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ABSTRACT

Plug and process loads (PPLs) are a critical part of any building, because they enable much of its functionality. PPLs are defined as loads that are not heating, ventilation, air conditioning or lighting. Examples include desktop computers, telephones, desktop accessories, and kitchen appliances. Many PPLs, such as workstation equipment, are controlled or specified by the tenants of commercial office buildings. Tenants require that sufficient electrical power is available for PPLs to meet the maximum anticipated load. Lease language thus often dictates a value of 5 to 10 W/ft^2 for PPLs. However, measured data show that actual loads are much lower than this, but prospective tenants and real estate brokers lack adequate references to encourage a change in the power capacity that is typically requested.

Overestimating PPL capacity leads designers to oversize electrical infrastructure and cooling systems. Better guidance would enable improved sizing and design of these systems resulting in more energy-efficient electrical and HVAC systems while saving upfront capital costs. Ultimately, this saves the occupant money in reduced rents because the owner does not need to recover the additional infrastructure costs. This paper shows measured evidence that actual peak PPL densities are significantly lower (by a factor of 5 to 10) than what is typically requested, negotiated, or required in leases.

Introduction

Plug and process loads (PPLs) provide much of the functionality of a building. They represent the computers and their related networks, telecommunications, security, personal amenities, and kitchen equipment. Any load that is not heating, ventilation and air conditioning (HVAC) or lighting is categorized as a PPL. Designing for PPLs can be difficult due to their: huge variety, sheer number, and small individual magnitudes. PPL power requirements are frequently overestimated because designers often use estimates based on "nameplate" data. To be conservative, design teams overestimate PPLs for equipment sizing to avoid undercooling or underpowering a space. The oversizing has been a long-standing issue and peak PPL estimates of 5 to 10 W/ft^2 are commonplace in the industry (see Table 1 below).

One important result of oversizing electrical distribution is that cooling, fan, and ductwork systems are also oversized thus increasing initial construction costs. From an energy perspective, the oversizing causes equipment to operate at part load, which is often less efficient and can cause zone temperature fluctuations that create discomfort. Transformers also become less efficient at part-load performance (see Figure 1). Thomas and Moller (2007) found that rightsizing chillers in two buildings reduced whole-building energy use by 3% to 4%. If an integrated design approach could enable 3% whole-building energy savings in all U.S. office buildings stock, it could save 34 TBtu of site energy per year—an energy savings that could be achieved without additional capital investment.

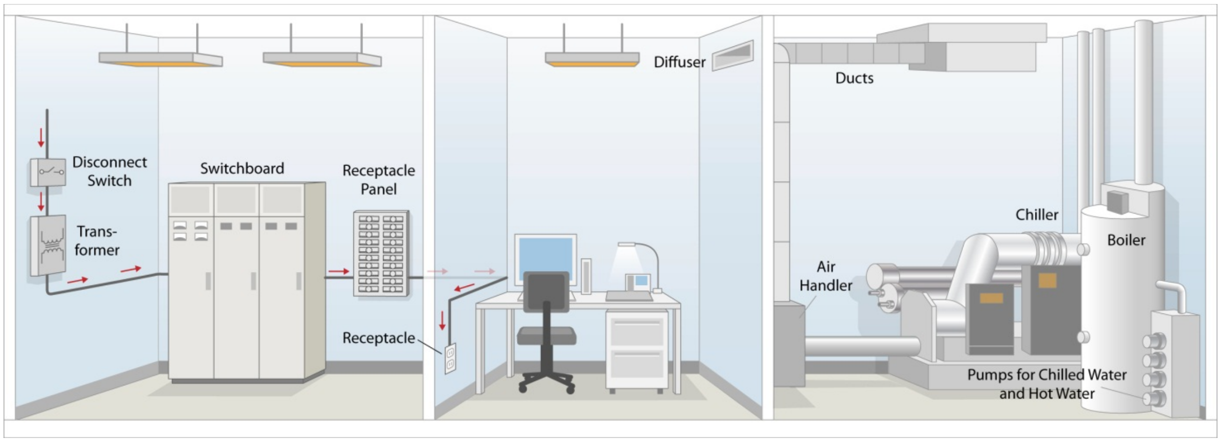

Figure 1. Systems that are affected by plug and process load densities specified in lease agreements. (Figure credit: Alfred Hicks/NREL)

Plug and Process Load Densities Reported in the Literature

Brokers suggest PPL density needs as high as 16 W/ft^2 as part of the lease structure (CBEA 2012). The available literature suggests that companies and institutions are specifying lower PPL capacities in their leases. For instance, in 2012, the U.S. General Services Administration (GSA) changed its standard lease requirements from a 7 W/ft^2 minimum to a 4 W/ft^2 minimum for PPLs (Pentland 2011; GSA Public Buildings Service 2011; GSA 2013) as part of its government-wide efforts to create green, sustainable buildings. Table 1 summarizes the PPL densities reported in the literature. The reported PPL densities show significant variability.

Table 1. PPL Power Capacities Reported in the Literature

Reference	Building Type	PPL Power Density (W/ft^2)
Wilkins and Hosni (2011)	Office	0.25 to 2.0 (minimum capacity)
ASHRAE (2009)	Office	1 (minimum capacity)
Srinivasan et al. (2011)	K-12 education	0.33 to 1.06 (average density)
Metzger et al. (2011)	Office	0.9 (average density - cubicle only)
NRDC (2011)	Office	7.5 (requested minimum capacity)
(GSA (2011); Haun (2013); GSA (2013)	Office	4 (requested minimum capacity)

A PPL design factors study (Wilkins and Hosni 2011) indicates that, for office buildings, PPL peaks could be lower than the traditional 1 W/ft^2 presented by ASHRAE (2009), and up to 2 W/ft^2 in the most extreme cases if very dense office equipment use and no diversity are assumed. A downward trend in PPL sizing has steadily evolved since the late 1980s, when loads were assessed from nameplate data and HVAC systems were sized for typical plug load densities of 3 to 5 W/ft^2. At five GSA office buildings Wilkins and McGaffin (1994) included individual loads and panel measurements and provided evidence of the discrepancy between density estimates from nameplate data and actual use. The analysis of PPL densities mentioned by Srinivasan et al. (2011) suggests that even 1 W/ft^2 is a high estimate. Because of advances in energy efficiency and requirements in electronic office equipment, realistic peak PPL densities can be as low as 0.25 W/ft^2 (Wilkins and Hosni 2011), or lower. Over time, however, a building tenant's level of commitment to energy efficiency can vary, so more conservative PPL sizing estimates are often advised (ASHRAE 2009).

Uncertainties in PPL density assessment stem from guidelines in commercial building models and simulations, and from limited availability of benchmarks and case studies that confirm simulations. Srinivasan et al. (2011) stress the importance of benchmarking as an essential tool to inform and avoid arbitrary or incorrect inputs used in building energy analysis. The study compares results from PPL densities with four established assessment approaches: The National Renewable Energy Laboratory (NREL), COMNET, ASHRAE 90.1-1989, and California Title 24 for classrooms with and without computers. Results show that all four approaches over- or underestimate PPL densities over measured values. In particular, PPL densities of 1.06 W/ft^2 and 0.33 W/ft^2 were needed for classrooms with and without computers, respectively.

Case Study: Empire State Building

A 2011 case study on a sustainability and energy efficiency retrofit for the Empire State Building in New York City (Empire State Building LLC 2013), and in particular for one of its tenants, Skanska (NRDC 2011), highlights lower PPL densities than current leasing energy allowance practices. Skanska U.S.A. relocated its New York headquarters to the 32nd floor of the Empire State Building. The investments in energy efficiency were based on the 15-year lease period, and are expected to save around $300,000 over that time. One outcome of the case study relates to tenant incentives. Lease terms can influence tenants to make energy-efficient choices. Conventional leases in New York City call for electrical capacity of 7.5 W/ft^2, but Skanska's project team calculated that the office would need 2 W/ft^2. As the lease was negotiated, Skanska was cautious about adjusting its terms to such a low capacity, seeing no benefit (and potential risks) in doing so. Skanska's landlord helped address these concerns by deploying a new "use it or lose it" clause. Tenants are not prevented from using the full electrical capacity in their leases, but if they do not consume the electricity after a period of time, they must either pay to keep it in reserve or lose the right to excess watts per square foot.

Case Study: U.S. Environmental Protection Agency Region 8 Headquarters

A plug load behavioral change demonstration project (Metzger et al. 2011) for the U.S. Environmental Protection Agency's Region 8 Headquarters included a benchmark study of PPL densities. Fully occupied in January 2007, the 420,000-ft^2, nine-story building houses approximately 775 employees. The building participated in a research study quantifying the effects of various mechanical and behavioral change approaches to PPL energy reduction. An inventory of PPL equipment for all participants was taken at the beginning and end of the study. A walk-through of the offices was conducted in January and July of 2011, preceding and following the experimental phase. Equipment wattages were estimated, because interaction with the occupants was restricted, and diversity factors were applied based on ASHRAE recommendations (ASHRAE 2005). Diversity factors take into account that all pieces of equipment are not always in use at the same time, and provide a more accurate representation of actual operating loads. Average cubicle sizes were 80 ft^2 with an average total connected equipment load of 145 W without diversity and 71 W with diversity. Average cubicle equipment power densities were 0.9 W/ft^2 with diversity factors.

The scopes of these studies were limited. Early studies were based on equipment nameplate data only. More recent studies have either: (1) focused on an isolated building (limiting the broad applicability of the data); or (2) employed meters at the cubicle level only (missing many PPLs distributed throughout the building). This report aims to fill in the gaps that previous studies missed and thereby improve leasing practices.

Review of Current Leasing Practices and Cost Structures

During the 2012 Commercial Buildings Energy Alliances (now called the Better Buildings Alliances) Efficiency Forum industry members from the commercial real estate sector stated: "We are putting far more capacity in buildings and creating a lot less efficient systems than we could because brokers are telling tenants they need 12, 14, 16 watts per square foot. That becomes part of the lease structure…" (CBEA 2012).

Clayton Ulrich (senior vice president of Engineering Services at Hines) noted that Hines' HVAC designers are fairly comfortable with their current assumptions of 2.5 W/ft^2 for PPLs and 1 W/ft^2 for lighting. The combination is used as part of the basis for sizing cooling systems. Ulrich (2013) added that the sizing of a building's electrical infrastructure varies from market to market; tenants in different regions expect different W/ft^2 for plug loads from the distribution transformers; 8 W/ft^2 is the default if Hines does not know the market. Furthermore, Tony Malkin and Duane Desiderio (Skanska) mentioned a retrofit project in which they achieved less than 2 W/ft^2 in their tenant buildout when the original request was for 7 W/ft^2.

Industry collaborators were interviewed to document cost structures for sizing electrical infrastructure and HVAC systems. During an interview with Rick Haun (GHT Limited Consulting Engineers) (Haun 2013), he was asked "Is the sizing of electrical infrastructure and HVAC systems based on W/ft^2 requested by tenants?" His response indicated that better equipment design maintains good part load efficiency and that there was a capital cost penalty for oversizing.

Methods

Although many sets of building data were available for use, only a few buildings had the PPL disaggregation (through submetering) from other building loads. The following criteria were used to make the final building selections:

- **Separate metering of PPL energy.** Strong candidates include those where "total" PPL energy is (or will be) separately metered from other end uses (e.g., lighting and HVAC).
- **Separation by space use type.** Ideally, any single measured value of total PPL energy is associated with just one major space type or business type (e.g., law enforcement space is metered separately from medical offices). If that is not possible, the next best case would be if types are mixed only minimally and differences are well documented.
- **Space use type applicability to others.** Strong candidates include spaces that are of interest to a large audience. Different types of office space, for example, are a primary target because they apply to many users. Other spaces of interest may vary with sector; in

higher education, for example, spaces of interest could include (but are not limited to) office, laboratory, and housing.

- **Knowledge of conditions on site.** Strong candidates will be able to document the loads and space use types associated with their meters.
- **Resource requirements.** More buildings can be considered for inclusion if their data are well aligned with project requirements and if the additional analysis can be completed within the project budget. In most cases, stronger candidates will be those with less need for on-site visits or those where on-site actions can be conducted by members.

Final Selections

Table 2 lists the data sources that were selected. Large office, small office, higher education (office and classroom), municipal office, and single- and multitenant office spaces are all represented.

Table 2. Finalized Data Sources

Data Source	Number of Buildings	Existing or New Metering	Building Types Represented	Level of Data Being Monitored
NREL	2	Existing	Office – Single Government Tenant[a] Office – Single Government Tenant w/ Data Center[a]	Whole panel
U.S. Dept. of Defense (DOD)	1	New	Office – Single Government Tenant	Branch circuit Receptacle
Stanford University	7	Existing	Higher Education – Classrooms, Meeting Areas, and Faculty Offices	Whole panel
Smarte Building	10	Existing	Office – Multitenant w/ Data Center Office – Multitenant Office – Municipal Office – Single Tenant w/ Warehouse Office – Single Corporate Tenant w/ Data Center Office – Single Corporate Tenant w/ Kitchen Office – Single Corporate Tenant w/ Laboratories	Branch circuit
GSA/ Hines	1	New	Office – Single Government Tenant	Branch circuit

[a] Data from a commercial office building with net-zero energy goals.

U.S. Department of Defense Office Building

This 18,818-ft^2 facility has approximately 90 occupants and is a typical DOD office environment. The building is composed of several space types such as cubicles, offices, kitchens, print rooms, and conference rooms. Table 3 describes the total number of space types throughout the building.

Table 3. Total Space Types Present in U.S. Navy Office Building

Space Type	Total
Libraries	1
Cubicles	57
Offices	30
Kitchens	3
Open Areas (Hallways)	12
Print Rooms	1
Conference Rooms	2
Mail Rooms	1
Reception Areas	1

Metering was deployed in this building to disaggregate PPLs from other building energy end uses. DOD traced all the PPL circuits in the building to confirm that the electrical panel schedules are accurate. One hundred eighty-four current transducers were installed in the building's electrical panels to submeter all PPL branch circuits. Additionally, 115 receptacle-level meters were installed to capture more than 95% of individual equipment loads. Utility bills made it possible to determine the proportion of PPLs to whole-building energy consumption. Figure 2 illustrates the metering installed in this building.

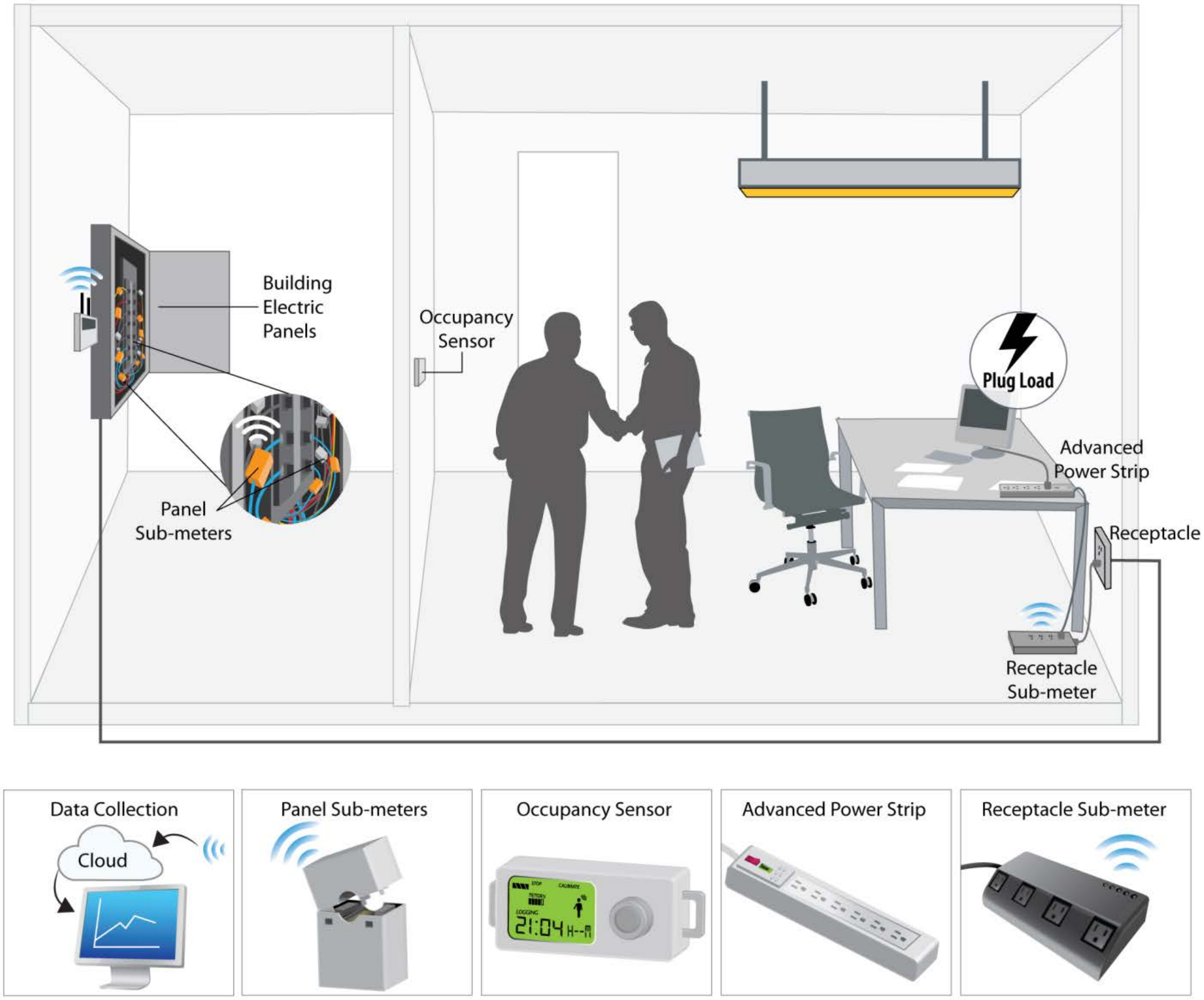

Figure 2. Metering that was installed in a DOD office building (Photo credit: Marjorie Schott, NREL)

U.S. General Services Administration-Occupied/Hines-Managed Office Building

This 18,755-ft^2 facility has approximately 60 occupants and is a typical GSA office environment that is representative of the larger building stock. The building is composed of several space types, including cubicles, offices, kitchens, print rooms, and hearing rooms. Table 4 describes the total number of space types throughout the building.

Table 4. Total Space Types Present in U.S. Navy Office Building

Space Type	Total
Cubicles	34
Offices	29
Kitchens	1
Open Areas (Hallways)	5
Print Rooms	1
Hearing Rooms	4

Metering was deployed in this building to disaggregate PPLs from other building energy end uses. Nine current transducers were installed in the building's electrical panels to submeter all PPL branch circuits.

Data Validation

The datasets collected were analyzed using the data validation approach developed by Sheppy et al. (2013). The key elements of this approach are summarized below:

- If less than one hour of data were missing, linear interpolation was used to fill in data.
- If more than one hour of data were missing, data from a typical hour during that same time of day or day of week were used to fill in the gap.
- Data that were out of bounds (including negative values) were replaced with valid data.
- Extreme meter spikes were flagged based on whether they were three standard deviations (or more) above or below the average value for that meter. Simple, linear interpolation was used to fill extreme meter spikes.

After the data were validated, meters were aggregated resulting in key building performance parameters, such as PPL energy use intensity (W/ft^2), HVAC energy use intensity (W/ft^2), and total annual PPL energy consumption (kWh/year).

Table 5. Measured Average and Measured Peak PPL Energy Use Intensity

Building Type	Average (W/ft^2)	Peak (W/ft^2)	Total Area (ft^2)	No. of Bldgs.
Office - Single Government Tenant	0.24	0.52	18,818	1
Office - Single Government Tenant	0.16	0.55	138,000	1
Office - Single Government Tenant w/ Data Center	0.34	0.51	18,755	1
Office - Single Government Tenant w/ Data Center	0.77	1.25	220,000	1
- Data center only	0.57	0.82		
Higher Education - Classrooms, Meeting Areas, and Faculty Offices	0.23	0.41	115,110	1
	0.30	0.64	49,360	1
	0.16	0.42	83,130	1
	0.40	1.08	26,326	1
	0.28	0.63	113,584	3

Findings

Findings from this PPL capacity analysis strongly suggest that actual PPL densities in leased buildings are substantially lower than are usually requested. Table 5 summarizes the measured average and measured peak PPL densities of four office buildings and seven higher education buildings. On average, the *peak*-divided-by-*average* PPL factor is 2.03 for office buildings and 2.30 for higher education buildings. This suggests that the buildings that were metered in this study are not doing a good job of shutting down PPLs during unoccupied hours. This highlights the need for improved plug load controls in these buildings, such as advanced power strips. It also shows that for most buildings, the peak density is less than 1 W/ft^2 and in all cases was below 2 W/ft^2.

Table 6 summarizes the measured *average* PPL densities of 10 additional office buildings that had average data, but not peak data. If we apply the *peak*-divided-by-*average* factor (2.03) from above, we can estimate that these 10 office buildings also have peak PPLs well below the 5 to 10 W/ft^2 that is typically requested in leases.

Table 6. Measured Average PPL Energy Use Intensity

Building Type	Average (W/ft^2)	Total Area (ft^2)
Office - Multi-Tenant w/ Data Center	1.17	50,725
Office - Multi-Tenant w/ Data Center	0.19	365,000
Office - Multi-Tenant w/ Data Center	0.37	191,799
Office - Multi-Tenant	0.49	173,302
Office – Municipal	0.40	172,000
Office - Single Tenant w/ Warehouse	0.19	94,621
Office - Single Corporate Tenant w/ Data Center	0.58	97,500
Office - Single Corporate Tenant w/ Data Center	0.36	195,721
Office - Single Corporate Tenant w/ Kitchen	0.64	91,980
Office - Single Corporate Tenant w/ Laboratories	2.27	222,616

Conclusions

Through our measurement and analysis of actual PPL densities over a range of commercial building types, we have documented significantly lower (by a factor of 5 to 10) peak PPL densities than what is typically requested, negotiated, or required in leases. On average, the *peak* PPL energy use intensities for offices (without laboratories or data centers) is 0.50 W/ft^2, and 0.64 W/ft^2 for higher education buildings; the *peak* PPL energy use intensity for offices with data centers is 0.88 W/ft^2. On average, the *average* PPL energy use intensity for offices (without laboratories or data centers) is around 0.28 W/ft^2, and 0.27 W/ft^2 for higher education buildings. Offices with data centers or laboratories do exhibit higher *average* PPL energy use intensities.

With this evidence in hand, building owners, leasing brokers, and energy managers can work toward setting realistic PPL power capacities that are commensurate with actual use. This should lead to the right-sizing of HVAC and electrical systems. Case studies of two buildings have shown that right sizing HVAC system components led to an average 14% reduction in upfront capital costs and a 3 to 4% reduction in energy costs.

During construction or in deep retrofits, it is advisable to design flexibility into HVAC and electrical systems, allowing for unknown future tenants. For example, rather than oversizing the entire system, HVAC distribution pipework and main ductwork can be generously sized to allow for larger capacity needs in the future.

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