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# Plug Load Energy Analysis: The Role of Plug Loads in LEED Certification

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**Abstract**

*Plug loads use 12% of site energy in U.S. office buildings. The relative importance of plug loads is rising and it is projected to increase more in years to come. We studied the predicted and simulated plug load energy consumption using data submitted to the U.S. Green Building Council for LEED certification. The study included 660 LEED for Commercial Interiors projects and 429 LEED for New Construction projects. This is the first study to analyze LEED submittal data related to plug load energy use. The submittal data from these projects was mined and statistically analyzed. The results show that 73% of the projects under LEED-CI that attempted the credit dedicated to plug loads earned 2 of 2 points available (90% or more of eligible equipment is ENERGY STAR rate). Additionally, we found that projects most frequently specify ENERGY STAR rated laptops, monitors, desktops and printers, whereas televisions, fax machines, refrigerators and dishwashers were less frequently specified. Under LEED-NC, the median peak plug load power intensity reported among the projects was 10.8 W/m$^2$. Most of the projects complied with the LEED requirement of 25% process load energy use, with the median percentage being 25% and the 1$^{st}$ and 3$^{rd}$ quartiles ranging from 18% to 31%. 32% of the projects reported using eQUEST as an energy simulation tool. Only 5 of 429 LEED-NC projects reviewed attempted and were approved exceptional calculations for claiming energy savings on efficient plug loads or office equipment.*

***Keywords – plug loads; LEED certification; energy simulation, ENERGY STAR***

## 1. Introduction

The environmental impact of buildings has approached a critical stage, and is considered one of the leading contributors of greenhouse gases to the environment. Buildings now comprise almost 40% of total primary energy use and 72% of total U.S. electricity consumption, which is expected to grow to 75% by 2025 [1]. More than ever, building energy use is becoming a critical factor in climate change mitigation, and reducing this energy use is essential to meeting national and regional energy reduction goals.

One crucial component of whole-building energy use is plug loads: 18% of California's total electricity consumption in commercial office buildings is attributed to this category [2], and the Commercial Buildings Energy Consumption Survey (CBECS) reports plug loads comprising 12% of total energy in all U.S. office buildings (see Fig. 1) [3].

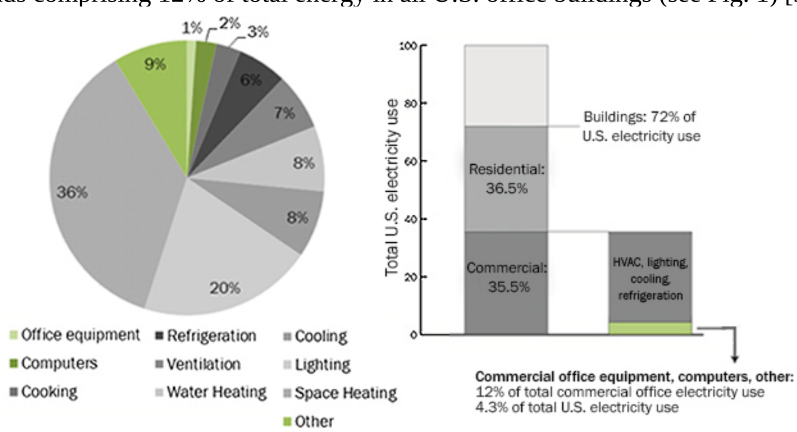


Fig. 1 Plug loads as a component of total commercial building energy use and total U.S. electricity use [3]

This portion is also anticipated to rise: the Energy Information Administration estimates that energy consumption for PCs will grow 3% annually and other office equipment will 4.1% annually [4]. Given that this is such a rapidly-growing end-use, it is essential that designers and engineers be able to properly estimate and account for this energy use in order to ensure that low-energy or net zero energy goals can be met.

### LEED and Plug Loads

One tool that the majority of designers in U.S. use to demonstrate achievement of green building principles is the LEED rating system. The U.S. Green Building Council offers different LEED rating systems that are customized to different project sizes and types. Among others, the LEED for Commercial Interiors (LEED-CI) focuses on commercial tenant fit-out projects, and LEED for New Construction and Major Renovation (LEED-NC) is targeted towards commercial and institutional new construction or renovation projects. Projects evaluated under this study were certified under the LEED-CI version 2.0 and LEED-NC version 2.2 rating systems.

The role that plug load energy use plays in these rating systems is unique to each. LEED-CI contains a credit dedicated to this end-use: Energy & Atmosphere Credit 1.4 (EAc1.4) focuses on ENERGY-STAR eligible equipment being installed in the project. The credit awards up to two points for meeting a percentage threshold of either 70% (for 1 point) or 90% (for 2 points) of ENERGY-STAR eligible equipment being ENERGY-STAR rated, based on rated (or nameplate) power of the equipment units.

LEED-NC does not contain a credit that exclusively evaluates plug load energy use; plug load energy use of the project is folded into the whole-building energy use prerequisite and credit, Energy & Atmosphere Prerequisite 2/Credit 1 (EAp2/c1). Under Option 1 of this credit (the most commonly attempted option), teams must submit results from two annual hourly whole-building energy use simulations: a baseline-case model and a design-case model. The models must comply with the requirements in ASHRAE Standard 90.1, Appendix G. Plug loads are included in both simulations, and fall under the broader category of "process loads." Under LEED-NCv2.2, process loads are required to be 25% of the baseline-case energy cost, and must remain unchanged in the design-case model unless an optional exceptional calculation method is pursued. Because this energy category is not governed by ASHRAE 90.1, an exceptional calculation method would entail submission of separate materials, evidence and explanation to demonstrate that the additional energy savings calculation is sound, and is thus rarely attempted by project teams. However, exceptional calculation methods can benefit the project in enabling project teams to demonstrate efficiency savings over and above what ASHRAE 90.1 governs, and enable the team to leverage efficient plug load energy use as a significant opportunity for energy savings.

A number of recent studies have measured plug load energy use, either in the field to understand turn-off rates, user behavior or equipment properties [5-7], or in a laboratory condition in order to measure resulting heat gain [8]. Others have aggregated these and other measurements to recommend plug load simulation variables [9-10]. No studies have yet quantified how designers are reporting this end use in practice, or specifically for LEED submissions. The objective of this research is to evaluate the methods that LEED currently uses to assess plug load energy use in buildings, as well as to identify the range of assumptions made by energy modelers regarding the energy use of plug loads in LEED certified buildings. It is the first study to analyze in detail the estimation of this end use in LEED projects.

## 2. Methods

A base list of 40,479 registered and certified projects used in this study was downloaded from the website of the Green Building Certification Institute (GBCI) on June 6, 2011. 9,187 of these projects (23%) were certified as of that download date; of these, 1,856 were LEED-CI certified, and 4,827 were LEED-NC certified. Of the LEED-CIv2.0 and LEED-NCv2.2 certified projects considered in this study, projects that were not confidential and designated as a "Commercial Office" were included. Not included were projects with corrupted templates, LEED-CI projects that did not attempt EAc1.4, LEED-NC projects that didn't attempt EAc1, LEED-NC projects that attempted EAc1 but chose a prescriptive path, and projects that attempted these credits but all points were denied in the review process. Due to time constraints, the collection of all the LEED-NC data is incomplete. The total number of projects with data collected for this project was 660 LEED-CI projects (58% of total non-confidential LEED-CI certified projects) and 429 LEED-NC projects (17% of total non-confidential LEED-NC certified projects).

The data were collected via LEED-Online v.2: each project submits individual forms of the data relevant to achieving each credit. The credit forms relevant to plug load energy use for each project were collected and compiled. Other general project information such as location, gross square footage and Full-Time Equivalents (FTE, an approximation of occupancy) were collected from the public spreadsheet or the project information tab within LEED Online.

Data were entered into a Microsoft Excel spreadsheet and analyzed with Excel and R. The data distributions are reported as box-plots when more than one variable is plotted. A box-plot is a way of graphically summarizing a data distribution. In a box-plot the thick horizontal line in the box shows the median. The bottom and top of the box show the $25^{th}$ and $75^{th}$ percentiles, respectively. The horizontal line joined to the box by the dashed line shows either the maximum or 1.5 times the interquartile range of the data, whichever is smaller. Points beyond those lines may be considered as outliers and they are plotted as circles in the boxplot graphs. The interquartile range is the difference between the $25^{th}$ and $75^{th}$. To compare means and to test statistical difference t-test and ANOVA were used when appropriate. For all tests the results were considered statistically significant when $p<0.05$. The statistical analysis was performed with R version 2.10.1 [11].

## 3. Results

### LEED-CI

660 LEED-CI projects were analyzed. Under LEED-CI, the point achievement is based on percentage of ENERGY STAR eligible equipment that is ENERGY STAR rated, based on rated (or nameplate) power. The equations used to determine the percentage achievement of this credit are in Equation (1) and (2).

$$\text{Percent ENERGY STAR equipment per type} = \frac{[(\text{Total installed ENERGY STAR equipment rated power}) \;x\; (\text{number of units})]}{[(\text{Total ENERGY STAR } \textit{eligible} \text{ equipment rated power}) \;x\; (\text{number of units})]} = \frac{i}{e} \quad (1)$$

$$\text{Total percent ENERGY STAR equipment} = \sum \frac{\mathrm{i}}{\mathrm{e}} \quad (2)$$

671 of the 917 LEED-CI certified commercial projects attempted EAc1.4 (74%), and 491 of these earned 2 of 2 available points. The median percentage of ENERGY STAR rated equipment per ENERGY STAR eligible equipment in this study's set is 93%. The first and third quartiles were 88% and 98%, respectively. 90 projects in this set (13% of total) estimated that 100% of their ENERGY STAR-eligible equipment would be ENERGY STAR rated. This suggests that these credit thresholds are accessible for LEED-CI projects and that the credit might benefit from additional, higher tiers of achievement.

When disaggregating the data to an equipment unit basis, projects are most likely to install ENERGY STAR rated laptops, monitors, desktops, and printers, which all had a 94% achievement rate or above (see Fig. 2). TVs and fax machines were less likely to be ENERGY STAR rated. This could be due to market availability or the lack of impact one television would have compared to several dozen laptops or computers under Equation (1).

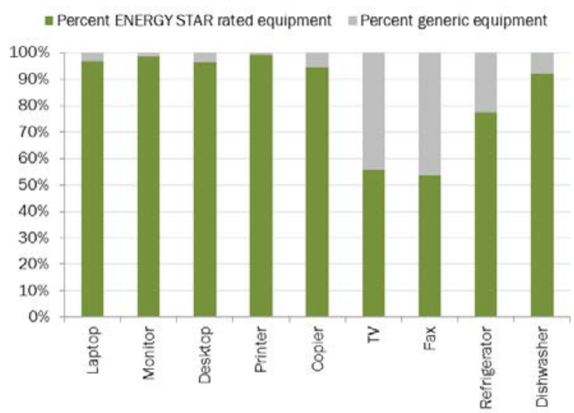


Fig. 2 LEED-CI ENERGY STAR rated equipment per unit

**LEED-NC**

Under LEED-NC, plug load energy loads fit under the process load category. The only requirement stipulated in the rating system is that process loads are at least 25% of the total baseline energy cost (unless the team has a specific reason to estimate more or less than 25%). The median percentage of process energy use attributed to the baseline energy model was 25%, which aligns with the LEED requirement, with the first and third quartiles at 28% and 32%, respectively.

LEED-NC project teams must also report their assumptions of their energy model separately from the actual outputs of the model. The LEED form requires a value for "receptacle load energy intensity" in units of W/ft$^2$. The median peak receptacle load energy intensity use values reported in these projects was 10.8 W/m$^2$. This is higher than the distribution reported in the New Building Institute's study on LEED energy performance, which reported a median of 15% process load energy use [12].

In the LEED energy modelling results, when daily and annual diversity loads were applied to this peak receptacle value in the models, the median receptacle energy annual energy use intensity is 4.0 W/m$^2$. Receptacle loads comprised 78% of the process energy use in projects, as the median total process annual energy use intensity for this general category among this set is 5.1 W/m$^2$. These findings are described in Fig. 4.

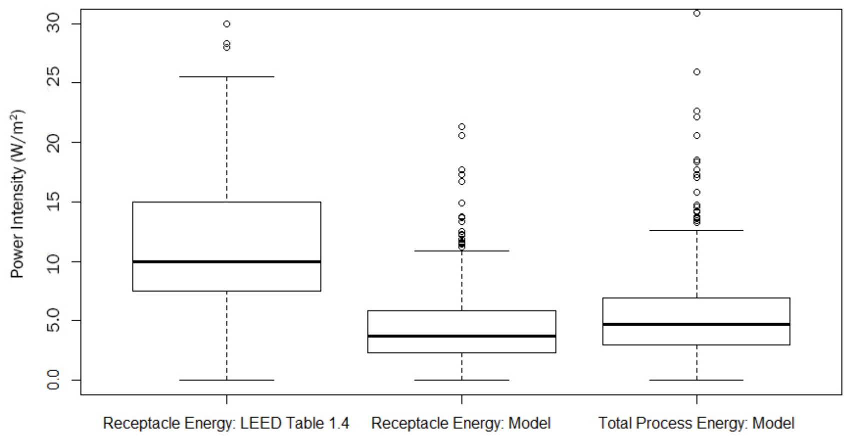


Fig. 3 Receptacle energy and process energy power intensities in LEED-NC projects

The median annual energy use reported for all fuel types is 1,857 GJ/year, which is a 27% improvement from the median simulated baseline energy use, at 2,554 GJ/year.

eQUEST was the most frequently used energy simulation software among these projects, with 32% of the teams reporting having used this tool. (Trane Trace and Carrier HAP were second, at 24% and 15%, respectively).

55 of 429 projects accessed in this study attempted some sort of exceptional calculation method; 5 projects within this set (or 1% of all projects accessed) attempted an exceptional calculation method related to plug load energy use. The projects that attempted an exceptional calculation method for efficiency in plug load energy use did so with a variety of methods and targeting different equipment types within the plug load energy use category, to varying degrees of impact (2% to 11% total electricity savings evident). Table 1 highlights two projects identified in this set that attempted and earned additional credit for efficiency in this category.

In these two examples, the same target equipment (substituting CRT monitors with more efficient equipment) achieved savings with alternative equipment, but the different teams attempted this calculation in different ways: ECM 1 considered different power levels and an annual diversity load, and accounted for reduction in cooling loads, whereas ECM 2 included a laptop/computer split, only accounted for a flat wattage difference (assumingly obtained from the manufacturers), and multiplied by the number of workstations. Both projects were awarded this exceptional calculation, but the use of such different methods suggests a need for LEED or ASHRAE to provide guideline in establishing a fair baseline as well as annual energy use calculations.

Table 1. Selection of plug load exceptional calculation methods in LEED-NC projects

| Exceptional Calculation Method Description | Savings calculation method | Annual electricity savings | Percent of total electricity use |
|---|---|---|---|
| ECM 1: LCD monitors used in lieu of CRT monitors (39 workstations) | "On" and "standby" power values for CRT and LCD monitors applied to work schedule (8 hrs on, 16 hrs standby, 250 days/year). Reduced cooling loads also accounted for, and a slight increase in heating loads. | 12,901 kWh | 11% |
| ECM 2: LCD monitors and laptops used in lieu of CRT monitors and desktops (1,504 workstations) | Mix of wattage equipment specifications (desktop + CRT, desktop + LCD, laptop only) applied to number of workstations anticipated to each. Baseline default was desktop + CRT configuration for all workstations. Cooling/heating loads unaffected. | 264,841 kWh | 6% |

## 4. Discussion

This study has illuminated a number of trends regarding simulation of plug load energy use, and also points to a few gaps or improvements to be made in the LEED rating system.

In general, the disparity between the LEED-NC and LEED-CI rating systems' approach to quantifying plug load energy use is apparent; there are benefits and drawbacks to each. In LEED-CI, the EAc1.4 calculation is not useful to designers as a finding or tool, as it is based on rated/nameplate power, which greatly exceeds the average and peak energy loads from most office equipment [10] and does not account for annual energy use or diversity. However, the existence of this LEED credit alone requires designers and project owners to consider plug load energy equipment as an independent variable in the total energy use of the project, and promotes installation of ENERGY STAR equipment as a viable option to achieve energy savings in this category. This is not the case in LEED-NC, where plug loads are relegated to a component of process energy use, which is not accompanied by any useful estimation metrics aside from the aforementioned 25% threshold, which appears to be an arbitrary benchmark and is bound to change as the proportion of plug load energy use grows in commercial buildings.

It should be noted that the draft of LEED Version 4 (out for public comment at the date of this paper) has removed this 25% requirement and proposes that teams calculate their own baseline-case and design-case plug load energy values. This is a laudable step forward, but only underlines the need for an established baseline and estimation process to ensure that all project teams are estimating plug load energy use and savings consistently, in order to reduce instances such that were found in the exceptional calculation methods reported in this study.

Recent research suggests that estimation of plug load energy intensities by equipment type and workspace density may be superior to a more "static" plug load energy intensity value, such as a flat power per square meter intensity value applied to an entire workspace [10]. The benefits of applying a targeted energy intensity value that is specific to the project's characteristics (e.g., high density workspace with desktop computers versus a sparsely occupied space with primarily laptop computers) are clear in the ability to address and adjust to a wide range of practices. However, this estimation method is not yet evident in design standards or energy simulation programs.

As plug load energy use is claiming a larger percentage of the total building energy designers and building owners need to become more attuned to an accurate assumption or simulation of plug load energy use. While LEED-CI projects are easily achieving credit for efficiently plug load energy use, LEED-NC projects are infrequently and inconsistently doing so. While the LEED rating system is adjusting to prioritize attention to estimation of this end use, the industry needs to establish a clear, replicable, and robust set of guidelines for estimating plug load energy use. This will ensure not only a fair playing ground for LEED projects, but will also drive the industry towards quantifying plug load energy use in the design stage, helping designers and owners reach their low-energy and net zero energy goals.

## 5. Conclusion

This study collected data related to plug load energy use from 660 LEED-CI projects and 429 LEED-NC projects. The data were statistically analyzed to understand how designers estimate and simulate plug load energy use in these rating systems.

Under LEED-CI, the median percentage of ENERGY STAR rated equipment per ENERGY STAR eligible equipment was 93%. Laptops, desktops, monitors, and printers were most frequently specified to be ENERGY STAR rated.

Under LEED-NC, plug load energy use falls under the broader category of process energy use. The median percentage of process energy use attributed to the baseline energy models was 25%, which aligns with LEED's requirement. The median reported receptacle energy annual energy use intensity is 4.0 W/m$^2$. Receptacle loads comprised 78% of the process energy use in projects. eQUEST was the most frequently used energy simulation tool in this project set, with 32% of projects electing to use this software. Only 5 of 429 projects attempted an exceptional calculation method relating to plug load energy use.

## 6. Acknowledgments

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