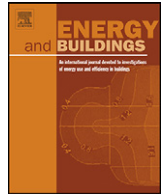




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Do LEED-certified buildings save energy? Not really...

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ABSTRACT

Newsham et al. have recently published a re-analysis of energy-consumption data for LEED-certified commercial buildings supplied by the *New Buildings Institute* (NBI) and *US Green Building Council*. They find that, on average, LEED buildings use 18–39% less energy per floor area than their conventional counterparts, consistent with and adding clarity to conclusions originally reached by NBI. These conclusions, however, hang on a particular definition of the *mean energy intensity* of a collection of buildings that is not related to the total energy used by those buildings. Furthermore, site energy considered by Newsham et al. and NBI, unlike source energy used for the EPA's building *Energy Star* rating, does not account for the energy consumed off-site in generating and delivering electric energy to the building, whose inclusion is crucial for understanding greenhouse gas emission associated with building operation. Here I demonstrate that both the site energy and source energy used by the set of 35 LEED office buildings and Newsham et al.'s matching CBECS office buildings are statistically equivalent. Hence Newsham et al. offer no evidence that LEED-certification has collectively lowered either site or source energy for office buildings.

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1. Introduction

In 2000 the *US Green Building Council* (USGBC) introduced the *Leadership in Energy and Environmental Design* (LEED) building rating system. While this is just one of several independent systems for rating “green buildings,” it has emerged as the leading green building rating system. Since its inception, the common assumption has been that a LEED building is an energy-efficient building. But until recently there have been little energy-consumption data put forward to support such an assertion. To address this issue the USGBC in 2006 contracted the *New Buildings Institute* (NBI) to study energy use by LEED-certified commercial buildings. The final report was released in March 2008 and concluded that “...average LEED energy use [was] 25–30% better than the national average...” [1]. NBI also point out the wide variability in LEED energy performance which they find as cause for concern.

From its initial release the NBI report has been the subject of much criticism [2–4]. Critics point out that NBI's method for gathering data, voluntary submissions from building owners, is likely to have resulted in biased sampling. They also complain that NBI skewed results by comparing the *median* energy use intensity (EUI)¹ of the LEED buildings with the *mean* EUI for all US

commercial buildings, as characterized by the 2003 CBECS.² [2,3]. Finally, NBI is criticized for ignoring data from the 21 LEED buildings with the highest EUI and focusing only on the remaining 100, so-called “medium energy” LEED buildings, again, comparing their median EUI with the mean for all CBECS.³ A fact left out of the NBI report is that the mean EUI for all 121 LEED buildings is actually higher, not lower, than that for all US commercial buildings [2–4].

Despite shortcomings, the NBI LEED energy data is the most comprehensive database for U.S. high performance buildings assembled to date. To their credit NBI has made summary versions of the LEED data available to others for independent analysis.

One such analysis has been completed by Newsham, Mancini, and Birt (NM&B) and reported in this journal [5]. NM&B consider only the 100 medium energy LEED buildings and develop a clever method for pairing each LEED building with its closest “match” of the 5215 sampled buildings in the CBECS 2003 database. NM&B develop various criteria for matching CBECS buildings with LEED buildings by principal building activity (PBA), size (gsf), climate zone, and year of construction (for CBECS). This methodology mitigates the influence of other building types and their relative populations that arises when simply comparing the mean EUI for

² The Energy Information Administration's quadrennial *Commercial Building Energy Consumption Survey*.

³ Actually, only 19 of the 21 buildings identified by NBI as “high energy type” buildings have the highest EUI in the LEED 121 building set. Two others, with similar activities, have EUI that fall within those of the remaining 100 medium energy buildings.

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¹ EUI's represent annual site energy intensities, and do not account for off-site losses in bringing energy to the building.

Table 1
Comparison of building-weighted mean site and source (case B only) energy intensities for LEED office sets with matched CBECs building sets (see text).

Case	LEED			CBECs			EUI reduction	LEED > CBECs	T-statistic	p value
	N	Mean	sdm	N	Mean	sdm				
<i>Site energy intensity</i>										
A	35	67.8	4.2	27	97.0	8.7	30%	12 (34%)	3.36	0.0019
B	32	67.6	4.4	26	98.9	9.0	32%	10 (31%)	3.53	0.0013
<i>Source energy intensity</i>										
B	32	178.3	13.2	26	227.5	18.9	22%	10 (31%)	2.53	0.0167

all LEED buildings with that for all CBECs. Depending on the building subset and matching criteria, NM&B found LEED mean EUI to be from 18% to 39% lower than for matching non-LEED buildings. Their results confirm NBI’s initial conclusion while providing further clarity and statistical rigor.

I have completed my own analysis of the NBI LEED energy-consumption data and have reached significantly different conclusions [6]. Focusing on source energy, which accounts both for energy used on-site and the off-site losses associated with the generation and distribution of electric energy, I find that LEED-certified commercial buildings, on average, show no significant primary energy savings over comparable non-LEED buildings.⁴ In other words, I find that LEED-certification, on average, is not lowering source energy consumption and, accordingly, is not delivering reduction in greenhouse gas emission associated with building operation. I also consider site energy. Like NM&B (and NBI) I find that LEED buildings use, on average, less site energy than comparable non-LEED buildings, but I find about half the savings (10–17%) reported by NM&B.

The purpose of this paper is to reconcile the differences in these two analyses (NM&B and Scofield). One of the key differences is the use of different definitions for the *mean energy intensity* of a collection of N buildings. NM&B (and NBI, whose results they confirm) weigh the energy intensities of each building equally, large or small. This “building-weighted” mean has no connection with the total energy consumed by a collection of buildings. In contrast, Scofield weighs the energy intensity of each building by its gsf. This “gsf-weighted” mean is exactly equal to the total energy used by all buildings divided by their total gsf. These different averaging methods yield different means, and correspondingly, give rise to significantly different conclusions when comparing mean energy intensities of various building sets.

2. Analysis

The NBI data that were the basis for both of these studies tabulate the purchased (annual) site energy intensity or site EUI (e_j) and gsf (A_j) for each of the $j = 1, \dots, 121$ LEED buildings included in the study.⁵ The total gsf for the $N = 100$ medium energy LEED buildings is

$$A_{Tot} \equiv \sum_j A_j, \tag{1}$$

which, for the 100 LEED buildings yields 11.09 million sf. The site EUI and gsf for individual buildings may be readily combined to obtain the purchased site energy,

$$E_j = e_j A_j, \tag{2}$$

⁴ Source energy is also the basis for the EPA’s building Energy Star scores.
⁵ The purchased energy does not include any renewable energy generated on site. Five of the smaller LEED buildings in the study also used onsite renewable energy to provide from 2% to 17% of their energy needs.

which, when summed, yields a total purchased site energy

$$E_{Tot} = \sum_j E_j = \sum_j A_j e_j. \tag{3}$$

For the 100 LEED buildings this sum is 872 billion Btu. The ratio of the total energy to the total gsf is, by definition, the energy intensity for the collection of buildings, namely

$$e_{Tot} \equiv \frac{E_{Tot}}{A_{Tot}}. \tag{4}$$

For the 100 medium energy LEED buildings this yields a site energy intensity $e_{Tot} = 78.6$ kBtu/sf, which is identical to what I report as their gsf-weighted *mean* site energy intensity.⁶ Mathematically this ratio is equivalent to the gsf-weighted mean of the individual building site energy intensities, namely

$$\bar{e} \equiv \sum_j w_j e_j = e_{Tot}, \tag{5}$$

where the weighting for each building, w_j , is given by its relative contribution to the total gsf, namely

$$w_j = \frac{A_j}{A_{Tot}}. \tag{6}$$

In contrast, NM&B report the mean (site) EUI for the 100 medium energy LEED buildings to be $\bar{e} = 67.5$ kBtu/sf, 14% lower than e_{Tot} .⁷ This figure is obtained using Eq. (5) but with equal weighting for each building, namely

$$w_j = \frac{1}{N}. \tag{7}$$

I refer to this as the “building-weighted” mean as it gives each building equal weight whereas the gsf-weighted gives each square foot equal weight. If you multiply this figure by the total gsf for the 100 buildings you do not get the total purchased site energy—instead you get a number that is, predictably, 14% lower.

As it will be used later, let me define the standard deviation of the distribution of energy intensities to be

$$\sigma_e = \sqrt{\bar{e}^2 - \bar{e}^2}, \tag{8}$$

where

$$\bar{e}^2 \equiv \sum_j w_j e_j^2. \tag{9}$$

The standard deviation of the mean (sdm) is found by dividing σ_e by the square root of N. Eqs. (8) and (9) may be used with either building- or gsf-weighting.

Gsf-weighting is employed by the EIA in reporting mean energy intensities for CBECs and by the EPA in reporting mean Energy Star scores for sets of buildings. Consider the mean EUI reported by

⁶ See the table in the appendix of reference 6.
⁷ This is actually the mean reported by NM&B in line 6 of Table 6 for 98 of the LEED medium energy buildings.

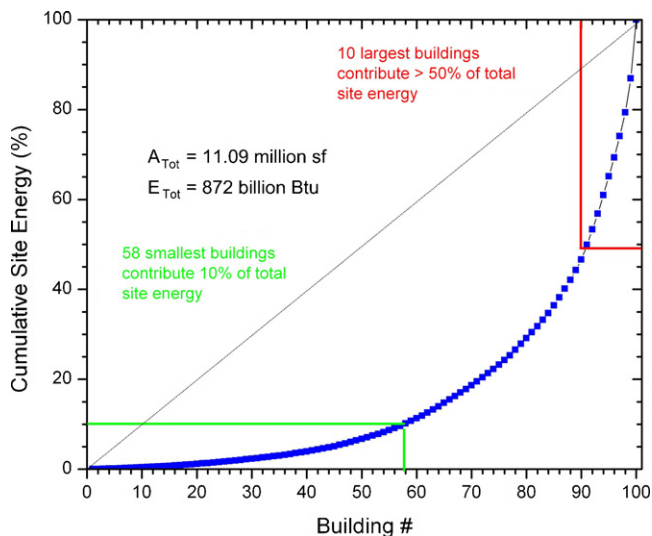


Fig. 1. The cumulative contribution to the total site energy of the 100 medium energy LEED buildings sorted by building site energy.

NM&B in Table 2 for various CBECs principal building activities (PBAs). All of the means listed differ from those reported by the EIA for the US commercial building stock. One extreme example is the mean EUI for *Food Service* buildings, reported by NM&B to be 332.6 kBtu/sf. This number is obtained by adding the EUI calculated for each of 242 of the 5215 sampled buildings in CBECs which correspond to PBA = 15 (food service) and dividing this sum by 242. But it is trivial to verify that this collection of 242 sampled buildings has a site energy intensity ($E_{\text{Tot}}/A_{\text{Tot}}$) of 209 kBtu/sf. Furthermore, each sampled building in CBECs represents many other similar buildings in the US building stock. If you include these weighting factors you find that the set of all *Food Service* type buildings in the US building stock (297,404 buildings with 1.65 billion gsf) have a site energy intensity of 258 kBtu/sf, as reported in Table 1 of my paper [6] and consistent with that reported by the EIA.⁸

If all buildings were the same size then there would be no difference between the building-weighted and gsf-weighted averages. But LEED buildings, and more generally, U.S. commercial buildings include buildings as small as a few thousand sf and as large as nearly a million sf. In the U.S. commercial building stock, 50% of the estimated 4.9 million buildings are less than 5,000 sf in size and contribute only 9% of the estimated 72 billion total gsf.⁹ At the other extreme, 5% of the buildings are greater than 50,000 sf and contribute 50% to the total gsf. These buildings contribute similarly to the total energy consumed by all buildings. A relatively few large buildings contribute enormously to the total energy consumption—it is not fair, but it is physics.

Fig. 1 shows the contribution of each of the 100 medium energy LEED buildings to their total site energy, $E_{\text{Tot}} = 872$ billion Btu. The graph shows that the 58 smallest buildings contribute just 10% of the total energy. These buildings dominate the building-weighted mean EUI, while contributing little to the total gsf or total energy. In contrast, the 10 largest buildings contribute more than 50% of the total energy and a similar amount of gsf. These buildings dominate the gsf-weighted mean EUI. The diagonal line in the figure represents what would be the case if each building contributed equally to the total energy consumption. The slope of the blue curve represents the marginal contribution of each

building to the total energy. Not until the 76th building (sorted by site energy) do we see the marginal energy contribution get to the 1/100th weighting of the building-weighted mean. Note that an analogous graph for the 35 LEED office building subset shows a similar trend.

3. Repeating NM&B analysis for office buildings

I now illustrate how NM&B's analysis changes when you use gsf-weighted means instead of building-weighted means for office buildings. Office buildings are a recognized PBA in both CBECs and LEED and represent the largest single PBA in the LEED data set. Restricting the analysis to office buildings avoids uncertainties introduced by accepting NM&B's "H + M + L activity uncertainty" in matching all of the medium energy LEED buildings. Newsham has kindly provided the list of CBECs buildings that were matched with 98 of the LEED medium energy buildings, including the 35-office buildings using liberal "match criteria."

Using liberal matching criteria and non-unique pairing NM&B matched the 35 LEED office buildings with 27 sampled CBECs office buildings. The building-weighted mean site energy intensity for both the LEED and CBECs office sets are compared in Table 1 as "case A." The information here is consistent with that shown in NM&B's Table 6 (line 14). The building-weighted mean EUI for the LEED offices is 67.8 kBtu/sf, 30% lower than that for the matching CBECs offices, 97.0 kBtu/sf. Also shown are the building-weighted standard deviations of the means (sdm). For calculating the paired t -statistic we define d_j to be the difference between the site EUI for the j -th LEED building and that of its paired CBECs building. The t -statistic is the ratio of the mean to the standard deviation of the mean, namely

$$t \equiv \sqrt{N} \frac{\bar{d}}{\sigma_d} \quad (10)$$

The building-weighted t -statistic of 3.36 and its associated p -value of 0.0019 confirm that the 30% reduction in building-weighted EUI of LEED offices relative to their CBECs matched offices is statistically significant. While the average EUI for LEED is lower than that for the CBECs matching offices, 12 (or 34%) of the LEED offices have EUI that exceed that of its CBECs pair.

Before introducing gsf-weighting to the analysis let me consider source energy, as that is a major focus of my study [6]. Source energy intensities were not tabulated in the original NBI data for the 121 LEED buildings, but fuel-type information were included for 98 of the buildings, permitting source energy to be calculated, assuming the average US electric generation mix and distribution efficiency. Additional source energy data were obtained for 11 of the 23 remaining buildings from another source [7], bringing the total to 109, 89 of these counted in the 100 medium energy buildings treated by NM&B.¹⁰ This set also includes 32 of the 35 LEED office buildings. Case B in Table 1 compares these 32 LEED office buildings with their 26 CBECs matches (from case A). This case was not considered by NM&B, but the results are quite similar. The building-weighted mean EUI for the 32 LEED offices is nearly identical to that for all 35 LEED offices while the building-weighted mean EUI for the 26 CBECs matching offices is a bit higher. In this case the LEED office mean EUI is 32% lower than that for the matching CBECs offices with only 10 of the LEED offices (31%) having EUI that exceed their paired CBECs office. As for case A the t -statistic and p -value confirm the differences in means is statistically significant.

⁸ See Table 5b. U.S. Commercial Buildings Energy Intensity Using Site Energy by Census Region and Principal Building Activity, 1992–2003.

⁹ Based on the 2003 CBECs.

¹⁰ Here we use a simplified definition for purchased source energy to be 3× purchased electric energy plus purchased non-electric energy. This is equivalent to site energy plus 2X purchased electric energy. For a more extensive discussion see reference 6.

Table 2
Comparison of gsf-weighted mean site and source energy intensity (for case B) for LEED office sets with matched CBECs building sets (see text).

Case	LEED			CBECs			EUI reduce	LEED > CBECs	T-statistic	p
	gsf	Mean	sdm	gsf	Mean	sdm				
<i>Site energy</i>										
A	5,303,460	77.1	3.4	5,196,100	80.7	8.4	4%	68%	-0.40	0.69
B	3,835,620	77.6	3.5	3,776,100	86.6	9.3	10%	63%	-0.97	0.37
<i>Source energy</i>										
B	3,835,620	205.0	9.6	5,196,100	211.9	18.7	3%	64%	-0.35	0.73

With case B we can also compare building-weighted source EUI, shown as the last line of Table 1. Here we find that LEED offices have a building-weighted mean source energy intensity that is 22% lower than for the matching CBECs offices. The difference is, again, statistically significant.

The NM&B analysis is now modified to use gsf-weighting for calculating means. The results are shown in Table 2, exactly matching the cases shown earlier. For Case A we find the LEED office mean site energy intensity to be just 4% lower than that for the matching CBECs set, while for Case B the LEED office mean is 10% lower. The gsf-weighted *t*-statistics are calculated using Eq. (10) with the weighting determined by the gsf of each LEED building. The *t*-statistics and associated *p*-values for both cases suggest no statistical significance to these differences. For case A there is a 69% chance that such a difference would be observed even if the two underlying distributions were identical. For case B it is a 37% chance. Hence these data provide no evidence that LEED office site energy intensity is lower (or higher) than that for the CBECs matched set. This is a very different conclusion than reached using building-weighted averaging.

What is going on? Recall that 12 of the 35 LEED office buildings (roughly 1/3) have EUI that exceed that of their CBECs office pair. It turns out that these are the larger LEED office buildings—containing 68% of the total LEED office gsf. In the building-weighted average the 23 buildings win and the LEED mean EUI beats CBECs by 30%. But in the gsf-weighted average the 12, mostly larger buildings dominate, and the LEED mean EUI is indistinguishable from CBECs.

Finally, we turn to source energy comparison. The gsf-weighted source EUI for the 32 LEED office buildings (case B) is 3% lower than for the matching CBECs offices, but the gsf-weighted *t*-statistic and

p-value show this difference to have no statistical significance (last line of Table 2). Again, the conclusion is that these data offer no evidence that LEED offices buildings collectively use more or less source energy than conventional offices buildings.

It is clear that larger buildings contribute more to total building energy than do smaller buildings. This was demonstrated by Fig. 1 for LEED buildings and is also the case for the U.S. commercial building stock. The above analysis suggests that smaller LEED buildings tend to out-perform (i.e., use less energy) CBECs more than do larger LEED buildings. This trend is supported by Fig. 2 where, for LEED office buildings, we make a log–log graph of the fractional contribution to the total site energy versus the fractional contribution to the total gsf. The blue line represents points for which $e_j = e_{Tot} = \bar{e}$. The graph clearly shows that all 16 of the smallest LEED offices have EUI lower than the mean, whereas the larger offices have some EUI that fall above and some below the mean. It is clear why building-weighted averaging produces a lower mean EUI than gsf-weighting.

4. Discussion

It is a long-standing practice in building science to calculate energy intensity of either a single building or a set of buildings by forming the ratio of their total annual energy (site or source) to their total gsf. This is equivalent to calculating the gsf-weighted mean energy intensity (site or source). Both NBI and NM&B have used a building-weighted method for calculating the mean energy intensity of a collection of buildings and, using this technique, have concluded that medium energy LEED commercial buildings have (roughly) 30% lower site energy intensity or EUI than comparable conventional buildings. This is not the first application of building-weighted averaging to LEED buildings as it was employed in smaller LEED building studies that were incorporated into the NBI data [7,8]. Because their definition of mean is not related to the total energy consumed by these buildings, it simply does not follow that these medium energy LEED buildings (collectively) use 30% less energy. To the contrary, I have shown using NM&B's approach to comparing LEED offices to non-LEED offices, that there is no statistical difference in the total site or source energy consumed by the LEED offices and their non-LEED matching set. In my earlier study, using a different method for comparing LEED and CBECs offices (that did not pair them with specific CBECs buildings) I found that LEED offices used, on average, 17% lower site energy than CBECs offices, but no less source energy. This result is consistent with those presented here.

The reason, of course, is that large buildings dominate the energy consumption of a set of commercial buildings. Despite the fact that many of the smaller LEED buildings outperform their conventional counterparts, it matters little because they do not contribute to the total energy nearly as much as a handful of larger buildings. LEED proponents may think it unfair that a few large buildings should dominate the total energy—but that is physics. Republicans think it unfair that CA and NY have so many electoral

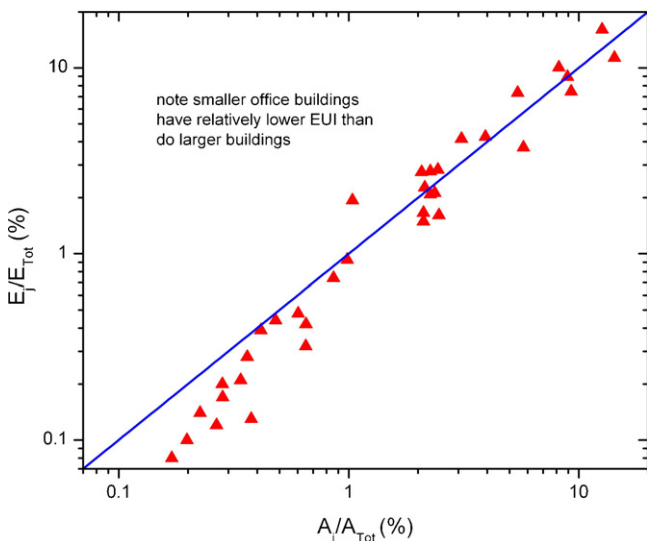


Fig. 2. log–log plot of the fractional site energy contribution to the fractional gsf contribution of each of the 35 LEED office buildings.

votes. My retirement portfolio would be much stronger if I could throw out market losses from a handful of bad days.

The fallacy of using “building-weighted” averaging to characterize the energy intensity of a collection of N buildings is readily apparent when you take it to a smaller extreme. Suppose you were to divide a single building up into N rooms, some big and some small. You could calculate the energy intensity of each room separately. There are two ways to calculate the mean room energy intensity. The “gsf-weighted” method yields a mean energy intensity identical to that of the building. The “room-weighted” or unweighted average does not. It is clear that only the former makes physical sense. The same is true when considering a collection of N buildings.

The fact that smaller LEED buildings have relatively lower purchased energy intensity (relative to non-LEED) while larger buildings show less savings is not just coincidental. The 35 LEED office buildings include three relatively small buildings (<34,000 sf) with on-site photovoltaic (PV) arrays that lower their purchased energy by from 2% to 17%. PV arrays and other measures that are not typically cost-effective are often included in small, trophy buildings where they can have a measurable impact, high visibility, and their costs can either be justified based on the building program or defrayed by a donor. Such measures simply do not scale to a 500,000 sf building where cost/benefit becomes paramount. These buildings achieve LEED-certification by acquiring the cheapest LEED points (bike racks, employee showers, etc.). Moreover, I speculate that energy consumption in larger buildings is dominated by plugloads and operating practices—which are not even addressed by LEED. Rather than to utilize a non-physical averaging technique that under-weighs large buildings, it would be better to change the LEED-certification process so that inefficient buildings do not gain LEED-certification—particularly large inefficient buildings.

Finally, we are left with two coexisting perspectives as to how LEED-certification is impacting building energy use—restricted here to LEED offices, but probably applicable to medium energy

buildings. The majority of LEED-certified offices are using less energy (site or source) than comparable non-LEED offices (on an individual basis). LEED proponents can take comfort in this conclusion. Collectively, however, because a relatively few large buildings dominate energy consumption, LEED offices (in total) are not using less energy (in particular, source energy) than their non-LEED counterparts. This should worry those concerned with national energy policy and global climate change.

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References

- [1] Cathy Turner Mark Frankel, Energy Performance of LEED for New Construction Buildings—Final Report, New Buildings Institute, White Salmon, WA, 2008.
- [2] Henry Gifford, A Better Way to Rate Green Building, http://www.aiact.org/user-files/file/COTE/GreenGoals_Resources/LEED_Critique_Gifford.pdf.
- [3] J.W. Lstiburek, Why green can be wash, *ASHRAE Journal* (2008) 28–36.
- [4] B. Richter, D. Goldston, G. Crabtree, L. Glicksman, D. Goldstein, D. Greene, D. Kammen, M. Levine, M. Lubell, M. Savitz, D. Sperling, F. Schlachter, J. Scofield, J. Dawson. 2008, Energy Future: Think Efficiency, American Physical Society, College Park, MD, <http://www.aps.org/energyefficiencyreport/index.cfm>.
- [5] Guy Newsham, Sandra Mancini, J. Birt Benjamin, Do LEED-certified buildings save energy? Yes, but . . ., *Energy and Buildings* 41 (8) (2009) 897–905.
- [6] John H. Scofield, A Re-examination of the NBI LEED Building Energy Consumption Study, in: International Energy Program Evaluation Conference, Portland, OR, August 12–15, 2009.
- [7] R. Diamond, M. Opitz, T. Hicks, B. Von Neida, S. Herrera, Evaluating the energy performance of the first generation of LEED-certified commercial buildings, in: Proceedings of the 2006 ACEEE Summer Study on Energy Efficiency in Buildings, vol. 3, American Council for an Energy-Efficient Economy, Washington, D.C., 2006 pp. 41–52.
- [8] C. Turner, LEED Building Performance in the Cascadia Region: A Post Occupancy Evaluation Report, Cascadia Region Green Building Council, Portland, OR, 2006.