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Impacts of LEED Standards on the Energy Performance of Large Buildings Inferred from City-Level Building Energy Benchmarking Data

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Abstract—Certification by the Leadership in Energy and Environmental Design (LEED) program is often proposed as a potential method to improve building energy efficiencies. This is despite the general lack of data regarding the efficacy of LEED certification and inconsistent results from past studies that often focused on a few buildings from a single city. Using recently available building energy use data from a nationwide set of 10 cities, we studied the effects of LEED certification on building energy efficiency measured by site energy use intensity, source energy use intensity, and greenhouse gas emissions. In addition, we used natural language processing methods to study patterns in the acquisition of specific credits by LEED-certified buildings. We find that LEED-certified buildings are not more energy-efficient by any measure except in a single city. In addition, neither the total amount of credits nor the number of Energy and Environment credits achieved correlate with building energy efficiency measures. Finally, buildings with high Energy and Atmosphere credits corresponding to renewables are not more energy-efficient in many cases. These conclusions call into question the use of LEED certification as a policy metric for improving the energy efficiency of buildings.

Keywords—Energy Efficiency, LEED, Building

I. Introduction

The Leadership in Energy and Environmental Design (LEED) program has often been proposed as a potential third-party standard to benchmark and improve the energy efficiency of buildings, but the empirical relationship between LEED certification and building energy use on a national level is not clearly understood. This issue has received increased scrutiny in recent years as concerns over climate change increase. In the United States, the building sector is responsible for 40% of the primary energy and 72% of electricity use. It is therefore crucial to determine the effectiveness of LEED standards in improving building energy performance considering the prevalence of energy and climate policies citing LEED certification.

In recent years, municipalities have enacted energy use benchmarking codes for large buildings to better track the energy consumption and footprint of city buildings. Generally, these codes apply only to commercial buildings above a particular square footage cutoff. These codes, and the public data associated with them, provide a valuable opportunity for evaluating the efficacy of LEED building standards in improving building energy performances nationwide. Several previous studies have examined city level benchmarking data for Chicago [8] and New York [7], and concluded that in those municipalities, overall LEED certification level does not associate with lower overall energy consumption. In this study, we expand this approach to a nationwide set of ten cities, and further examine LEED sub-credit scores that specifically address energy efficiency and utilization.

II. Background

From the perspective of building owners or operators, the primary motivation for investment in green building certifications is to signal quality and other tangible benefits (increased rents, lower operating costs, etc.) to stakeholders [2], [3]. LEED is one of the most popular rating schemes, and utilizes a credit-based approach, where specific investments in construction or building design are rewarded with a corresponding number of credits. Surpassing credit thresholds results in the award of a certification depending on which threshold was achieved. LEED does not mandate specific pathways to certification. As a result, there is a wide range of possible credit composition for a certain LEED certification.

This heterogeneity in credit naturally leads to variance in energy efficiencies between identically certified buildings. This is of interest due to the proliferation of municipal building codes specifically mandating LEED certification with the express intention of reducing energy consumption. As a result, there has been significant interest in evaluating whether certified buildings indeed consume less energy than similarly uncertified counterparts. Previous work tends to focus on restricted samples without a clear conclusion. An analysis of 100 LEED certified buildings found that relative to type and occupancy matched controls, LEED certified buildings used less energy per floor area, but more energy overall [5]. A separate analysis of the same buildings using updated definitions of energy usage failed to identify a LEED certification effect [7]. Examination of 21 LEED certified buildings in New York City [7] and 132 certified buildings in Chicago [8] found that these certified buildings did not consume less energy than similar non-certified buildings. A LEED certification treatment effect was observed in a study of 134 LEED buildings in Los Angeles, but the observation was on the edge of statistical significance ($p > 0.05$) [1].

III. Materials and Methods

We surveyed cities with energy consumption reporting policies in the US according to published lists from the Institute for Market Transformation. We found 27 cities that have such policies. Among these, 12 publish the collected data publicly. We found that the reported data from Austin, Texas and Cambridge, Massachusetts were of particularly poor quality (containing data from few buildings or containing only outdated data), and excluded them from our analysis. The datasets included building-identifying information (address, zip code, project name) and building-level site energy use intensity. In general, three sets of energy use intensities are reported. First, site energy use intensity (site EUI) measures energy use reported directly from electricity meters in buildings. Second, source energy use intensity (source EUI) measures energy use from the energy generation source while additionally taking into account generation and transmission losses. Uniform conversion factors are used across US for electricity, natural gas, and steam respectively to convert from site EUI to source EUI. Third, greenhouse gas (GHG) emissions measure the amount of GHG emitted as a result of building energy uses. Different conversion factors are used to calculate GHG emissions from electricity usage across the US to account for different GHG emission efficiencies of regional electricity grids. For most cities, building energy use as a percentage of gas, electricity, steam, and renewable sources are also available. Using this information, we calculated missing values from the benchmarking report and were able to obtain all three energy use efficiency measures for all cities except for GHG emissions in Los Angeles. Furthermore, Energy Star scores (an alternative energy efficiency reporting standard) are reported in many cities. In summary, we obtained building energy use data from 10 cities in the US. Details on these policies are listed in Table 1.

TABLE I. Summary of Building Energy Reporting and Benchmarking Policies

City	Policy Name	Data Collected for Buildings
Boston	Building Energy Reporting and Disclosure Ordinance	Nonresidential, >35,000 sf; Residential, >35,000 sf or > 35 units; Parcel (multiple buildings) > 100,000 sf or > 100 units in sum
Portland, OR	Building Energy Performance	Commercial, >20,000 sf
Seattle	Building Energy Benchmarking and Reporting Program	Non-residential, > 20,000 sf Multifamily, > 20,000 sf
Los Angeles	Existing Buildings Energy & Water Efficiency Program	City-owned, >7500 sf; Privately-owned, >20000 sf
Minneapolis	Energy Benchmarking	Public commercial, >25000 sf; Private commercial, >50000 sf
Chicago	Chicago Building Energy Use Benchmarking Ordinance	Municipal, > 50,000 sf Commercial, > 50,000 sf Residential, > 50,000 sf
Washington DC	Clean and Affordable Energy Act of 2008	Private, > 50,000 sf
Philadelphia	Energy Benchmarking and Disclosure Law	Commercial, > 50,000 sf Multifamily, > 50,000 sf
New York City	NYC Benchmarking Law	> 25,000 sf
San Francisco	Existing Commercial Buildings Energy Performance Ordinance	Nonresidential, >10,000 sf

These databases represent policies put into place at different times and provide information from different years. To facilitate the cross-city comparison, we used data from 2016, which is the latest year that all cities made reported data available.

We obtained LEED data from the U.S. Green Building Council (USGBC) website. LEED-certified buildings are classified into a four-tier system, Certified, Silver, Gold, or Platinum. The levels are awarded based on the number of credits that a project claimed from a pre-defined checklist of standards covering energy use, water use, choice of building materials and methods, indoor environmental quality, and so on. One dataset directly downloadable from the LEED website included building identifying information (a unique ID, project name, street address, city, state, zip code, and country). It also listed the version name of the LEED system under which the building was certified, the level and date of certification, and total points achieved by the building. We also obtained subcategory-level credit distributions from individual building webpages. These included the specific name of the category that buildings obtained credit for, the number of credits awarded, and the total achievable number of credits.

We conducted some basic cleaning for these datasets. For energy benchmarking datasets, we excluded entries without any energy use data. For the LEED database, we excluded data with erroneous and/or unrecognizable addresses (for example, when the city name was used as the street address name). To match buildings in the LEED database and energy use datasets, we looked up individual building coordinates (latitude and longitude) using Google Maps API for both datasets. We then identified matched pairs of buildings with identical coordinates. After correcting for repeated LEED records and selecting buildings that obtained their certificates after 2016, we found 1566 total matched records. The number of buildings found for each city is listed in Table 2.

The goal of our analysis is to find the treatment effect of LEED certification on building energy performance. This cannot be achieved by simply comparing LEED-certified buildings with other buildings. In order to account for biases between buildings that seek LEED certification and those that do not, we conducted nearest neighbor matching between ‘treated’ LEED buildings and ‘untreated’ non-LEED buildings based on building use, year of construction, square footage, and postal code.

TABLE II. SUMMARY OF BUILDING COUNTS ACROSS CITIES

	# Buildings in Energy Benchmarking Database	# Matched Buildings in LEED Database	# Buildings Matched in Both Databases
Boston	1544	172	96
Chicago	2884	424	284
Los Angeles	6308	387	235
Minneapolis	430	65	38
New York City	11931	558	323
Portland	456	105	61
Philadelphia	1589	91	68
Seattle	3470	311	197
San Francisco	1753	222	128

For each city, we examined correlations between building level energy use and i) LEED certification ii) fraction of overall credits achieved, and iii) fraction of Energy and Atmosphere credits achieved.

To identify natural clusters in which LEED subcategory credits are co-acquired, we conducted an analysis of the textual descriptions of each LEED subcredit across every available standard. Term frequency–inverse document frequency (tf-idf) was utilized to classify each document according to its most characteristic component terms. This allowed us to identify similarly motivated subcredits across different LEED standards. We utilized this grouping of subcredits to construct a canonical mapping of the buildings in our dataset and applied Uniform Manifold Approximation and Projection (UMAP)-based clustering. UMAP is a dimensionality reduction and visualization tool that has been found to produce more condensed clusters than t-SNE or PCA. The parameters in a UMAP manifold were learned and optimized using stochastic gradient descent and resulted in the production of an embedding space that buildings can be projected into. We utilized k-means clustering to identify clusters of buildings projected into the UMAP manifold and visualized LEED certification level and city with respect to defined clusters.

IV. RESULTS AND DISCUSSION

A. *LEED Certification and Energy Use Efficiency Measures*

We first examined the treatment effect of LEED certification on building energy use. We conducted paired t-tests for buildings that were LEED-certified compared to buildings that were not LEED certified. These results are reported in

Table 3. We found that LEED certification does not have consistent treatment effects for any of the three energy use efficiency measures we studied. When comparing values for buildings in individual cities, we found that at the Bonferroni corrected p = 0.05 level, LEED-certified buildings performed better only in Washington DC. In addition, on a national level, we found no treatment effect of LEED certification on any energy use efficiency measures.

TABLE III. PAIRED T-TEST VALUES FOR BUILDING ENERGY USE EFFICIENCIES WITH AND WITHOUT LEED CERIFICATIONS

City	Site EUI	Source EUI	GHG emissions
Chicago	-1.8	-2.7	-2.8
Boston	-1.0	-0.9	-0.8
Seattle	0.4	0.5	1.2
San Francisco	-2.5	-2.0	-1.3
New York City	-0.6	0.9	2.6
Los Angeles	-2.6	-2.6	
Washington DC	-3.8*	-3.8*	-3.1*
Portland, WA	-1.2	-1.5	-1.6
Philadelphia	2.0	2.3	1.8
Minneapolis	-1.2	-1.4	-1.3

*p<0.05

LEED credits for various certification standards. Here, the fraction is used instead of the actual number of LEED credits to correct for discrepancies between different LEED certification versions. The result from this comparison is shown in Fig. 1. Linear regression was also conducted. None of the linear regressions show statistically significant R2 values or p values (<0.05). This result is consistent with that outlined in the previous paragraph for buildings with and without LEED certifications.

B. Building Energy Performance and Energy and Atmosphere Credit

Some studies in the past have suggested that using LEED certifications to predict building energy performance could be a misguided method since LEED subcategories include many scoring criteria that are not energy related. It is therefore also instructive to look at how energy-specific criteria predict building energy performance. To examine this, we considered whether credits achieved in the Energy and Atmosphere category correlated with energy use efficiency measures. The scatter plots of the building energy performance vs LEED scores achieved is shown in Fig. 2. The number of buildings investigated in each city is shown in the parenthesis on the plot. There are fewer buildings than listed in Table 1

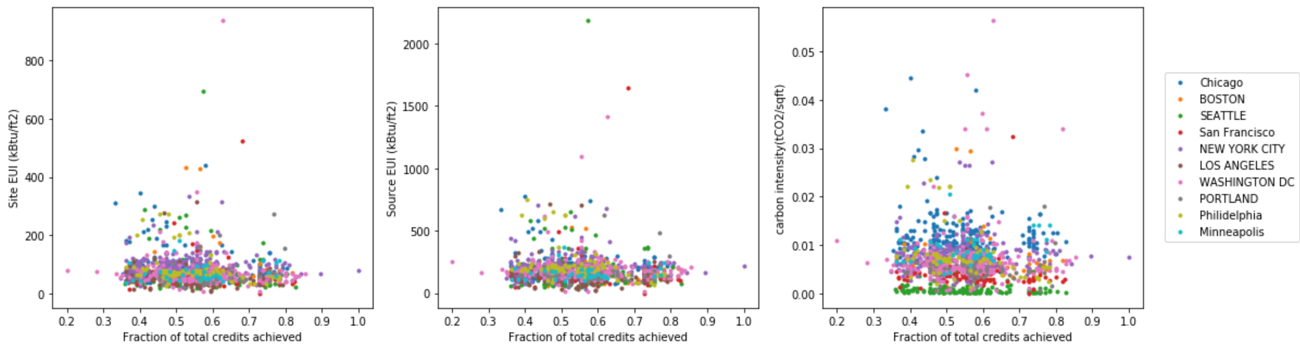

Fig. 1. Correlation between the number of LEED credits achieved and energy use efficiency measures.

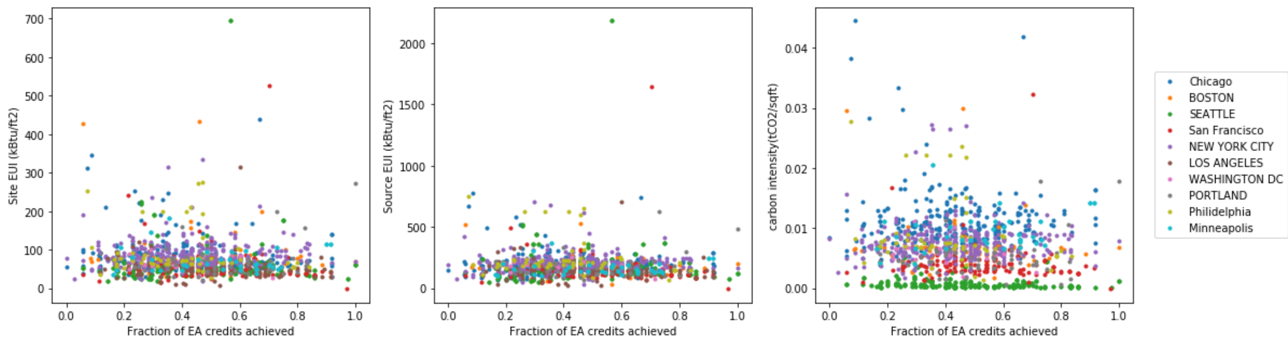

Fig. 2. Correlation between the number of LEED credits achieved in the Energy and Atmosphere category and energy use efficiency measures.

In addition to comparing buildings with and without LEED certifications, we also explored the effects of achieving different levels of LEED certifications. For this purpose, we obtained the total number of LEED credits achieved for LEED-certified buildings as a fraction of total achievable because the LEED database does not contain detailed subcredit information for all buildings. Again, the fraction of maximal possible credits achieved is used. Linear regression was also conducted. None of the linear regressions show statistically significant R2 values or p values (<0.05). We consequently report no observed correlation between the Energy and Atmosphere credits and building EUI.

C. *UMAP Clustering of Buildings by Subcredit Acquisition Patterns*

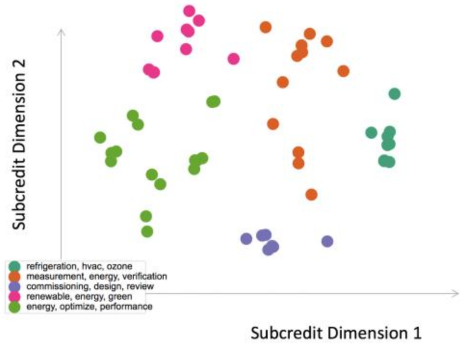

Fig. 3: TF-IDF Energy and Atmosphere Subcredit Clustering

In order to classify buildings by subcredit acquisition patterns, it was necessary to first create a unified mapping of subcredits across the different LEED standards. We hypothesized that clusters of subcredits could be identified based on patterns in their descriptions. Fig. 3 shows the Energy and Atmosphere subcredits across every LEED standard considered, colored by the words that best define the cluster. The relative position of each point represents the distance between subcredits based on textual description. The five identified credits correspond to refrigerant use, measuring and verifying energy use, commissioning and review, renewable energy, and performance optimization. Given a particular subcredit, this would allow for the identification of an equivalently motivated subcredit from another LEED standard. Three identified pairs include i) EAc1: Optimize Energy Performance (LEED-NC 2.2) and EAp2: Minimum Energy Performance (LEED-NC v2009), ii) EAc2: On-site Renewable Energy (LEED-CS v2009) and EAc6: Green Power (LEED-NC 2.2), and iii) EAp3: CFC Reduction in HVAC (LEED-CI 2.0) and EAp3: Fundamental Refrigerant Management (LEED-EB:OM v2009).

We are able to utilize this mapping of subcredits to group all buildings by age, size, energy use, and subcredit acquisition patterns (Figure 3). We identified fifteen distinct clusters of buildings based on the types of credits they acquired. For each cluster, we identified the most over- and under-represented credits. We find that buildings that achieve higher credits (or high performing clusters) 3,10, and 13 are characterized by high scores in Energy and Atmosphere credits corresponding to renewables, on average achieving more than 98% of the available credits. However, we note a similar level of performance in renewable energy credits among clusters 2 and 7, which score on average 10% fewer LEED credits overall. In general, the renewable energy credits achieved by the clusters had a strongly bimodal distribution, with four clusters scoring above 95%, and the remaining 11 clusters scoring below 18%.

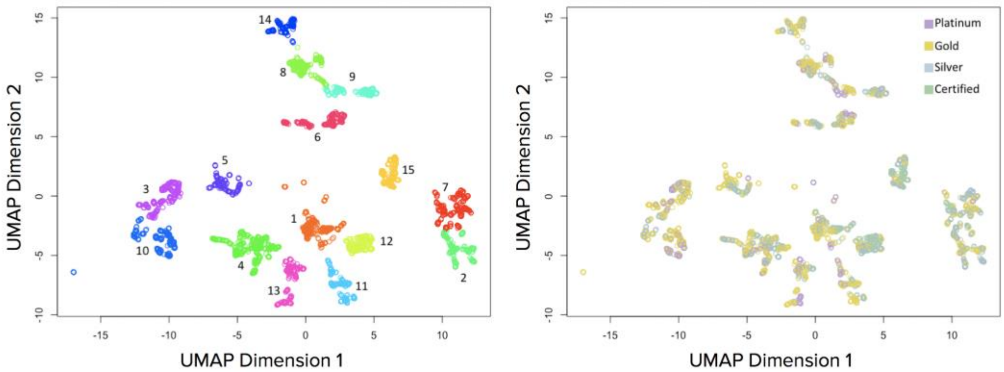

Fig. 1. UMAP Projection colored by cluster (left) and achieved rating (right).

V. CONCLUSIONS

We investigated the relationship between LEED certification and building energy performance in ten US cities by using publicly available information from LEED database and city-level building energy benchmarking data. We find that obtaining LEED certification does not improve building energy efficiency in general except for Washington DC. Further, we find that obtaining higher credits in LEED Energy and Atmosphere category does not correlate with better energy performance, further calling into question the utility of LEED standards in improving building energy performance in practice. Finally, we identified distinct patterns in the types of subcredits achieved by different groups of buildings, and find that in particular, Energy and Atmosphere credits corresponding to renewables has a strongly bimodal distribution, suggesting that, in many cases, the credits offered does not justify investment.

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REFERENCES

[1] Asensio, Omar Isaac, and Magali A. Delmas. “The Effectiveness of US Energy Efficiency Building Labels.” Nature Energy, vol. 2, no. 4, 2017, doi:10.1038/nenergy.2017.33.

[2] Flowers, Mallory E., et al. “For What It's Worth: Evaluating Revealed Preferences for Green Certification.” Journal of Environmental Planning and Management, vol. 62, no. 5, 2018, pp. 843–861., doi:10.1080/09640568.2018.1447444.

[3] Mason, Charles F. “The Economics of Eco-Labeling: Theory and Empirical Implications.” International Review of Environmental and Resource Economics, vol. 6, no. 4, 2013, pp. 341–372., doi:10.1561/101.00000054.

[4] Matisoff, Daniel C., et al. “Performance or Marketing Benefits? The Case of LEED Certification.” Environmental Science & Technology, vol. 48, no. 3, 2014, pp. 2001–2007., doi:10.1021/es4042447.

[5] Newsham, Guy R., et al. “Do LEED-Certified Buildings Save Energy? Yes, but….” Energy and Buildings, vol. 41, no. 8, 2009, pp. 897–905., doi:10.1016/j.enbuild.2009.03.014.

[6] Reinhart, Christoph F., and Carlos Cerezo Davila. “Urban Building Energy Modeling – A Review of a Nascent Field.” Building and Environment, vol. 97, 2016, pp. 196–202., doi:10.1016/j.buildenv.2015.12.001.

[7] Scofield, John H. “Do LEED-Certified Buildings Save Energy? Not Really….” Energy and Buildings, vol. 41, no. 12, 2009, pp. 1386–1390., doi:10.1016/j.enbuild.2009.08.006.

[8] Scofield, John H. “Efficacy of LEED-Certification in Reducing Energy Consumption and Greenhouse Gas Emission for Large New York City Office Buildings.” Energy and Buildings, vol. 67, 2013, pp. 517–524., doi:10.1016/j.enbuild.2013.08.032.

[9] Walls, Margaret. “Energy Efficiency: Building Labels Lead to Savings.” Nature Energy, vol. 2, no. 4, 2017, doi:10.1038/nenergy.2017.55.

[10] Esty, Daniel, and Reece Rushing. “The Promise of Data-Driven Policymaking.” *Issues in Science and Technology* 23, no. 4 (Summer 2007).