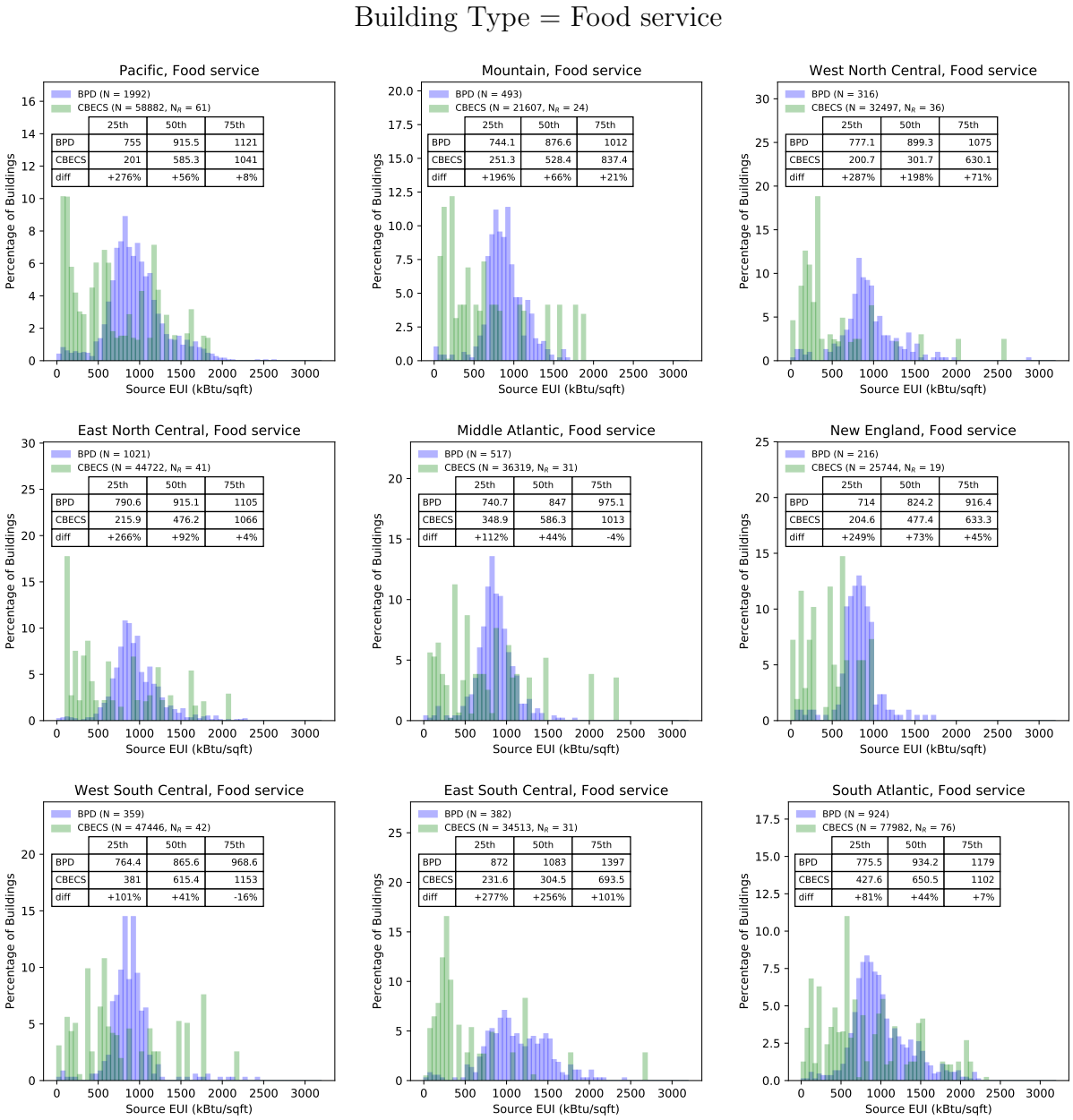


Figure 51: Histograms of source EUI for Food service buildings in each census division.

Building Type = Inpatient health care

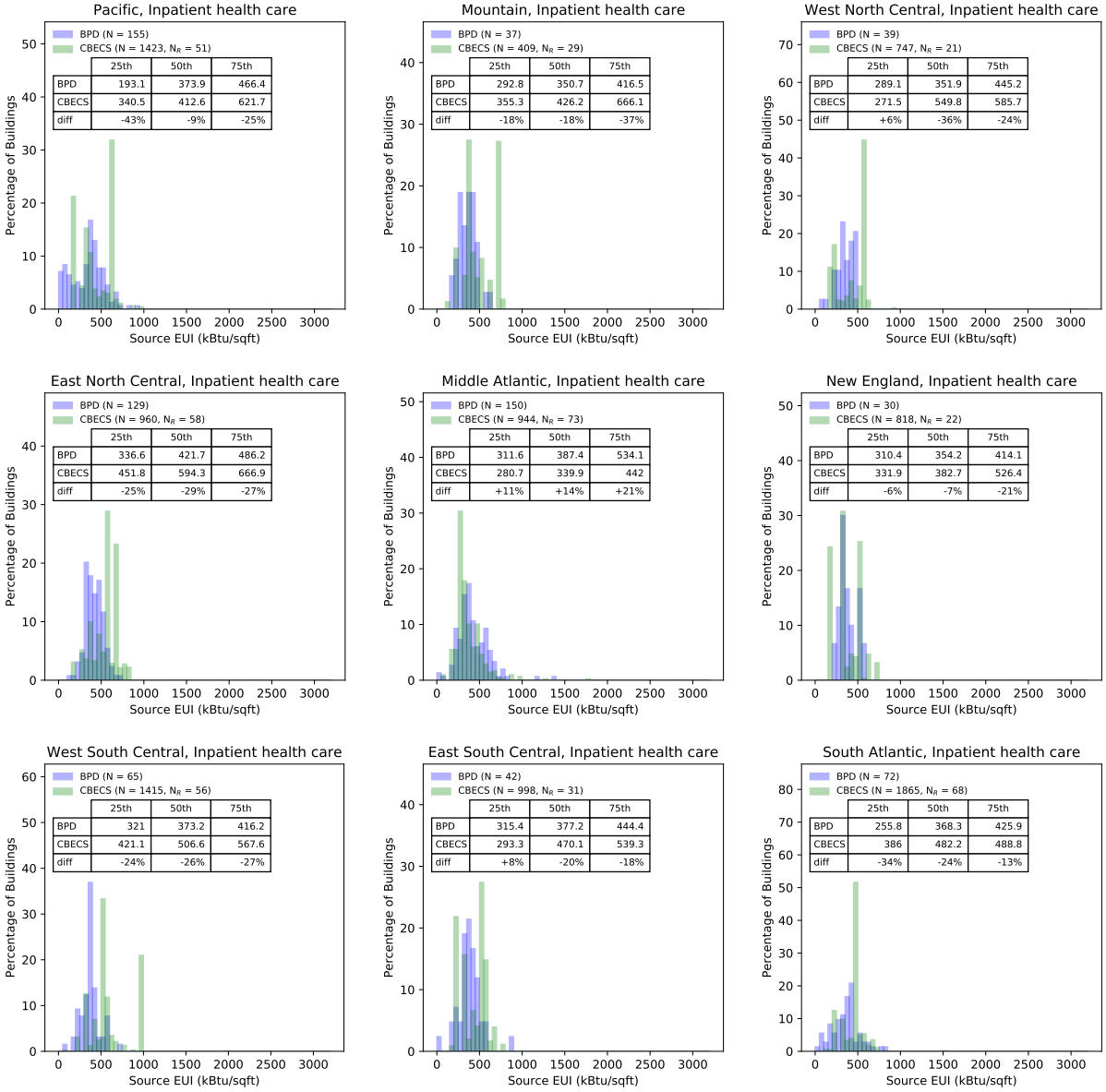


Figure 52: Histograms of source EUI for Inpatient health care buildings in each census division.

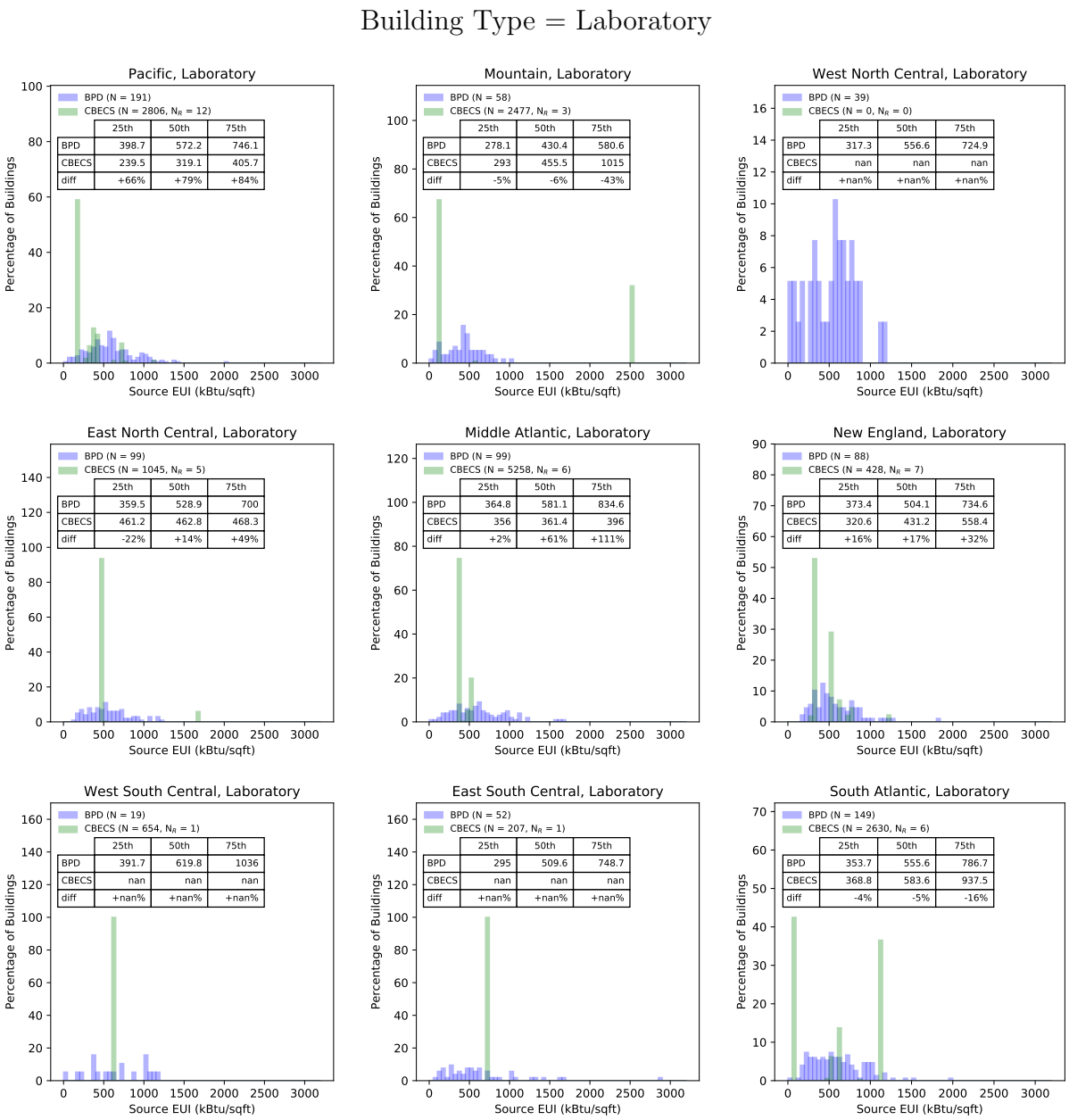


Figure 53: Histograms of source EUI for Laboratory buildings in each census division.

Building Type = Lodging

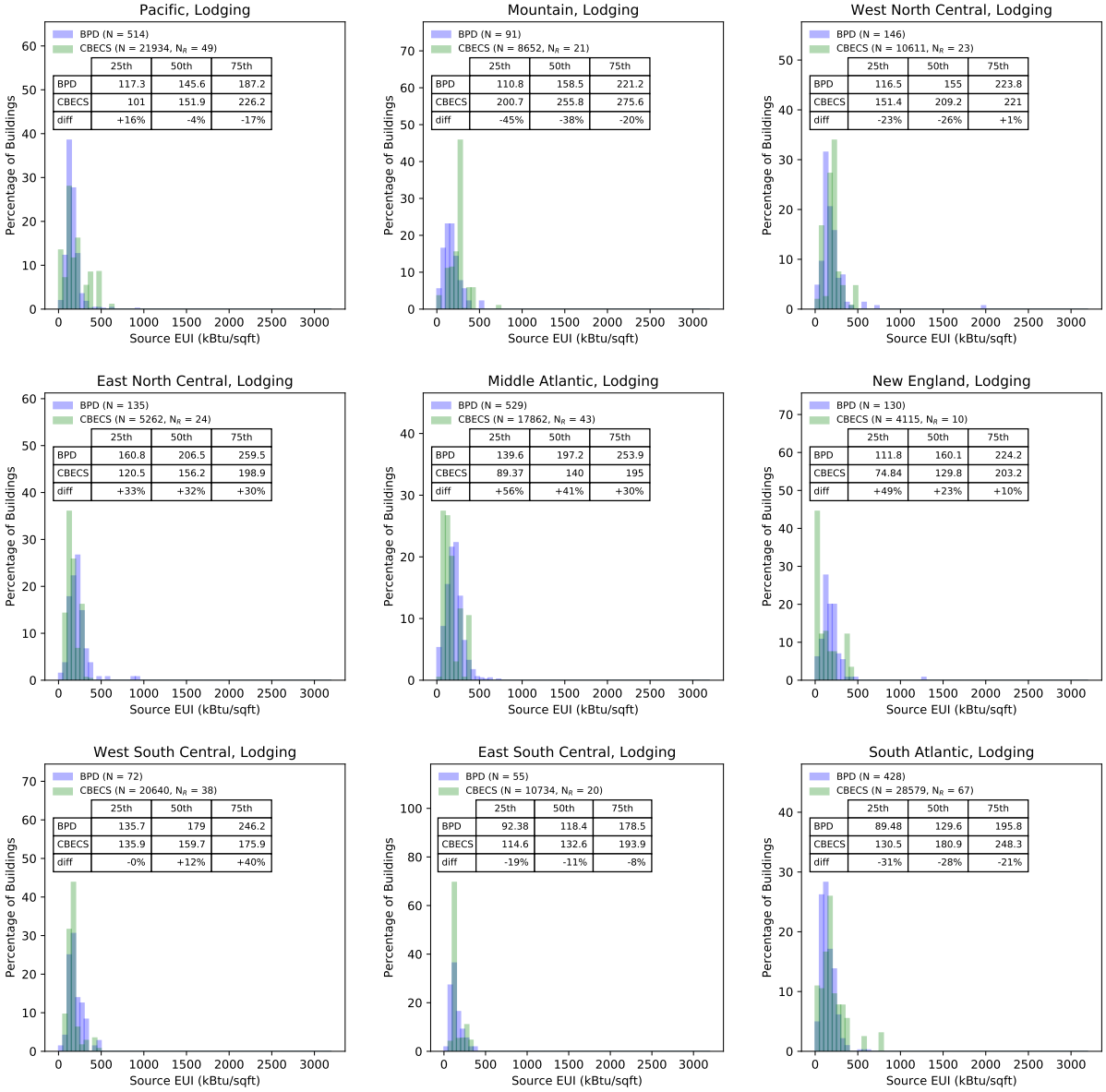


Figure 54: Histograms of source EUI for Lodging buildings in each census division.

Building Type = Nonrefrigerated warehouse

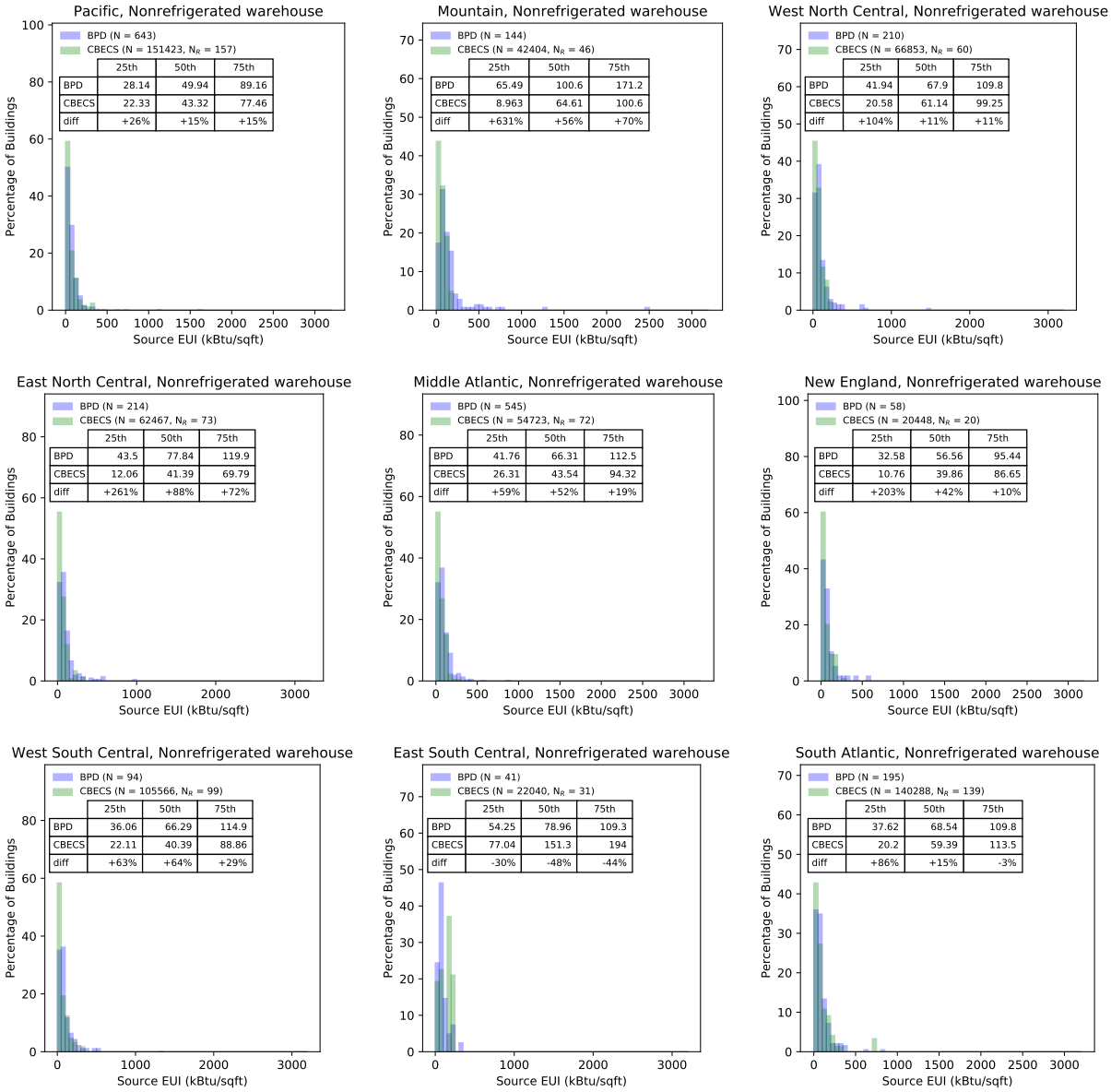


Figure 55: Histograms of source EUI for Nonrefrigerated warehouse buildings in each census division.

Building Type = Nursing

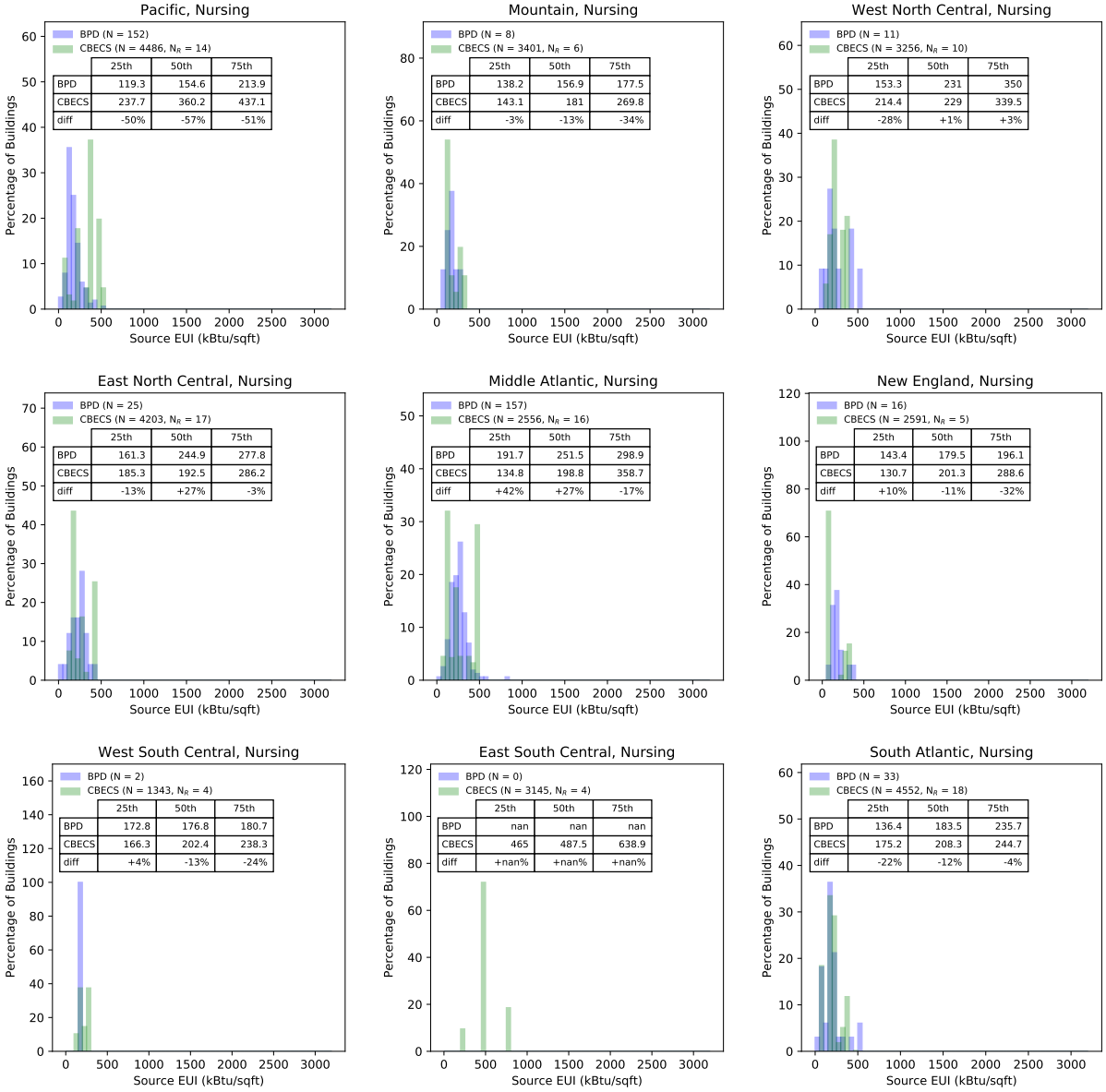


Figure 56: Histograms of source EUI for Nursing buildings in each census division.

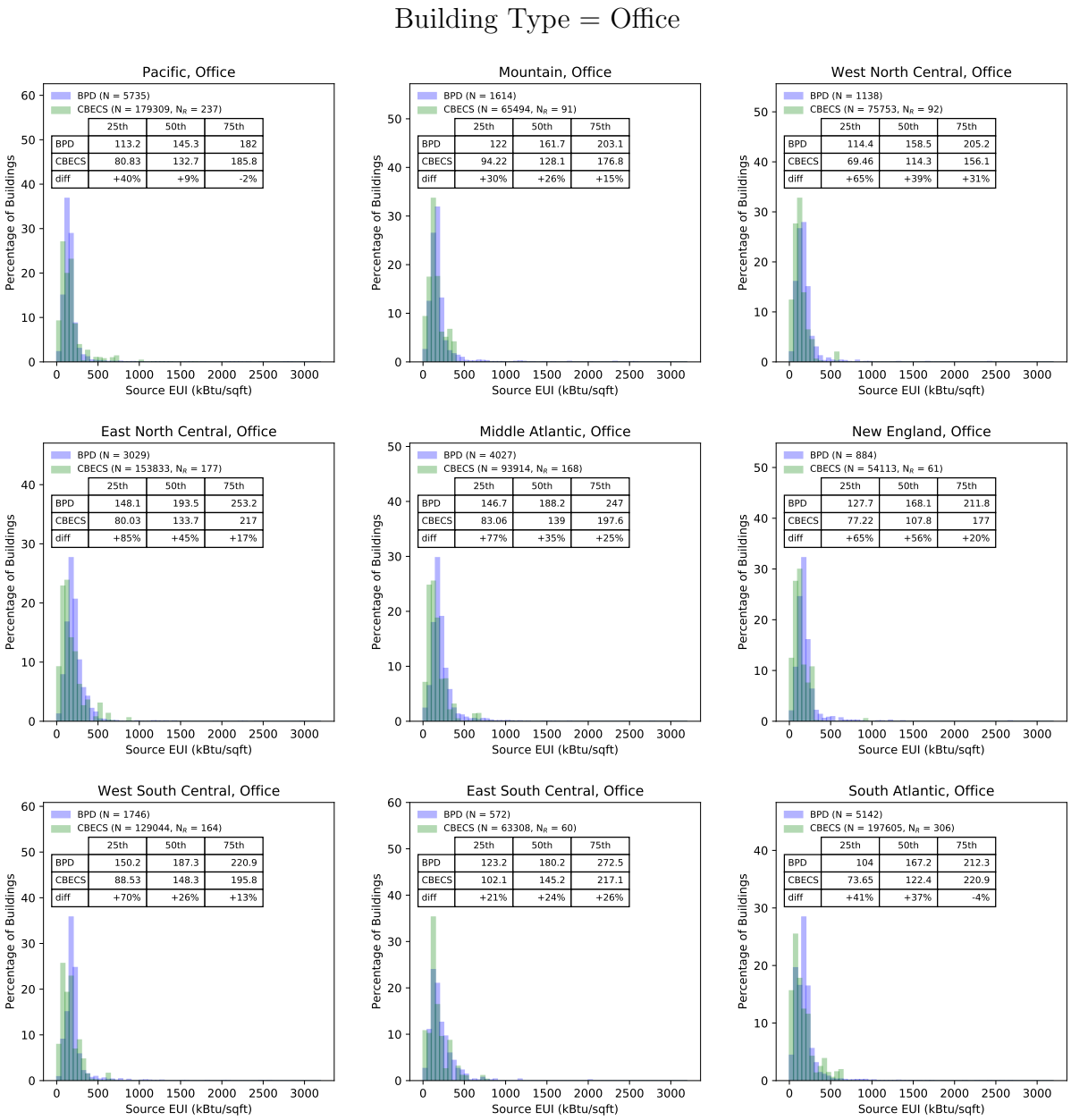


Figure 57: Histograms of source EUI for Office buildings in each census division.

Building Type = Other

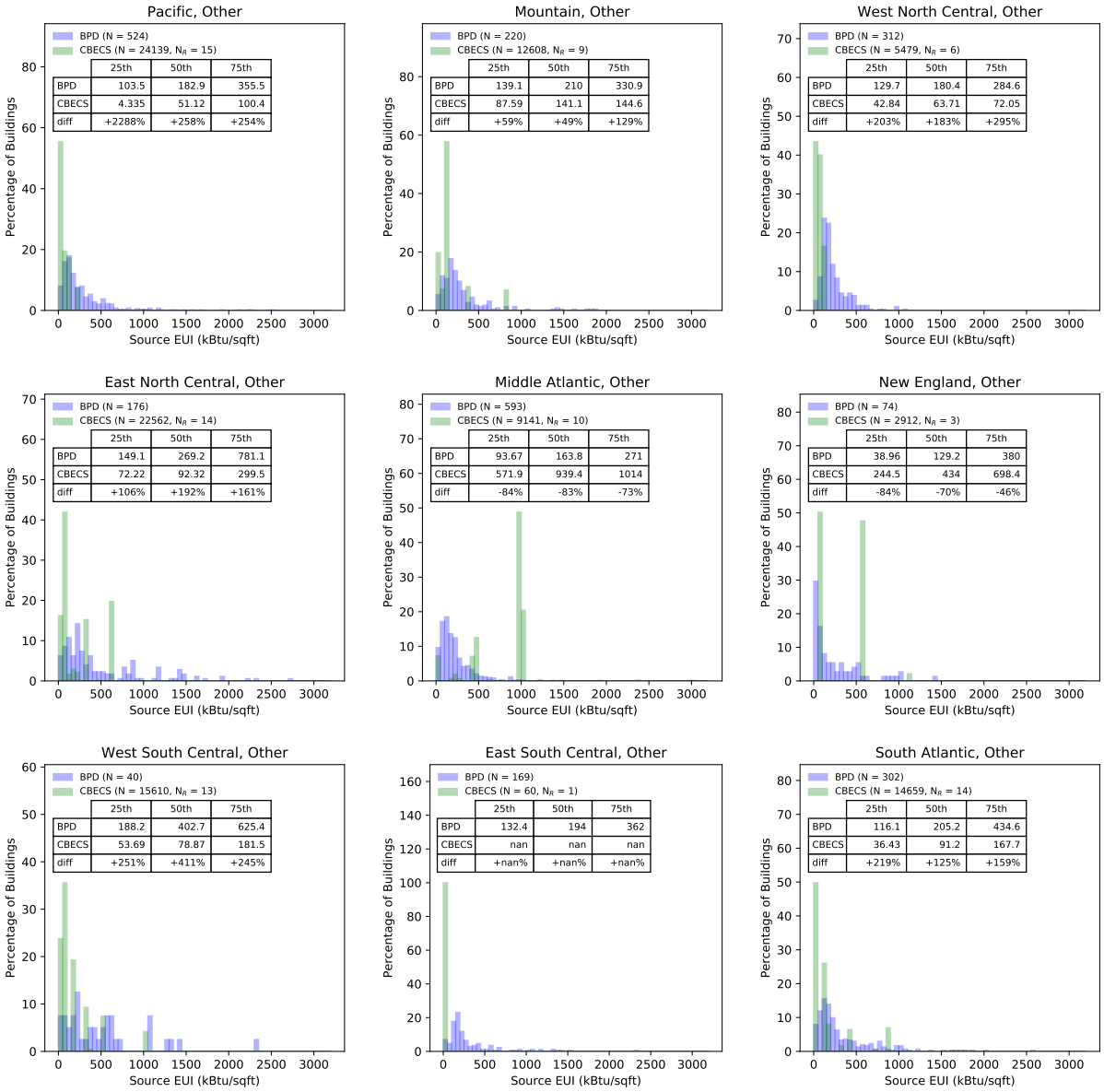


Figure 58: Histograms of source EUI for Other buildings in each census division.

Building Type = Outpatient health care

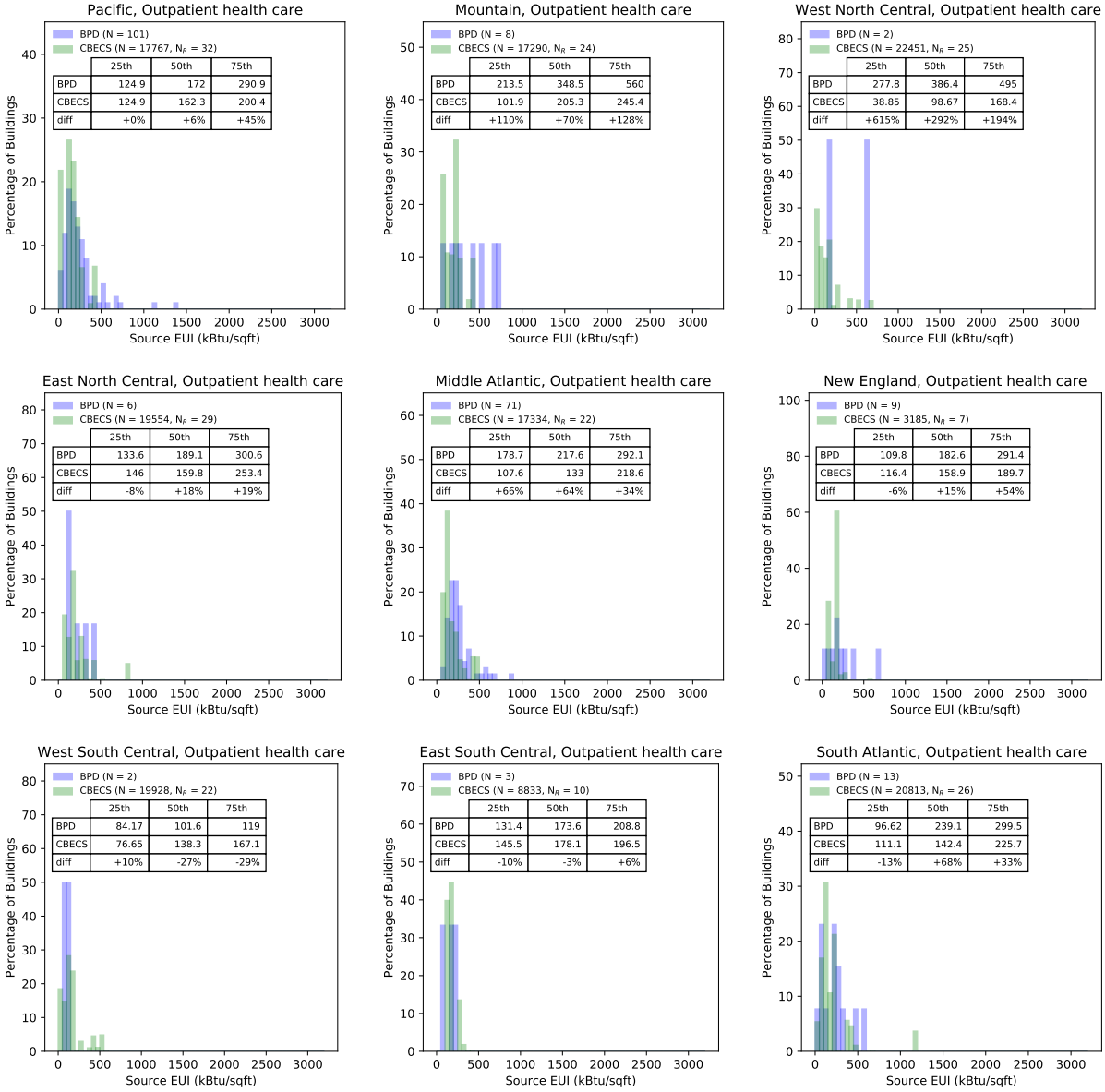


Figure 59: Histograms of source EUI for Outpatient health care buildings in each census division.

Building Type = Public assembly

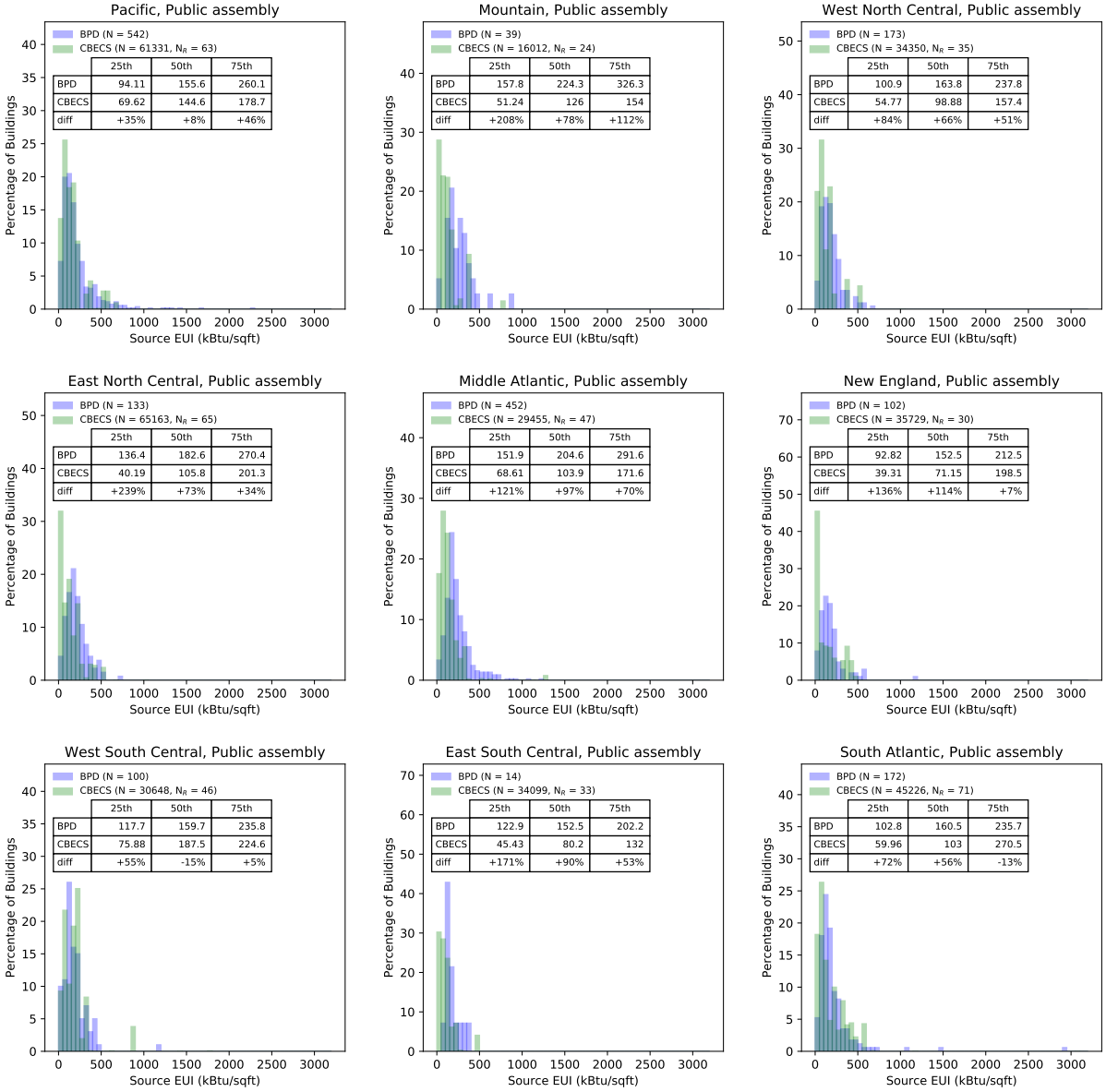


Figure 60: Histograms of source EUI for Public assembly buildings in each census division.

Building Type = Public order and safety

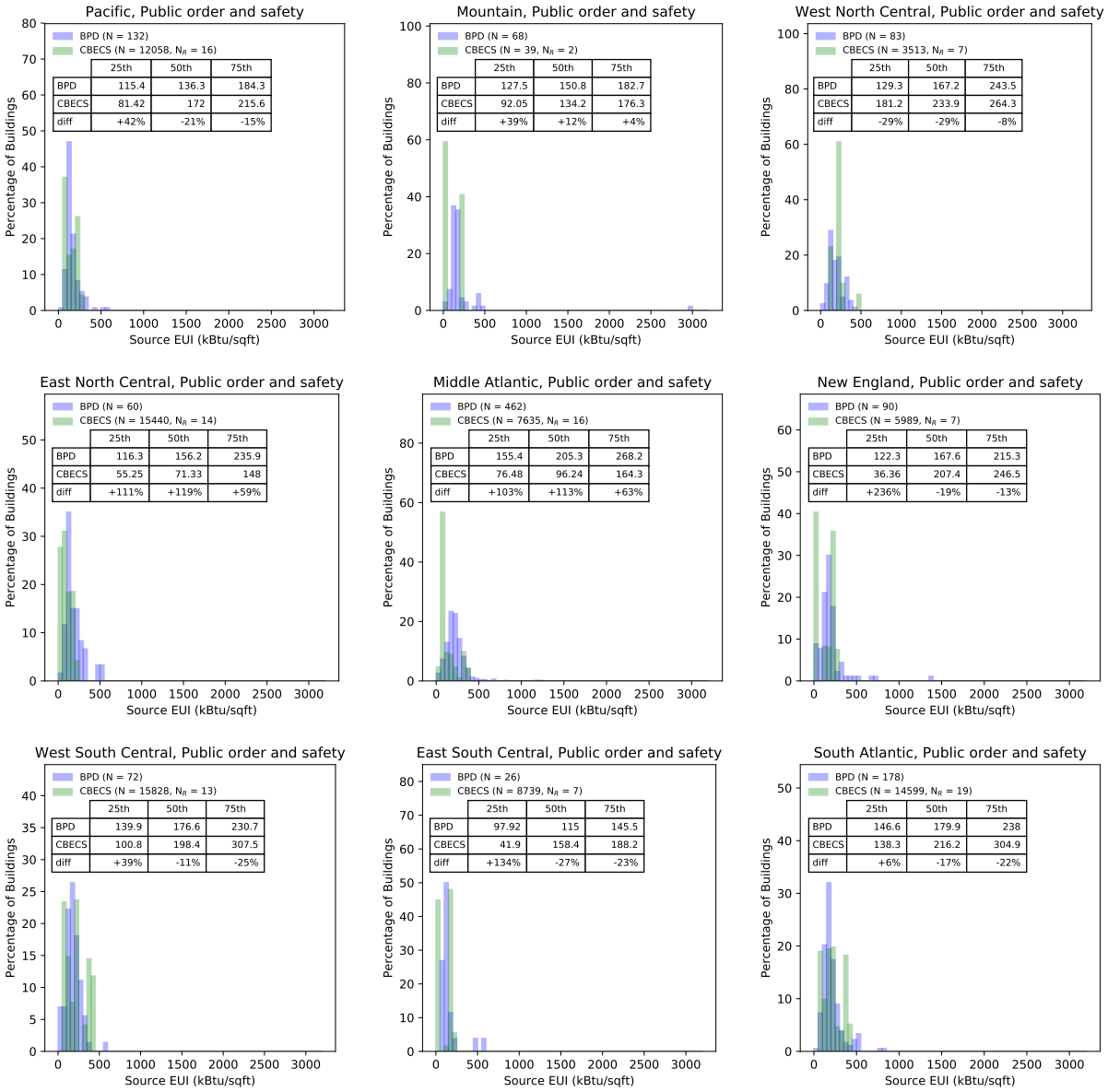


Figure 61: Histograms of source EUI for Public order and safety buildings in each census division.

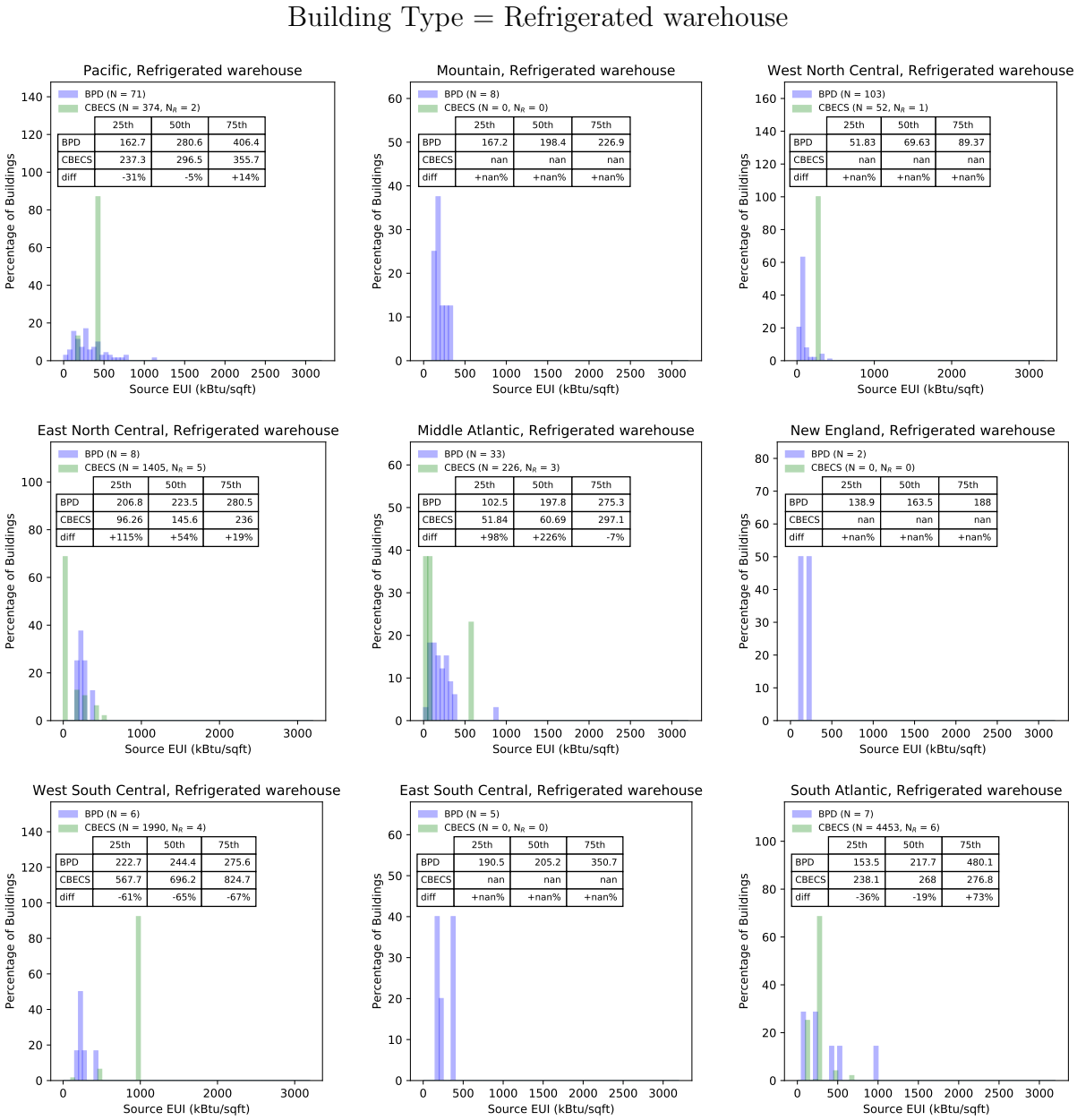


Figure 62: Histograms of source EUI for Refrigerated warehouse buildings in each census division.

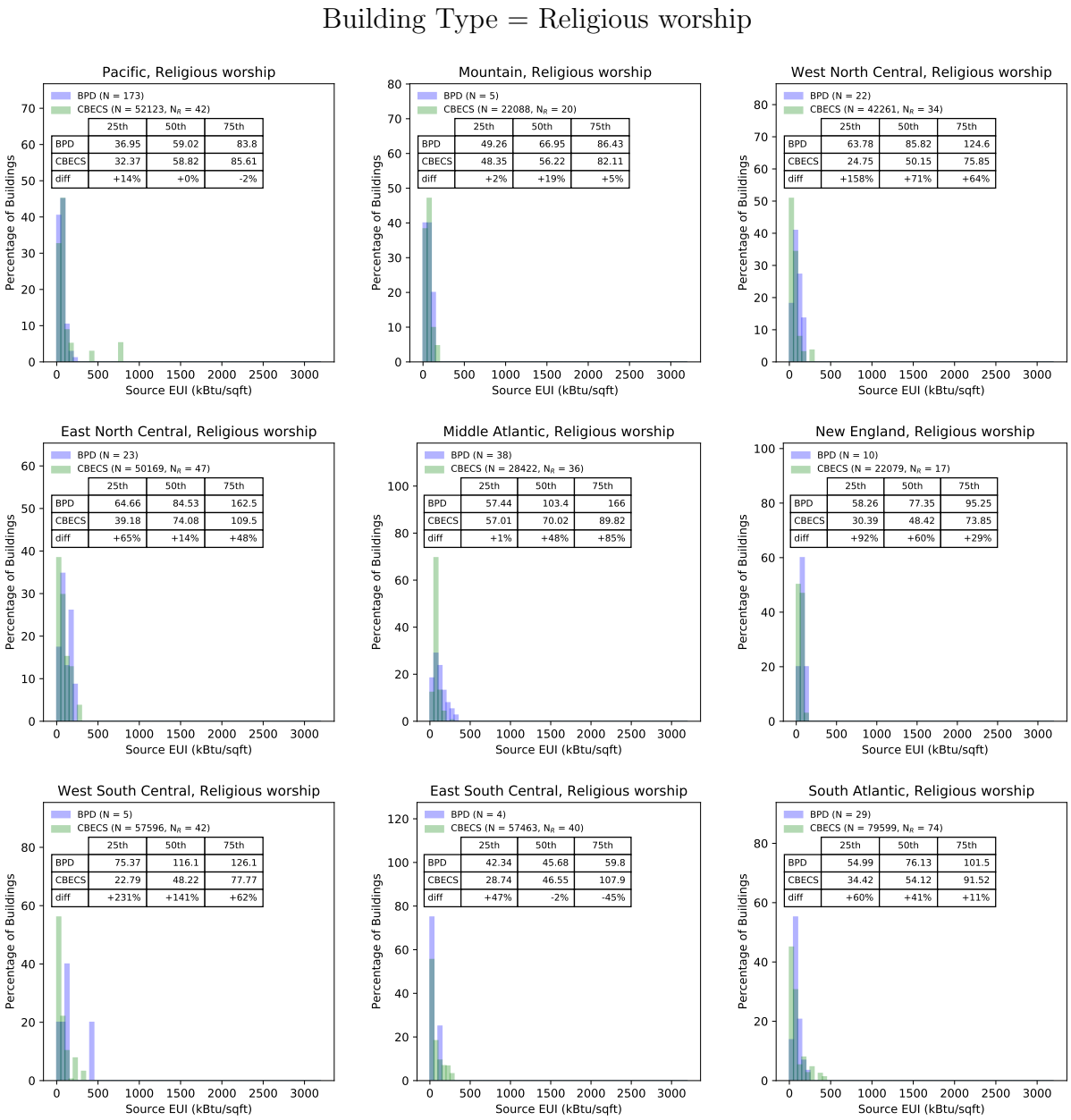


Figure 63: Histograms of source EUI for Religious worship buildings in each census division.

Building Type = Retail other than mall

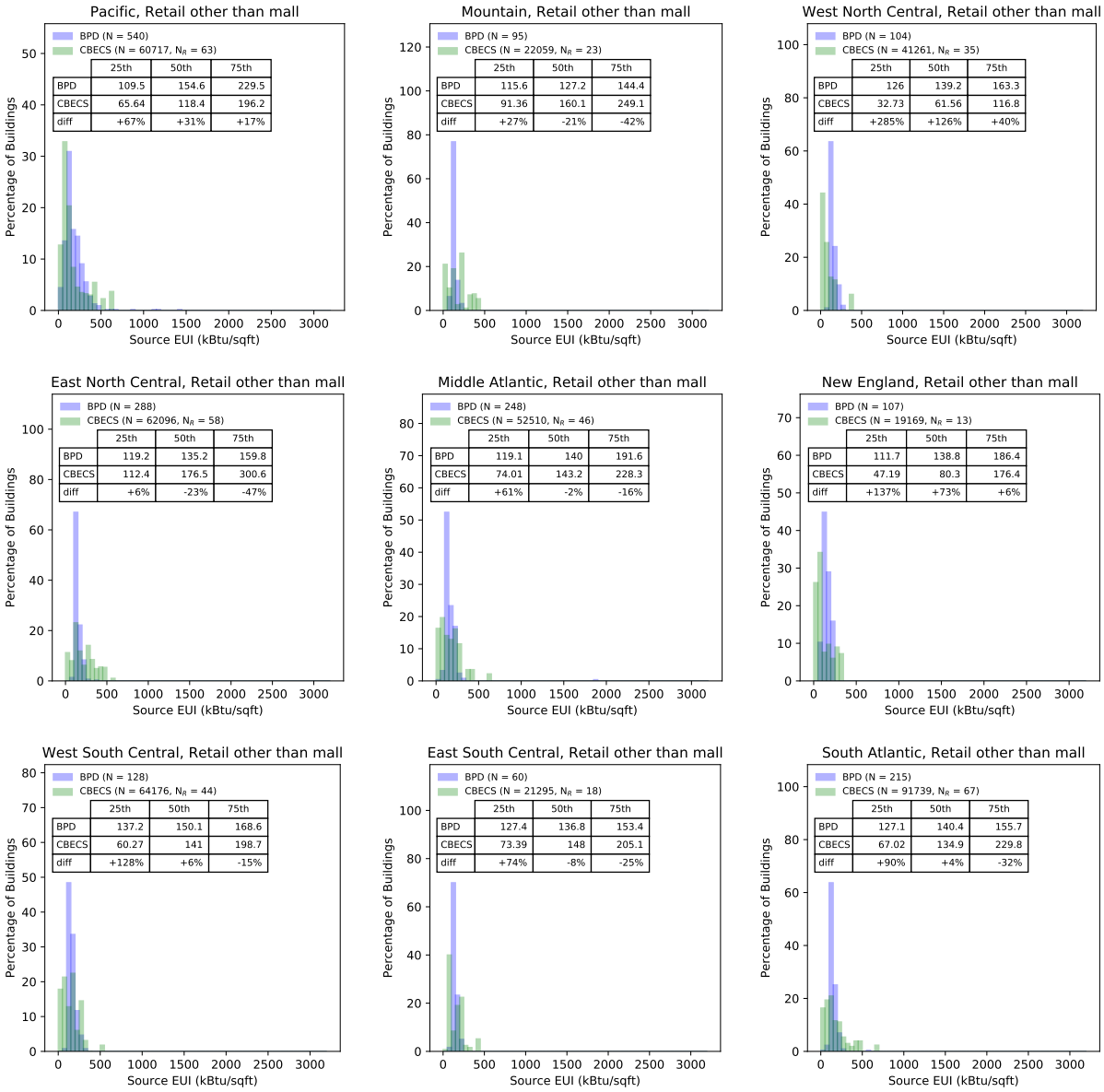


Figure 64: Histograms of source EUI for Retail other than mall buildings in each census division.

Building Type = Service

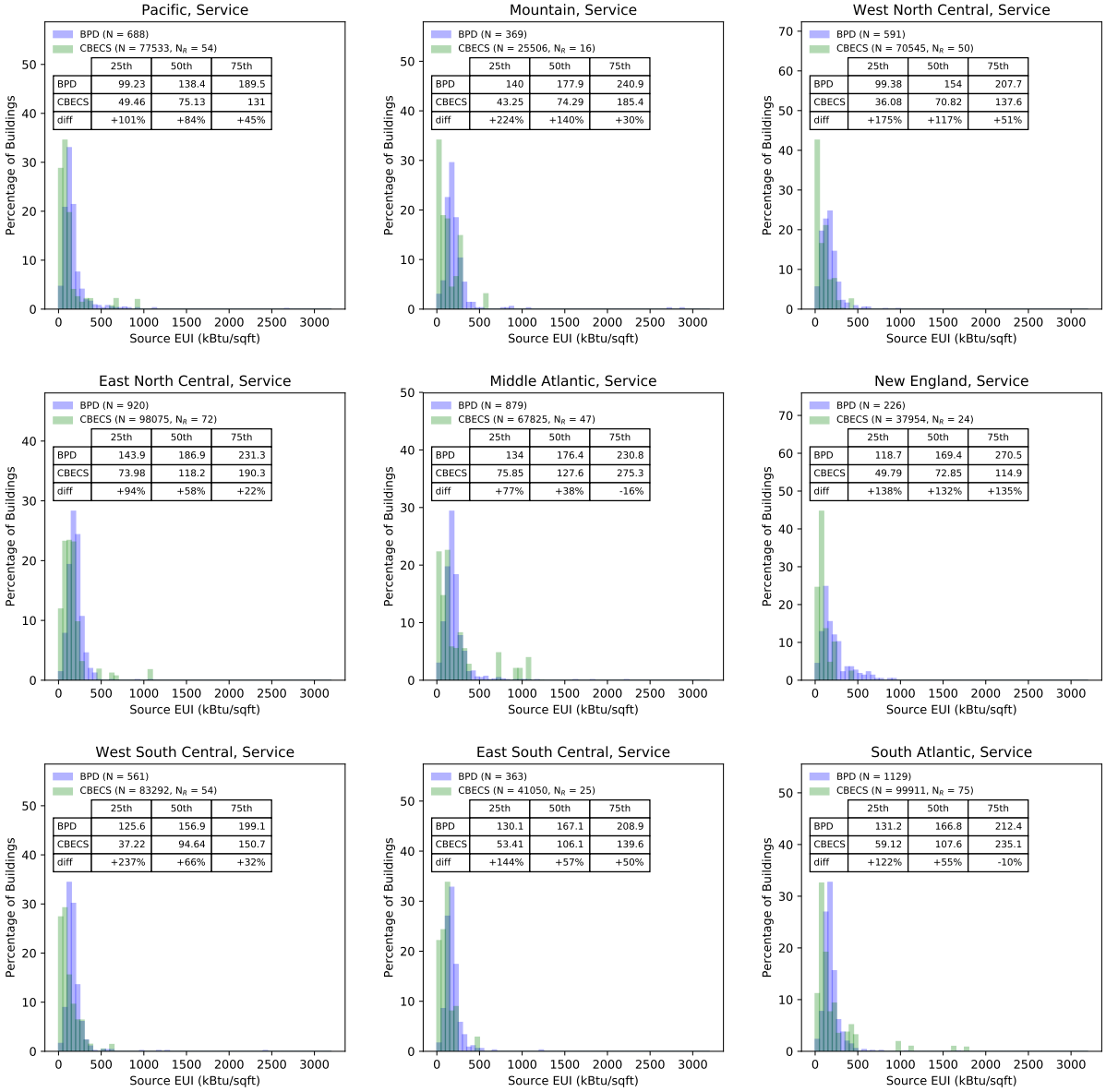


Figure 65: Histograms of source EUI for Service buildings in each census division.

Building Type = Strip shopping mall

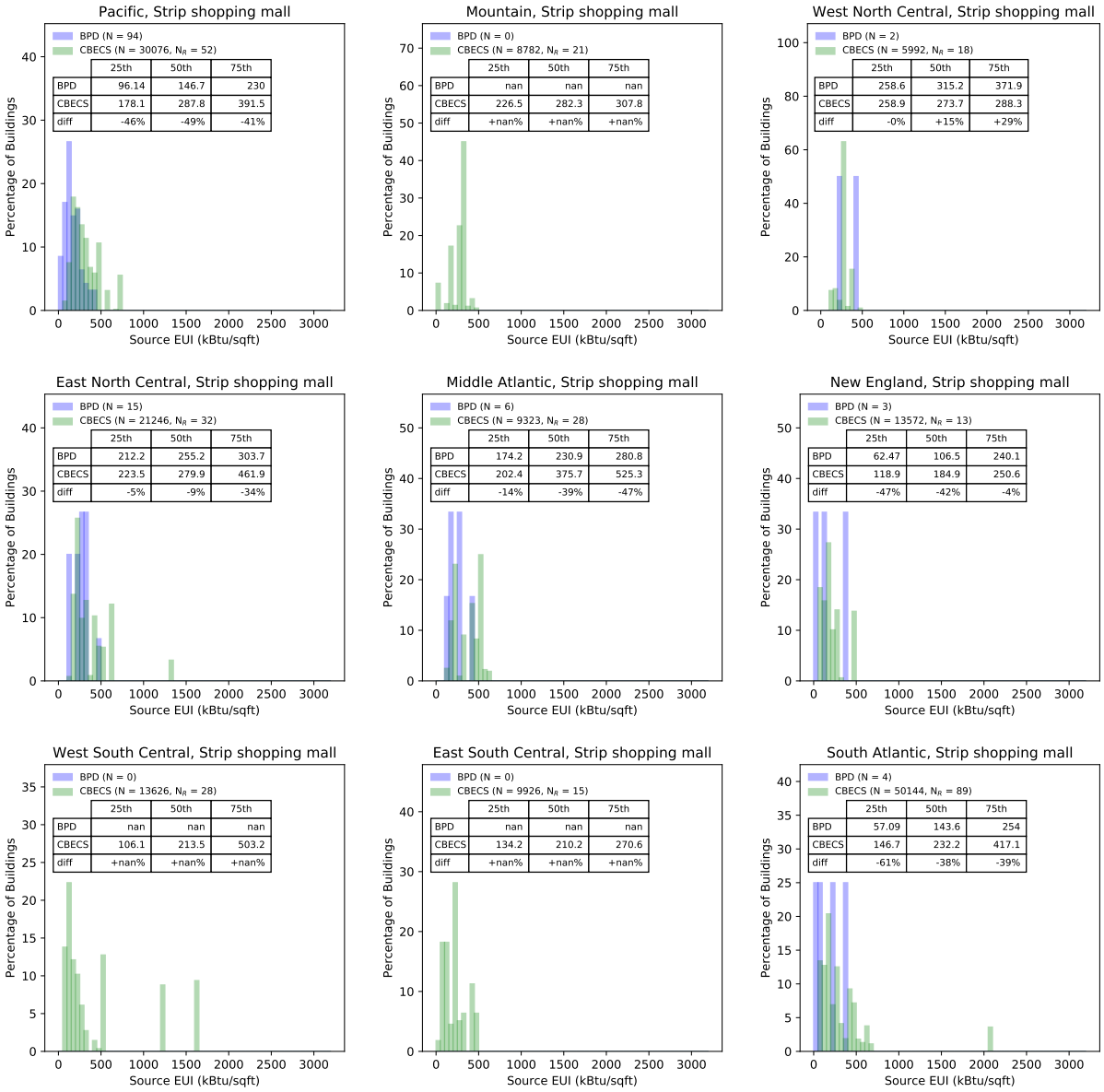


Figure 66: Histograms of source EUI for Strip shopping mall buildings in each census division.

Building Type = Vacant

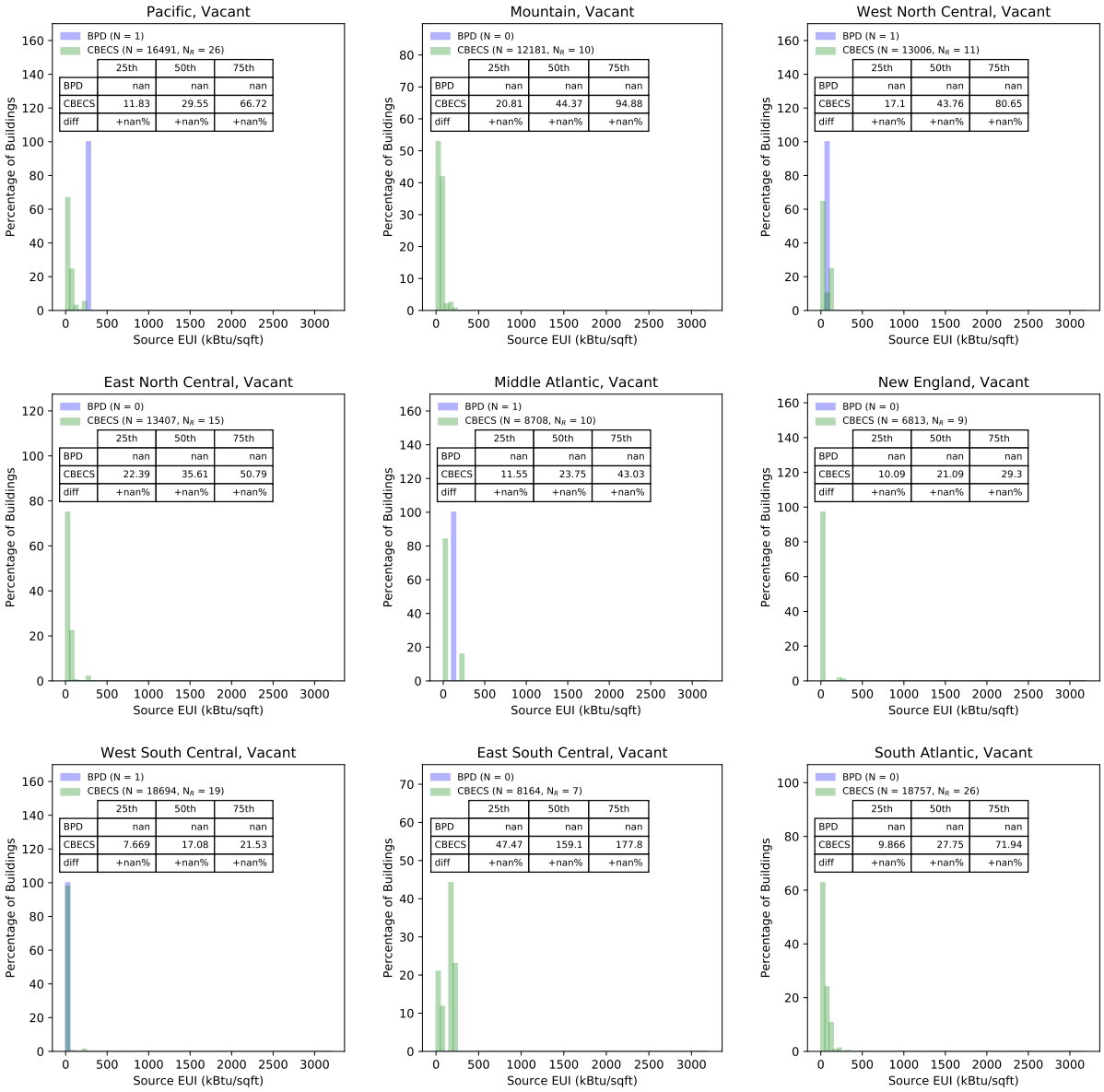


Figure 67: Histograms of source EUI for Vacant buildings in each census division.

Percentile scatterplots

The following 3 pages contain scatterplots of the 25th, 50th, and 75th percentiles of floor area, site EUI, and source EUI for the BPD and CBECS datasets. Each circle represents one combination of building type and census division. The blue line indicates all values where the BPD and CBECS percentiles are equal.

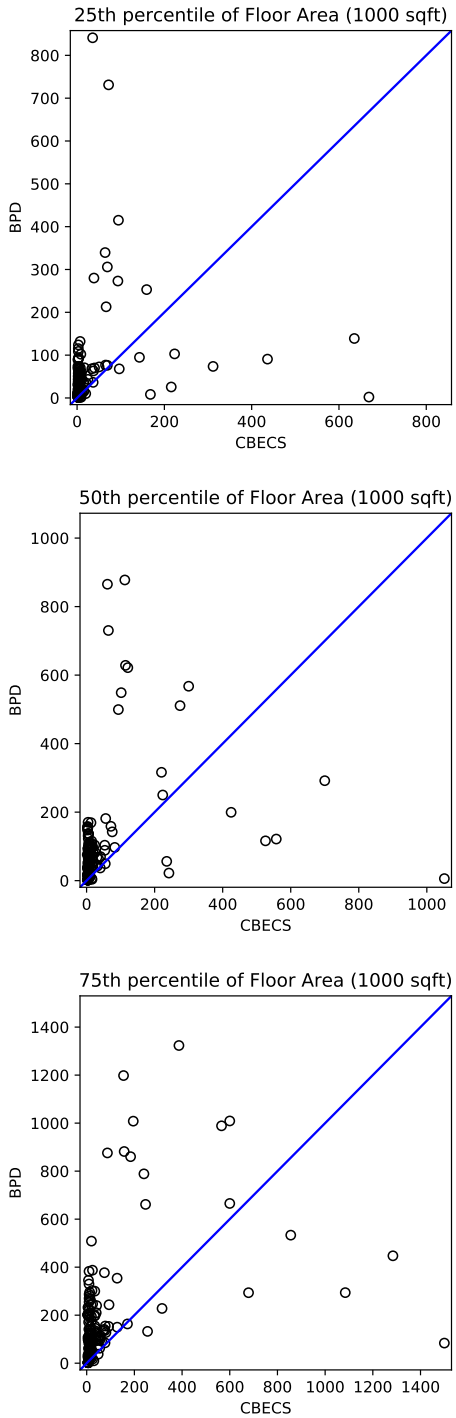


Figure 68: Scatterplots of the 25th, 50th, and 75th percentiles of floor area.

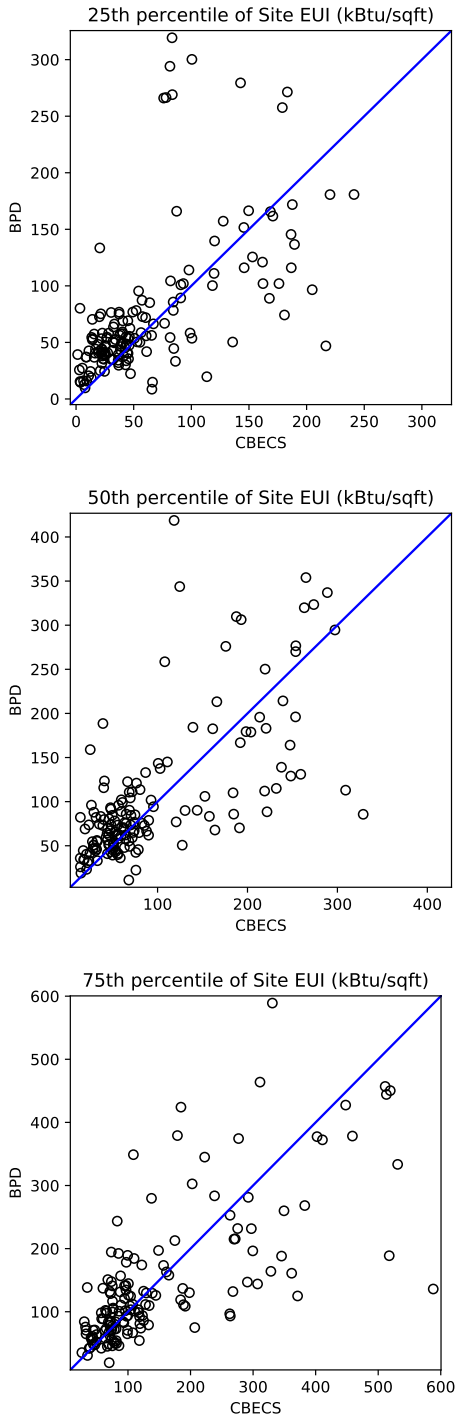


Figure 69: Scatterplots of the 25th, 50th, and 75th percentiles of site EUI.

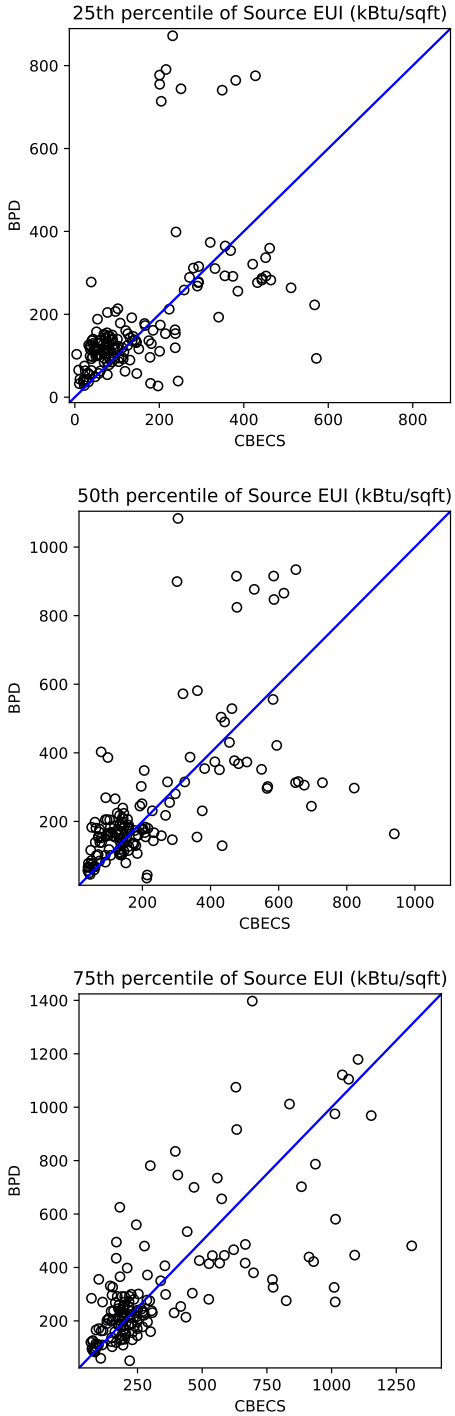


Figure 70: Scatterplots of the 25th, 50th, and 75th percentiles of source EUI.