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Commercial office plug load energy consumption trends and the role of occupant behavior

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ABSTRACT

This study evaluates the energy patterns of 137 individual plug loads (desktops, laptops, monitors, and task lights) collected in a California office building over two years, and the effects of a behavior-based intervention on a subset of these devices to reduce plug load energy consumption. An analysis of the data reveals that desktops consume the most power per person and demonstrate the widest range of power consumption, and that occupants are more likely to turn equipment off before a longer break from the office than overnight during the week. Much of the literature on reducing commercial plug loads is focused on technology-based solutions, while the literature on changing occupant behavior is focused on residential occupants. Multiple studies show that non-financial incentives, such as games, can motivate behavior change. An online sustainability game, Cool Choices, was initiated on-site with 30 occupants, where players competed on teams to earn points for completing resource-saving actions. The analysis revealed that because occupants were already engaging in relevant energy saving behaviors (e.g. turning equipment off at the end of the day), there was limited opportunity for further behavior-based reductions. This study highlights the need for additional research in commercial buildings examining how to motivate occupant behavior change through non-financial incentives.

1. Introduction

Plug load energy use is emerging as an increasingly important end-use in commercial office buildings. While the efficiencies of heating, cooling and lighting systems have been steadily increasing due to code mandates and standards, plug loads are becoming a larger percent of overall building energy consumption. Plug loads currently account for 12%–50% of commercial building energy consumption, and they are expected to increase in both proportion of energy use and actual energy use, as office equipment energy consumption is expected to rise at a rate of 0.8% per year [1,2]. The literature suggests that energy efficiency and behavior-based strategies have the potential to reduce energy consumption, however existing studies are largely concentrated in the residential sector.

The term “plug load” is not used consistently within the literature and does not have a standardized definition. Fuertes [3] evaluated the terminology used in codes, standards, peer-reviewed articles, surveys (e.g. Commercial Buildings Energy Consumption Survey), and whitepapers, finding that they were also called “miscellaneous equipment,” “miscellaneous electronic loads,” “process loads,” “receptacle loads,” or “office equipment.” Definitions varied from very specific (e.g. only equipment plugged into an AC outlet) to more broad (e.g. all miscellaneous loads outside of HVAC, lighting, water heating, and major appliances). For this paper, plug loads are considered to be devices plugged into an electrical outlet in a commercial office building, primarily including, but not limited to, IT equipment.

1.1. Plug load end use in commercial office buildings

The 2003 Commercial Buildings Energy Consumption Survey estimates that plug loads account for 12% of energy end-use in commercial office buildings [2]. The 2006 California Commercial End Use Survey estimates that, among small and large offices, plug load energy use (categorized as office equipment) accounts for 14% of total building energy use [4]. In a report conducted for the United States Department of Energy’s Building Technologies Program, plug and process loads (PPLs) were estimated to account for 33% of total US commercial building electricity use [5]. While these categories are not all defined equally, it is clear that these unregulated loads do account for a nontrivial percent of total building energy use.

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For highly energy efficient buildings with low energy lighting and HVAC systems, plug loads are proportionately even more significant. For example, at the net zero energy IDeAs Z2 Design Facility in San Jose, California, plug loads account for approximately 40% of total building energy use due to the extremely efficient space conditioning and lighting systems installed [6]. Similarly, for NREL's Research Support Facility in Golden, Colorado, plug loads are responsible for 55% of total building energy use (including an on-site data center) [7]. The New Buildings Institute's study of verified net zero energy buildings in the United States reports that plug loads can account for 50% of their total energy use [1].

Plug loads are increasing in absolute sense as well, as more electronic devices are used in office buildings. While electricity use due to personal computers (e.g. laptops, desktops, monitors) is decreasing due to improvements in efficiency, expanding use of unregulated miscellaneous electronic equipment is expected to result in a 21.4% increase in energy intensity (energy use per unit area) between 2012 and 2040. [8]. The buildings industry is also moving towards stricter energy targets on the way to achieving net zero energy status through regulatory and voluntary standards. In California, the Public Utilities Commission is using the state's energy code, Title 24, to push towards net zero energy status for all new residential construction by 2020 and all new commercial construction by 2030 [9]. Architecture 2030, a non-profit organization, issued a challenge in 2008 encouraging industry firms to commit to designing all net zero energy buildings by 2030 [10]. Understanding daily, weekly, and monthly plug load patterns will be vital in achieving further reductions in energy consumption.

The importance of understanding occupant behavior is echoed in the international community through the establishment of the International Energy Agency's Annex 66 under the Energy in Buildings and Communities Programme (EBC). Annex 66's tasks are to set up a standard occupant behavior definition platform, establish a quantitative simulation methodology to model occupant behavior in buildings, and understand the influence that occupant behavior has on building energy use and indoor environmental quality. Subtasks C and D are specifically relevant to the research reported here, as their goals are to establish a systematic approach to measuring and modeling occupant behavior, and to integrate occupant behavior with current building energy modeling programs [11].

1.2. Approaches to reducing plug load energy use: technology and behavior

There are multiple papers in the literature outlining recommendations for assessing and reducing plug load energy consumption based on case studies of existing buildings. Table 1 provides a summary of the key strategies found in 12 sources, selected because they based their recommendations on buildings that have been monitored, or were meta-studies compiling multiple case study buildings.

Technology-based strategies fall into two categories: equipment and control. Equipment strategies rely on the equipment to use less energy, either by using more energy efficient devices, or by reducing the quantity of installed equipment. The remaining technology-based strategies advocate controlling energy use. Adjusting power management settings, setting equipment timers, and utilizing smart power strips that control energy use are ways to cut down on energy consumption when equipment is not in use. These strategies specifically address the issue of wasting energy during non-working hours, or when equipment is simply not being used.

Table 1 suggests that technology-based strategies are more common and widely studied than behavioral solutions, likely because technological solutions remove responsibility from the user, thereby removing the element of uncertainty associated with occupant behavior. However, behavioral strategies are important to consider as they can be more cost effective, especially in existing buildings where options available to replace old systems may be limited for a variety of reasons (cost, space constraints, historic regulations, etc.).

Table 1
Published strategies for reducing plug load energy consumption in office buildings.

		Strategies
Technology-based	Equipment	Replace equipment with energy efficient versions (1,3,4,5,6; A,C,E,F)
		Remove unused equipment and consolidate personal equipment to shared devices (5; A,F)
		Utilize virtual server software to reduce physical server size (1,3,4)
	Control	Adjust power management savings to reduce energy use during non-working hours (3,5; A,B,C,E,F)
		Set timers on equipment with regular schedules (4; A,C,D,E,F)
		Install load-sensing outlets and power strips that turn equipment off when not in use (4,5; B,C,D,F)
		Use occupancy-sensing power strips to turn equipment off in unoccupied workspaces (1,3,4,6; A,E,F)
		Control plug loads remotely (1; B)
		Wire plug loads on same circuit and turn off at night to reduce vampire loads (2,3)
Behavior-based		Offer rewards for reduced energy consumption (F)
		Write energy budget into lease agreement, with overage penalty (1; E)
		Educate and train staff to use new devices and to reduce energy use (A,F)
		Email occupants reminders to turn off equipment (A,B,C,E)
		Provide feedback displays showing real time energy use (1; C,E)
		Encourage changes in habits (C)

Buildings: 1-Bullitt Center [12], 2-DPR Phoenix [13], 3-IDeAs Z2 Design Facility [14], 4-Packard Foundation [14,15], 5-NREL Research Support Facility [7] 6-Stevens Library [14]. Metastudies: A-Reducing Plug Loads [16], B-Ghatikar [17], C-Mercier & Moorefield [18], D-Metzger et al. [19], E-NBI Getting to Zero [1], F-NBI Best Practices [20].

The first two behavioral solutions in Table 1 are incentive and penalty strategies. For example, in the case of Seattle's Bullitt Center, tenants were rewarded with a full refund of their submetered electricity bill for staying within their agreed-on energy budget, while the penalty for exceeding their budget was payment of the full bill themselves. The remaining solutions in Table 1 are educational and feedback strategies in the form of informational tips and reminders to occupants to empower and encourage them to make behavioral changes.

The literature on behavior interventions for reducing energy consumption indicates that the most effective interventions use