

# A Re-examination of the NBI LEED Building Energy Consumption Study

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## ABSTRACT

A recent study by the *New Buildings Institute* looked at the energy performance of 121 LEED certified commercial buildings and concluded they were saving 25-30% energy relative to conventional buildings. Here we identify several critical flaws in the NBI analysis and, upon re-examination of the data, reach different conclusions. We find that the average energy consumption by LEED certified buildings is actually higher than the corresponding average for the US commercial building stock. This difference is shown to be largely due to the over-representation of “high-energy” principle building activities (PBA’s) such as laboratories and the under-representation of “low-energy” PBA’s such as non-refrigerated warehouses in the LEED building data set, relative to their occurrence in the U.S. commercial building stock. Eliminating high- and low-energy PBA’s from both data sets yields “medium-energy” building subsets free of these disparities. Comparing these we find that LEED medium energy buildings, on average, use 10% less site energy but no less source (or primary energy) than do comparable conventional buildings. LEED office buildings achieve 17% reduction in site energy, but again, no significant reduction in primary energy use relative to non-LEED office buildings. We further find that these results do not change significantly if LEED buildings are compared with newer vintage, non-LEED buildings. As green house gas (GHG) emission correlates with primary energy, not site energy, we conclude that LEED certification is not yielding any significant reduction in GHG emission by commercial buildings.

## Introduction

In 2000 the *US Green Building Council* (USGBC) introduced the *Leadership in Energy and Environmental Design* (LEED) building rating system.<sup>1</sup> 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, though this assertion has not, until recently, been supported by data (Diamond et al., 2006; Turner, 2003).

In an attempt to understand how much energy is used by LEED buildings the USGBC commissioned the *New Buildings Institute* (NBI) to study energy consumption by LEED buildings. The results of that study were first presented at the *GreenBuild Conference* in Chicago in November 2007, and the written report was later released in March 2008 (Turner & Frankel, 2008). The NBI study, which focused on LEED NC (new construction) version 2 buildings certified through 2006, concluded:

*“...on average, LEED buildings are delivering anticipated savings. Each of three views of building performance show average LEED energy use 25-30% better than the national average, a level similar to that anticipated by LEED modeling.”*

This conclusion and its derivatives have been widely disseminated by the USGBC (USGBC 2008a, 2008b; Watson 2008).

Some have questioned the validity of this conclusion, and indeed, the methodology used in the NBI study (Gifford 2008a, 2008b; Richter et al. 2008; Lstiburek 2008). Henry Gifford, for instance, has suggested a number of shortcomings in the NBI analysis. An *Energy Efficiency Study Committee*

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<sup>1</sup> For more about LEED go to <http://www.usgbc.org/>.

constituted by the *American Physical Society* (APS) noted that the LEED buildings in the NBI study use more energy per square foot than the average for all existing commercial buildings – a fact difficult to reconcile with NBI’s assertion that LEED commercial buildings are 25-30% more efficient (Richter et al. 2008).

Cathy Turner, the lead author of the NBI study, has made a summary version of the NBI LEED dataset available for independent analysis.<sup>2</sup> Here we re-examine these data, noting two flaws in NBI’s method for calculating average energy use intensities (EUI’s). Next we consider data from the Energy Information Administration’s 2003 *Commercial Building Energy Consumption Survey* (CBECS) and compare LEED with CBECS site energy intensity distributions. We then digress to introduce source energy intensity, and argue that it, not site energy intensity, is the appropriate measure of building energy efficiency. We then extract subsets of the LEED and CBECS databases that contain comparable buildings, allowing relevant comparison of their average site and source energy intensities. Finally, we consider ENERGY STAR<sup>®</sup> scores for the LEED buildings which also depend on building source energy intensities.

## LEED Building Energy Consumption Data

The NBI data set includes measured annual site energies ( $E_j$ ), gross square footage ( $A_j$ ), site energy intensities ( $e_j$ ), and primary building activities for each of  $j = 1, 2, \dots, 121$  of the 552 commercial buildings receiving LEED NC version 2 certification between 2000 and 2006.<sup>3</sup> In the case of 98 of the buildings fuel type data are included, enabling the calculation of annual source energy. Data for the remaining 23 buildings were apparently not gathered for this NBI study, but instead, were borrowed in summary form from earlier, more-focused studies (Diamond et al. 2006; Turner 2006). The site energy intensities (SiteEI) for the LEED-121 buildings are shown in Figure 1(A). The graph is similar to Figure ES-2 in the NBI report, except that here we include the 21 buildings (omitted from the NBI graph) that Turner and Frankel identified as “high-energy” type buildings (in dark green), owing to their unusually large process or plug loads. High-energy building activities included laboratories, grocery stores, medical facilities, and data centers. Turner and Frankel identified the remaining 100 buildings (light green) as medium energy buildings with plug loads comparable to those of conventional office buildings.

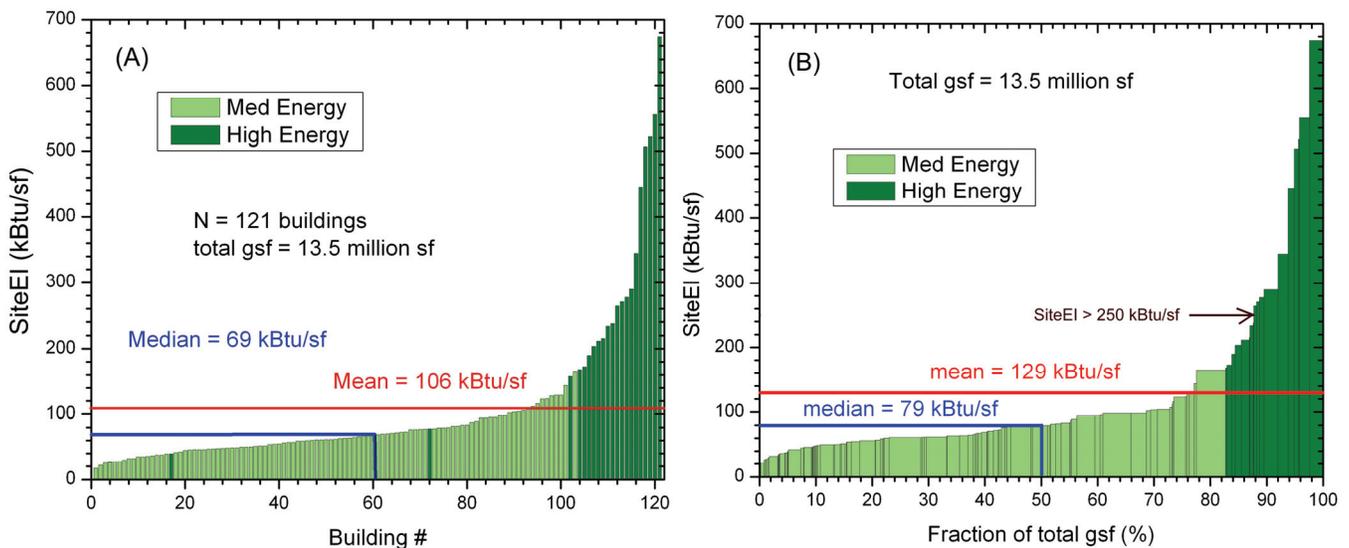
Turner and Frankel calculated the **median** SiteEI for the 121 LEED buildings to be 69 kBtu/sf, and noted that it was 24% lower than the **mean** SiteEI (91 kBtu/sf) reported by CBECS for all commercial buildings. The (unweighted) median and mean SiteEI are represented in Figure 1(A) as horizontal blue and red lines, respectively. The vertical bars in Figure 1(A) all have equal width indicating the SiteEI of each building, large or small, is given equal weight.

This comparison, and all other comparisons in the NBI report between LEED and CBECS energy intensities, suffer from two critical flaws. The first flaw, pointed out by Gifford and others, is the invalid comparison of the **mean** of one distribution to the **median** of another, when in fact, the two measures diverge considerably because both LEED and CBECS SiteEI distributions are skewed by relatively few, high-energy buildings (Gifford 2008a; Lstiburek 2008). It is appropriate to compare the means for the two distributions, or the medians, but to compare the mean of one with the median of the other introduces bias by compensating for skew in only one distribution.

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<sup>2</sup> In conducting the study, NBI had full access to LEED submission, building owners and managers. The data made available are summary tables in the form of an Excel file, with building identities and locations removed.

<sup>3</sup> The total gsf and site energy intensities are given by  $A_{Tot} = \sum A_j$  and  $e_j \equiv E_j / A_j$ , respectively.



**Figure 1.** (A) Unweighted and (B) gsf-weighted site energy intensities for the 121 LEED buildings included in the NBI data set.

The second flaw is that Turner and Frankel calculate un-weighted averages for the LEED buildings and compare them with gsf-weighted averages for CBECS. Simple mean and median SiteEI that do not weight by the gsf of each building have no physical meaning. The average density of a collection of  $N$  objects is not given by the sum of their individual densities divided by  $N$ . Instead it is the ratio of their total mass to their total volume, equivalent to their volume-weighted mean density. The appropriate mean SiteEI is similarly given by the ratio of the total site energy used by all buildings divided by their total gsf. Mathematically this is the gsf-weighted mean of the SiteEI of the individual buildings.<sup>4</sup> Gsf-weighted averaging is used by CBECS in calculating average building site and source energy intensities and by the EPA in publishing mean ENERGY STAR scores for a collection of buildings. It is the only physically meaningful way to calculate mean and median energy intensities for a collection of buildings of vastly different size.<sup>5</sup>

The SiteEI data from Figure 1(A) are re-graphed in Figure 1(B), this time with “bar widths” that reflect the contribution of each building’s area to the total gsf (13.5 million sf) for all 121 buildings. The gsf-weighted median<sup>6</sup> (79 kBtu/sf) and mean (129 kBtu/sf) are also shown on the graph. Both averages are significantly higher than those obtained without weighting by building size.

Unless otherwise noted, gsf-weighting will be used for calculating all averages (means or medians) in the rest of this paper. The Appendix summarizes numbers for this and other building sets considered in this paper.

## CBECS Database

Energy consumption data for the US commercial building stock are surveyed every four years by the U.S. Department of Energy’s (DOE) *Energy Information Administration* as part of its *Commercial Building Energy Consumption Survey* (CBECS).<sup>7</sup> The most recent data available are from 2003. The

<sup>4</sup> The gsf-weighted mean SiteEI is given by  $\bar{e} \equiv \sum A_j e_j / \sum A_j = E_{Tot} / A_{Tot}$ .

<sup>5</sup> 50% of US commercial buildings are 5,000 sf or less and contribute just 9% of the total gsf. In contrast, 5% of US buildings are 50,000 sf or larger and contribute 50% to the total gsf.

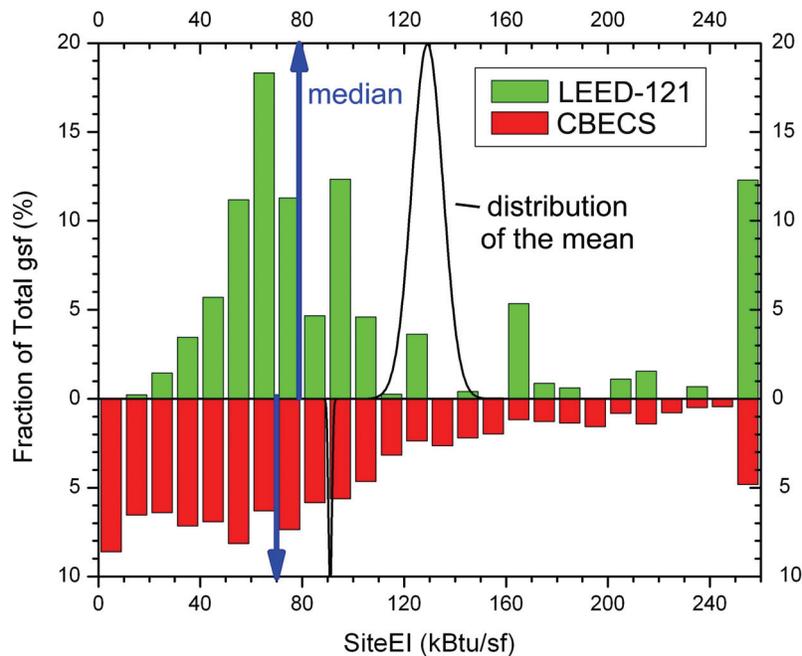
<sup>6</sup> The gsf-weighted median SiteEI is the value for which 50% of the total gsf have lower and 50% higher SiteEI.

<sup>7</sup> For more information on CBECS go to <http://www.eia.doe.gov/emeu/cbeecs/>.

2003 CBECS gathered building characteristics, including principal building activity, year of construction, gsf, and energy consumption (and much more) for  $M = 5,215$  “sampled buildings” specifically chosen to represent the entire U.S. stock of commercial buildings. By weighting data for each of the sampled buildings by  $W_j$ , the number of similar buildings in the building stock (which range from 1 to 6,374), CBECS approximates the properties of the entire commercial building stock consisting of  $N = 4.86$  million buildings and 71.7 billion gsf.<sup>8</sup>

The formats for Graphs 1(A) and 1(B) were chosen to reflect the presentation in the NBI report. A more useful method for presenting these data, however, is to calculate a SiteEI histogram that displays the percentage of the total gsf with SiteEI falling into equally spaced bins, chosen here to be 0-10, 10-20, ..., and 240-250 kBtu/sf. The final bin gives the percentage of gsf with SiteEI in excess of 250 kBtu/sf.

Figure 2 compares histograms for the LEED-121 (green – plotted upwards) with CBECS (red – plotted downwards). Also shown in Figure 2 are the gsf-weighted means and medians for the two SiteEI distributions. The distribution means are represented by black Gaussian curves.<sup>9</sup> The medians are represented by vertical blue lines. For both the LEED and CBECS SiteEI distributions, medians are significantly lower than means, confirming that both distributions are skewed to higher energy by relatively few buildings.



**Figure 2.** Histogram of the site energy intensity (SiteEI) for LEED commercial buildings (green plotted up) compared with that for CBECS (red plotted down) – see text for more details.

<sup>8</sup> For CBECS the total gsf, total site energy, and mean site energy intensity are given by  $A_{Tot} = \sum_{j=1}^M W_j A_j$ ,

$E_{Tot} = \sum_{j=1}^M W_j E_j$ , and  $\bar{e} = E_{Tot} / A_{Tot}$ . Note that averages for the sampled set without the weighting factors bare no resemblance to those for the US building stock as the 5,216 sampled buildings are not randomly chosen.

<sup>9</sup> The SiteEI distributions themselves are clearly not Gaussian and have standard deviations much larger than those represented by the “bell curves.” A Gaussian curve represents the distribution of the SiteEI mean which, owing to the central limit theorem, is normally distributed. Hence the mean and standard deviation of the mean for the SiteEI distributions are represented by the center and “width” of black Gaussian curves.

As Figure 2 shows the mean SiteEI for LEED buildings exceeds that for CBECS by 41% and the LEED median exceeds that for CBECS by 14%. Hence by either consistent metric, LEED buildings, on average, use more site energy per square foot than the average US commercial building.

This simple fact, however, is insufficient to draw conclusions about the relative energy efficiency of LEED versus non-LEED buildings. Building energy consumption varies dramatically with use. The most efficient hospital will necessarily use more energy than the most inefficient warehouse. Differences in the kinds and relative numbers of buildings contained in the LEED-121 and CBECS data sets can overshadow and mask any differences in average efficiency between the two sets. Turner and Frankel correctly assert that the LEED-121 building dataset includes a higher proportion of building types such as laboratories and data centers with inherently high energy demands, relative to the US commercial building population (i.e., CBECS).

Disparity in the two distributions is apparent in Figure 2. Nearly 15% of the gsf for CBECS has SiteEI < 20 kBtu/sf. Much of this is associated with vacant buildings and non-refrigerated warehouse which have little<sup>10</sup> (warehouse) or no (vacant) representation in the LEED set. At the other extreme more than 12% of the LEED gsf have SiteEI exceeding 250 kBtu/sf, whereas this corresponds to less than 5% for CBECS. Clearly these differences in the two distributions impact their medians and means. To compare the energy efficiencies of LEED and CBECS buildings we will need to select out comparable subsets of each that are relatively free of these differences.

## Source Energy Intensity as a Measure of Efficiency

In the US SiteEI is commonly used as the metric for building energy consumption. In contrast, the EPA has adopted source energy intensity (SourceEI) as the metric for the ENERGY STAR national energy performance rating.<sup>11</sup> Building source energy, which accounts both for on-site building energy use and off-site losses in bringing the energy to the building site, is a good measure of the primary energy use and emissions associated with building operation.<sup>12</sup>

In 2006 US electricity, a secondary form of energy, was generated and distributed with an overall efficiency of 31% (Richter et al. 2008). On average, one unit of electric energy delivered to a building came at the cost of more than three units of primary energy consumed off-site at the power plant. Fuel switching from natural gas to electric resistive heat, will always lower the site energy of a building – but is, on average, accompanied by an even greater increase in primary energy consumption. Are we to call a building “more efficient” if it lowers SiteEI while actually causing primary energy consumption (on and off site) to increase? This is ludicrous – yet it is exactly what is going on today with many “high performance” buildings and, as is a significant problem with LEED buildings. Building SourceEI accounts for the off-site losses in the electric sector by weighing the on-site electric use by a factor of three.<sup>13</sup> Use of site energy is problematic as a measure/metric of energy and environmental performance, not just for LEED buildings, but across the industry.

**Energy efficiency must be defined in terms of primary energy, and efficiency improvements must result in reduced primary energy consumption. Whether or not efficiency**

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<sup>10</sup> Several “mixed use” buildings in the LEED-121 were classified by NBI as warehouses for their ENERGY STAR scores.

<sup>11</sup> For more information see [http://www.energystar.gov/index.cfm?c=evaluate\\_performance.bus\\_portfolio manager](http://www.energystar.gov/index.cfm?c=evaluate_performance.bus_portfolio manager).

<sup>12</sup> For a discussion of site and source energy intensities see [http://www.energystar.gov/index.cfm?c=evaluate\\_performance.bus\\_benchmark\\_comm\\_bldgs](http://www.energystar.gov/index.cfm?c=evaluate_performance.bus_benchmark_comm_bldgs).

<sup>13</sup> Here we employ a simple definition of *source energy* to be *site energy* plus twice the *electric energy* (used on site). This is equivalent to weighing the electric energy used on site by a factor of three. The EPA uses a more complicated formula that weighs electric energy by 3.34, natural gas by 1.047, and other fuels by factors slightly greater than unity. Changing to EPA numbers would raise SourceEI figures for both CBECS and LEED by 7-10%, but have no significant impact on their comparison.

**measures raise or lower site energy is irrelevant.** Hence the relevant metric for building energy consumption is SourceEI, not SiteEI. In what follows we provide both measures of building energy consumption.

The LEED-121 data include fuel-type information for 98 of the 121 buildings, making it possible to calculate their SourceEI. Turner was not able to supply fuel-type information for the remaining 23 buildings as data for these buildings were lifted in summary form from two previous LEED building studies (Diamond et al., 2006; Turner 2006). We were able to obtain SourceEI data for 11 of the 23 buildings from Rick Diamond, the author of one of the previous studies. Hence we were able to augment the NBI LEED data set to calculate SourceEI for 109 of the original 121 buildings. (In what follows, we will adopt the notation “LEED+” to refer to data obtained both from NBI and from Rick Diamond.)

Properties of the LEED+109 buildings and CBECS, including mean and median SourceEI, are summarized in the Appendix. The “average” SourceEI of the LEED+109 buildings exceeds that of CBECS by 39% as determined by means or 54% as determined by medians.

## Constructing Comparable Subsets for LEED and CBECS

Table 1 provides a breakdown of CBECS by principal building activity (PBA). Column 2 provides a description of the PBA while the corresponding CBECS PBA code is listed in column 3. Columns 4, 5, 7, and 8 give the number of buildings with this PBA, their combined gsf, and their gsf-weighted mean site and source energy intensities. The last five rows in the table indicate averages for various combinations of PBA’s. The first summary line is all CBECS buildings (including vacant ones) and the second is for all non-vacant buildings. The remaining three rows represent CBECS subsets with (-Low) low-energy buildings removed, (-High) high-energy buildings removed, and (Medium) both low and high energy buildings removed.

Table 1 shows wide variation in both site and source energy intensity depending on principal building activity. In particular, vacant buildings (PBA=1) and non-refrigerated warehouses (PBA=5) account for nearly 17% of the gsf in the US building stock with minimal energy use. These two building types are largely responsible for the low-energy portion of the CBECS histogram in Figure 2.

Removing PBA = 1, 5, and 12 from CBECS eliminates many of the low-energy building activities from CBECS, but does nothing to address the over-representation of high-energy building activities in LEED.

To address this issue consider the building types represented in the LEED data set, shown in Table 2. Three of these uses – labs, supermarkets, and health care – correspond to “high-energy” PBA’s in CBECS. NBI identified “data centers” as a fourth “high-energy” use for the LEED buildings. Together these four categories contain 16% of the gsf of the LEED buildings. In contrast, the four “high-energy” PBA’s in Table 1 (labs, food sales, food service, and inpatient health) account for less than 8% of the gsf in CBECS.<sup>14</sup>

Following NBI’s lead we now divide the LEED-121 buildings into two sets: (1) 21 “high-energy” buildings and (2) 100 “medium energy” buildings. Our goal is to compare the “medium energy” buildings with a comparable subset of CBECS. As was the case for the full LEED-121 data set, we do not have fuel-type information enabling us to calculate SourceEI for all the LEED-100(M) buildings. Instead, SourceEI may be calculated for 89 of these – what we will refer to as the LEED+89(M) medium energy data set.

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<sup>14</sup> It is not clear that the last category, recreation, is properly categorized as a high-energy use. But moving recreation to the medium energy category results in one very- high SiteEI datum in that group, skewing the result. So for practical more than philosophical reasons we classify “recreation” as a high-energy building category.

**Table 1.** Breakout of CBECS data by principal building activity – PBA (see text).

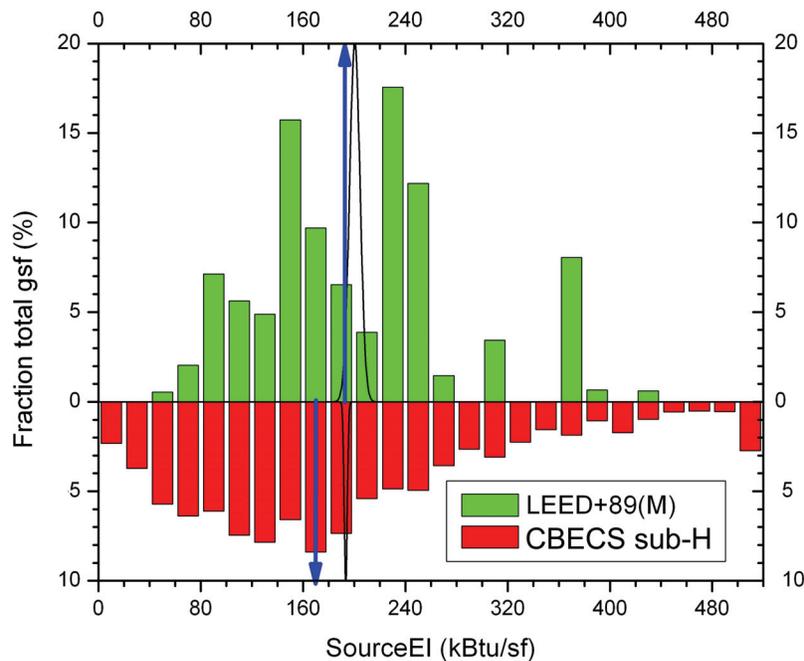
	Principal Use	PBA	# Buildings	Sq. Footage (sf)	Rel. sf (%)	Site (kBtu/sf)	Source (kBtu/sf)
low	Vacant	1	182,168	2.57E+09	3.6%	21	33
	Office	2	823,805	1.22E+10	17.0%	93	211
high	Lab	4	9,000	6.54E+08	0.9%	305	572
low	non-R warehouse	5	581,834	9.55E+09	13.3%	42	84
high	Food Sales	6	225,751	1.26E+09	1.8%	200	532
	Public Safety	7	70,500	1.09E+09	1.5%	116	220
	Outpatient health	8	120,819	1.26E+09	1.8%	95	205
	Ref. Warehouse	11	15,100	5.26E+08	0.7%	98	268
low	Religious Worship	12	370,481	3.75E+09	5.2%	43	77
	Public Assembly	13	276,617	3.94E+09	5.5%	94	179
	Education	14	385,923	9.87E+09	13.8%	83	158
high	Food Service	15	297,404	1.65E+09	2.3%	258	520
high	Inpatient Health	16	7,890	1.90E+09	2.7%	249	436
	Nursing	17	21,526	9.83E+08	1.4%	125	229
	Lodging	18	120,913	4.11E+09	5.7%	94	183
	Strip Shopping Mall	23	209,423	4.86E+09	6.8%	110	268
	Enclosed Mall	24	3,955	2.01E+09	2.8%	83	220
	Retail non-mall	25	443,216	4.32E+09	6.0%	74	172
	Service	26	622,040	4.05E+09	5.7%	77	151
	Other	91	70,383	1.08E+09	1.5%	79	164
All	All buildings		4,858,750	7.17E+10	100.0%	91	190
non-vac	no-1 (non-vacant)		4,676,581	6.91E+10	96.4%	94	196
-Low	no-1,5,12		3,724,266	5.58E+10	77.8%	106	223
-High	no-4,6,15,16		4,318,705	6.62E+10	92.4%	78	165
Medium	no-1,4,5,6,12,15,16		3,184,221	5.03E+10	70.2%	90	193

**Table 2.** Summary of Building Activity Type for buildings in the NBI LEED study.

Building Use	# bldgs	gsf	gsf (%)
Labs	10	1,594,257	11.8%
Data Centers	6	448,003	3.3%
Supermarkets	2	99,060	0.7%
Health care	1	12,177	0.1%
Recreation	2	212,000	1.6%
<b>high energy</b>	<b>21</b>	<b>2,365,497</b>	<b>17.6%</b>
Office	35	5,303,464	39.4%
K-12 education	7	923,913	6.9%
Public order	5	563,174	4.2%
Interpretive Center	9	185,249	1.4%
Library	4	400,760	3.0%
Multi-use	18	1,589,739	11.8%
Multi-unit residential	6	550,630	4.1%
Remaining Types	16	1,573,129	11.7%
<b>medium energy</b>	<b>100</b>	<b>11,090,058</b>	<b>82.4%</b>
<b>Total</b>	<b>121</b>	<b>13,455,555</b>	<b>100.0%</b>

Turner and Frankel compare the (un-weighted) median SiteEI (62 kBtu/sf) of the LEED-100(M) buildings with the (gsf-weighted) mean (91 kBtu/sf) for all of CBECS and conclude that the medium energy LEED-100(M) buildings use 32% lower energy than CBECS. They further break-out the LEED medium energy buildings by LEED certification level – *Certified* (38), *Silver* (35), and *Gold/Platinum* (27), and compare the (un-weighted) median for each subgroup with the (gsf-weighted) mean for CBECS.<sup>15</sup> They conclude that the 51 kBtu/sf (unweighted) median for the *Gold/Platinum* LEED medium energy buildings is nearly meeting the present target for the *Architecture 2030 Challenge* of having 50% lower GHG emission than CBECS.<sup>16</sup>

To proceed with our analysis we must extract a medium energy building subset from CBECS that is comparable to the LEED medium energy subset. Looking at Table 2 we first remove laboratories (PBA= 4), food sales (PBA=6), food service (PBA = 15), and inpatient-health facilities (PBA=16), as these are analogous to high-energy uses that have been eliminated in forming the LEED+89(M) data set. On the low energy side we remove vacant buildings (PBA=1), non-refrigerated warehouses (PBA=5), and religious worship buildings (PBA=12) on the grounds that these low-energy buildings are not represented in the LEED data set. The resulting CBECS medium subset-H is listed in the last line of Table 1 and further summarized in the Appendix. Its SourceEI histogram and that for the LEED+89(M) medium energy buildings are graphed in Figure 3.



**Figure 3.** SourceEI distributions for medium energy subsets of LEED (green) and CBECS (red).

As Figure 3 shows, both the median and mean SourceEI for the medium energy LEED+89(M) buildings are higher than for the medium energy CBECS Subset-H. The mean SourceEI for the LEED medium energy buildings is 4% higher than that for comparable non-LEED buildings. In contrast, the LEED medium energy buildings have 10% lower SiteEI (see the Appendix).

But are these differences statistically significant? This question is answered by performing a “T-test for the significance of the difference between the means of two independent samples” using

<sup>15</sup> There are only two LEED platinum buildings in the NBI data set. Accordingly the platinum and gold buildings are combined into one subset.

<sup>16</sup> For more information see <http://www.architecture2030.org/>.

numbers supplied in the Appendix.<sup>17</sup> At the 95% confidence level we find that the LEED+89(M) medium energy buildings use 10% less site energy than comparable non-LEED buildings, but that there is no significant difference in their source or primary energy consumption from that of comparable non-LEED buildings.<sup>18</sup>

We have considered 4-5 other “medium energy” subsets of CBECS by keeping or removing different PBA’s – all with similar results. Figure 4 for CBECS subset-H is representative of the results for other comparisons.

## Comparing LEED with Newer Vintage CBECS Buildings

Henry Gifford (Gifford 2008a) has pointed out that the LEED buildings in the NBI study are all relatively new, yet have been compared with all of CBECS which contains mostly older buildings. Since building energy codes and technologies are continually improving, one might expect any new commercial building to demonstrate lower energy use than the CBECS averages – which are dominated by older buildings. The assumption is reasonable, but not supported by data.

The CBECS database includes information regarding the year of construction or vintage for sampled buildings. We have extracted CBECS records which correspond only to buildings constructed between 2000-2003. CBECS Subset-H consists of 3,670 of the 5,215 CBECS records (i.e., sampled buildings). Restricting this to just the newest building vintage returns just 280 CBECS records.<sup>19</sup>

What we find – and this trend is born out by other newer vintage CBECS subsets – is that, like the (new) LEED buildings, new non-LEED buildings have relatively higher SourceEI and relatively lower SiteEI than older buildings. Comparing LEED medium energy buildings with new vintage medium energy CBECS buildings we find that LEED has a mean SourceEI that is 6% below that for newer CBECS, but like the previous comparison, the difference is not statistically significant (p-value = 32%). The mean SiteEI for LEED is 8% below that for newer CBECS and as before, is statistically significant.

Hence we conclude that LEED medium energy buildings, on average, use 10% lower site energy but the same amount of primary or source energy as do other comparable commercial buildings – whether restricted to new vintage or not.

The LEED+89(M) medium energy buildings may further be broken out by LEED certification level, *Certified* (35), *Silver* (32), and *Gold/Platinum* (22). Figure 4 graphs the *mean* SiteEI and SourceEI for the various subsets, and also for CBECS Subset-H for comparative purposes.

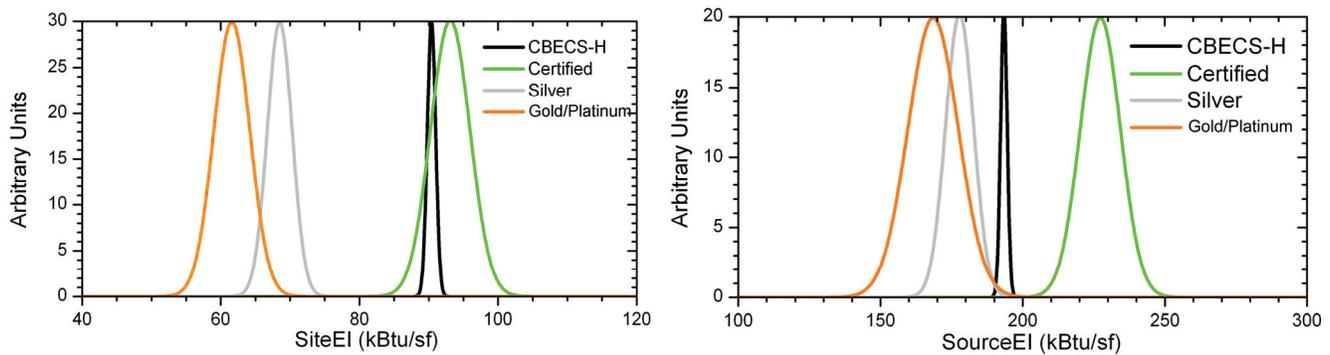
Note that LEED Certified buildings use significantly more (18%) source energy and slightly more site energy than do conventional, medium energy buildings. LEED Silver buildings use 8% less and LEED Gold/Platinum buildings 13% less source energy than conventional buildings. LEED Silver and Gold/Platinum buildings use 23% and 31% respectively, less site energy than conventional medium energy buildings.

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<sup>17</sup> In applying the T-test to CBECS data the number of degrees of freedom is determined by M, not N. Note that we have not included the additional uncertainty associated with the errors in sampling. If included, these add to the sdm for CBECS source and site energy intensities, further reducing the significance of any differences in means.

<sup>18</sup> Note that the mean SiteEI for the LEED-100(M) buildings is 3% lower, at  $(78.6 \pm 3.2)$  kBtu/sf. This mean is not significantly different from that of the LEED+89(M) data set.

<sup>19</sup> The graph by Bill Rose presented in the Lstiburek (2008) paper was an earlier attempt to compare LEED buildings with newer vintage CBECS, but failed to account for the weighting factors,  $W_j$ .



**Figure 4.** Comparison of the mean (a) SiteEI and (b) SourceEI for LEED+89(M) medium energy buildings by certification level with that for CBECS medium energy Subset-H.

## Comparing Office Buildings

While the above analysis is statistically robust, skeptics on both sides of this debate will harbor doubts as to whether the CBECS and LEED medium energy subsets contain comparable building uses.

Consider then another comparison. Focusing on Office buildings yields smaller data sets but ones that are more homogenous with regard to building activities. The LEED-121 data set contains 35 Office buildings. LEED+32(O) is the subset for which we have been able to determine source energy. Office buildings correspond to a specific PBA in CBECS, so it is easy to extract data for Office buildings of all vintage or just the most recent vintage (constructed between 2000-3). Comparing these subsets we find that LEED offices have mean SiteEI 17% lower than that for CBECS offices of all vintage, but that both sets have insignificantly different SourceEI means. The same conclusion is reached in comparing LEED offices with the newest vintage CBECS offices.<sup>20</sup>

## ENERGY STAR Scores

The above analysis has been exclusively directed to comparing measured LEED building energy consumption with that for comparable non-LEED buildings using CBECS. There are several reasons for focusing on this component of the NBI LEED study: 1) the data lend themselves to relatively quantitative analysis, 2) the data are relatively transparent and free of biases that might be introduced by building owners and NBI, 3) comparisons to CBECS are widely employed by building designers in quantifying the “efficiency” of their buildings, and 4) this aspect of the NBI study has been the subject of considerable criticism.

It is much more difficult to offer independent analysis of the other two foci of the NBI Study, LEED building ENERGY STAR scores and comparison of Design with Baseline energy models. To duplicate these aspects of the NBI study would require access to the LEED submissions and much more data than are in the summary Excel file supplied by NBI. Nevertheless, as ENERGY STAR scores are also based on source energy it is important to re-examine these.

NBI looked at ENERGY STAR scores for half of the LEED buildings – those whose principal building activities made them eligible for such scores. ENERGY STAR scores are based on building source energy, location, climate, principle building activity, occupancy, building hours, and other factors. ENERGY STAR scores are calculated from user-supplied data entered into the EPA’s on-line *Portfolio Manager* calculator using a regression algorithm that normalizes for a variety of factors and scores the building in question against other comparable buildings from CBECS data. The algorithm returns

<sup>20</sup> Newer CBECS offices use slightly higher source energy, but the difference is not statistically significant.

scores of 1 – 100. The score is designed so that the median score for all US commercial buildings is 50.<sup>21</sup> Portfolio Manager is only able to supply ENERGY STAR scores for certain building types. Turner and Frankel report a median ENERGY STAR score of 68 for the 60 eligible LEED buildings, citing this as further evidence that LEED buildings are 25-30% more efficient than other buildings. Note that this value falls below the 75 score required to earn the building ENERGY STAR label.

We do not have access to the raw data that were used to calculate the LEED ENERGY STAR scores – only the ENERGY STAR scores themselves. The median LEED ENERGY STAR score calculated by NBI has no comparative value. Instead we calculate the mean<sup>22</sup> ENERGY STAR score for the 60 eligible buildings to be 64. (Below we compare this value with means reported for other sets of commercial building.) Because the mean ENERGY STAR score exceeds 50 it is tempting to conclude that these 60 LEED buildings use significantly less source energy than comparable buildings. But things are not that simple. The mean or median ENERGY STAR score for N buildings can exceed 50 while the N buildings collectively use more source energy than comparable model buildings. It is difficult to interpret average ENERGY STAR scores for a set of buildings, and hopeless for anything but the gsf-weighted mean.

57 of the 60 LEED buildings with ENERGY STAR scores are medium energy buildings, and 51 of these are in the LEED+89(M) medium energy subset for which we have source energy information. We refer to these 51 buildings as LEED+51(Mes). We can make direct comparison between the LEED+51(Mes) and the larger LEED+89(M) medium energy subset. We find the mean SourceEI for the LEED+51(Mes) buildings to be  $(188 \pm 9)$  kBtu/sf, 6% lower than that for the LEED+89(M) building and slightly lower than CBECS subset (H) medium energy buildings. The gsf-weighted mean ENERGY STAR score for these 51 buildings is 59. We conclude that the mean SourceEI for the LEED buildings for which ENERGY STAR scores are calculated is in fact lower than for the other LEED buildings in this study. Clearly it follows that the mean SourceEI for the remaining 38 buildings in the LEED+89(M) set have a higher SourceEI mean. Hence the mean ENERGY STAR score of 64 is not in conflict with our earlier conclusion that medium energy LEED buildings have SourceEI that is not significantly different from comparable medium energy buildings.

## Discussion

Figure 4 displays mean SiteEI and SourceEI for medium energy buildings by LEED certification level. We find *Certified* buildings use more site energy and more primary energy than do comparable medium energy non-LEED buildings. LEED *Gold/Platinum* buildings use 13% less primary energy than comparable non-LEED buildings. This positive efficiency improvement is still well short of the 2008 goal of 50% reduction in fossil energy set by the *Architecture 2030 Challenge*. The *Gold/Platinum* buildings achieve site energy reduction of 31% below comparable non-LEED buildings. This suggests that 30% of the LEED certified buildings are making strides towards their energy target – it is just the wrong target.

Inasmuch as buildings are responsible for roughly 40% of US primary energy consumption and associated GHG emission this has important policy implications. All strategies for reducing our nation's GHG emission start with improving building efficiency. LEED certification has not been useful at reducing building primary energy consumption and, by inference, GHG emission associated with building operation. There may be many green benefits from LEED certification – but reduction of primary energy consumption for building operation is not one of them. Studies have shown that, over

<sup>21</sup> This is a building-weighted or un-weighted median, referring to numbers of buildings not fraction of total gsf.

<sup>22</sup> Both un-weighted and gsf-weighted calculations coincidentally yield the same mean. In characterizing the ENERGY STAR scores for a collection of buildings the EPA typically uses the gsf-weighted mean.

the lifetime of a building, energy used for operating the building dominates – far exceeding the embodied energy of construction (Dimoudi & Tompa 2008). There then appears to be no scientific basis for institutions such as colleges, universities, or the Federal Government to require that, as a GHG or energy reduction strategy, all new buildings obtain LEED certification. Similarly there is no justification for USGBC claims that LEED Certified commercial buildings are using significantly less electricity or have significantly lower GHG emission associated with their operations than do conventional buildings (USGBC 2008a, 2008b; Watson 2008).

We return now to discuss ENERGY STAR scores. ENERGY STAR scores provide a powerful tool for comparing building source energy consumption with that for comparable buildings, but they also suffer from a data integrity problem. To earn the ENERGY STAR label a score of 75 or higher must be verified by data gathered on site by a licensed professional engineer. But all other ENERGY STAR scores, including these for LEED buildings, are based on unverified owner-supplied data, data which are likely filtered through “rosy-tinted” glasses. ENERGY STAR scores, for instance, are sensitive to the reported number of building hours and/or occupants. Roughly 12 billion sf of commercial buildings have been entered into *Portfolio Manager* with a mean ENERGY STAR score of 60 (vonNeida 2009). Perhaps there is a tendency for owners of more-efficient buildings to determine their ENERGY STAR scores. Or maybe, like the mythical children of Lake Wobegon, “all self-reported data are above average.”

It is also worth comparing the LEED ENERGY STAR scores with scores for other relatively new buildings. A study 157 California office buildings constructed from 1992-1995 found their average ENERGY STAR score to be 64 –identical to that for the LEED buildings here (Johnson 2002). The ENERGY STAR scores for LEED buildings constructed from 2000-6 are clearly similar to conventional office buildings constructed in CA in the early 90’s.

There is no question that the method for gathering data for this study is flawed. Ideally data would be gathered from all 552 LEED certified buildings and verified by independent audits – gathering energy data directly from utilities rather than filtered through building owners. Alternately, data from a subset of randomly selected LEED buildings could serve in its place. Neither method was employed, nor could be, as LEED certification has no monitoring or reporting requirement. Instead, NBI began their data collection with known results from two smaller studies then supplemented these “seed data” by soliciting voluntary submissions from the remaining 431 LEED-certified building owners. It is worth noting that the medium energy “seed buildings” have lower SiteEI and higher ENERGY STAR scores than do the remaining medium energy buildings gathered new for this study. One has to wonder what bias was introduced in rejecting submissions from 128 additional building owners, or in deciding how aggressively to follow up on incomplete submissions. Skeptics, including this author, doubt that data gathered are representative of the 431 LEED-certified buildings not included in this study. Henry Gifford poignantly compares the process to one of setting up a voluntary breathalyzer test along the side of the highway (Gifford 2008b). One of the various reasons that Turner and Frankel state that building owners declined to provide data was that they were still “tuning” their buildings. It was this author’s experience that both owner and designer of a high-performance academic building strongly resisted disclosure of energy performance data citing a similar argument. Disclosure proved embarrassing yet drove positive change and subsequent building improvements (Scofield 2002). LEED building owners receive all the positive benefits of green publicity – including the presumption of energy efficiency – before their building is ever constructed and have little to gain (and much to lose) from disclosing energy consumption data

Despite its shortcomings, the NBI LEED energy consumption database comprise the largest and most complete collection of its kind (a sad statement) and it is useful to squeeze any information available from it. NBI, and the USGBC who have promoted the main conclusion of the NBI study, apparently believe the data are reliable and reflective of the wider set of LEED buildings. Our re-

examination of the NBI data shows that LEED certification has done nothing to lower building primary energy consumption and associated GHG emission. In the interest of saving space we refer the reader to the abstract for a summary of our key conclusions.

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## Appendix

Properties of the LEED and CBECS building subsets described in the text are summarized in the table below. For each category we supply the number of sampled buildings (M), number of buildings represented (N), the total gsf, the mean, standard deviation of the mean (sdm), and median SiteEI and SourceEI – in all cases weighting by gsf. For LEED buildings (O) stands for office buildings and (M) "medium-energy" with c, s, g, and es further denoting certified, silver, gold/platinum, and ENERGY STAR subsets. For CBECS, subset (F) is offices and (H) is medium energy, described in the text. The "+" sign with LEED data indicates additional source energy data from Rick Diamond (see text).

Building Category	samples	# bldgs	Annual Energy Intensities (kBtu/sf)							
			M	N	gsf			source		
					(sf)	mean	sdm	median	mean	sdm
LEED Buildings										
LEED-121	121	121	13,455,600	129.1	12.2	79.3				
LEED+109	109	109	11,121,200	140.8	13.7	82.3	264.6	19.1	227.0	
LEED-100(M)	100	100	11,090,100	78.6	3.2	71.3				
LEED+89(M)	89	89	8,836,010	81.4	3.6	77.2	200.5	8.2	194.0	
LEED+35(Mc)	35	35	3,918,080	96.5	6.4	94.4	227.3	14.1	239.0	
LEED+32(Ms)	32	32	3,664,460	69.3	3.8	61.3	177.8	9.9	164.0	
LEED+22(Mg)	22	22	1,889,720	62.5	5.9	57.3	168.5	17.7	143.0	
LEED+51(Mes)	51	51	6,418,020	75.4	3.2	77.2	188.5	8.7	181.0	
LEED-35(O)	35	35	5,303,460	77.1	3.4	77.3				
LEED+32(O)	32	32	3,835,620	77.6	3.5	77.3	205.0	9.6	216.0	
CBECS All Vintage										
All Bldgs	5,215	4,858,750	71,657,900,000	91.0	1.3	69.8	190.4	2.6	147.3	
Sampled Bldgs	5,215	5,215	522,465,000	139.4	1.6	101.2	275.9	2.6	229.9	
(F) office buildings	976	823,805	12,208,000,000	92.9	2.2	80.3	210.6	4.2	187.9	
(H) med. energy bldgs	3,670	3,184,220	50,317,000,000	90.4	1.2	76.2	193.4	2.3	169.9	
CBECS 2000-3 Vintage										
All Bldgs	410	346,655	6,262,300,000	81.6	4.4	66.0	192.4	10.5	154.7	
(F) office buildings	61	38,662	649,836,000	93.1	6.7	82.2	218.3	15.4	201.2	
(H) med. energy bldgs	280	189,733	4,086,640,000	88.9	4.0	79.3	213.6	10.5	195.7	