Integrated Lighting and Plug Load Controls

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ABSTRACT

With increased use of electronic appliances and desktop office equipment, plug loads are becoming a major electricity end-use load in office buildings, contributing to both increased energy usage and growth in greenhouse gas emissions. Approaches to plug load power reduction are being considered by facility managers, energy efficiency program implementers and policymakers. This paper focuses on the use of hardwired control solutions to reduce plug load energy usage. These new building control concepts provide a fresh perspective in designing electrical systems in non-residential buildings.

This paper describes the technical considerations, energy savings potential, and cost effectiveness of integrated designs for lighting and plug load controls, including both central timer controls and distributed occupancy sensor controls. While this paper discusses the utilization of advanced lighting control technologies, more emphasis is placed on demonstrating the use of prevailing technologies to achieve integrated designs. Energy savings from plug load controls depend on control schedules, power consumption characteristics of controlled plug loads, and occupant behaviors. Based on results from existing plug load studies and additional assumptions of occupant behaviors, this study analyzed energy savings potential of different integrated design options for a small and a large prototype office building. Cost effectiveness of different design options were analyzed with cost consideration of both control equipment and electrical wiring requirements.

This study demonstrates that integrated lighting and plug load controls can be easily implemented with existing technologies widely used for general lighting controls. The cost effectiveness of these hardwired plug load strategies depends on existing lighting control practices and occupant behaviors. Simple payback of less than four (4) years can be achieved with proper selection of lighting control equipment and electrical wiring designs.

Introduction

Office equipment represents the third highest electricity end-use in California buildings; it accounts for about 19.2% of the total building electricity consumption (CEUS 2006). Despite penetration of newer and more efficient technologies, this electricity end-use is steadily increasing as the use of personal computers and other electronic devices in offices continues to grow. Forecasts by the Energy Information Administration's 2010 Annual Energy Outlook predict a 36% increase in energy consumption by office personal computer (PC) equipment from 2010 to 2030, and a 65% increase for those by non-PC office equipment. Reducing plug load energy consumption has become one of the major challenges in achieving zero net energy goals.

While using high-efficiency office equipment is the primary choice to reduce plug load power consumption, further energy savings can be achieved by turning off office equipment when they are not in use. Automatic plug load shutoff controls can be achieved using smart power strips with timer and/or occupancy sensor controls. Costs of these products are reasonable, and they can be very easily installed. However, their applications can be limited. For example, they cannot be used to control task lights integrated into cubicle systems, and it is not practical to install a smart power strip at every electric outlet to allow easy access to plug load controls. The hardwire control solution is to incorporate automatic shutoff controls into the building electric system to control all applicable plug loads. Such a system would allow building owners/operators to better implement their plug load control policies. When building occupants change, the hardwired plug load control system will stay and provide energy savings to the new occupants.

In an electrical system equipped with hardwired plug load controls, there would be two sets of receptacles available to occupants, uncontrolled and controlled. They would be installed close to each other so that occupants will have easy access to both. Certain office appliances, e.g. fax machines, need to be powered all the time to provide uninterrupted services. These would be connected to the uncontrolled receptacles. Other appliances, e.g. task lamps, personal fans and heaters, and monitors, do not need to be powered without the presence of occupants. They are considered as controllable plug loads and would be plugged into the controlled receptacles for automatic shutoff controls. A hardwired control system provides the capability and convenience for automatic plug controls. Ultimately, it depends on building occupants to determine the appliances to be controlled.

Integrating plug load controls with building lighting controls is the natural solution to hardwired plug load controls. This is because plug load electrical circuits can be shut off in the same way as lighting circuits are shut off by a lighting control. Some manufacturers already promote the use of their lighting control products for plug load controls in response to the growing market demand for reducing plug load energy consumption. Due to the existing code requirements on building lighting controls, electrical designers, contractors, building operators, and building officials are already familiar with the design, installation, and operation issues of lighting controls. Hence, there are neither infrastructure nor market barriers to the expansion of lighting controls to cover plug loads. This study provides detailed design solutions and energy savings analysis to demonstrate the feasibility and cost effectiveness of integrated solutions. This study was sponsored by the Southern California Edison Company (SCE) Codes and Standards program in support of the California Energy Commission (CEC) 2013 building energy code (Title 24, part 6) development.

Integrated Lighting and Plug Load Control Designs

Existing building codes, such as ASHRAE 90.1 and California building energy code (2008 Title 24), require automatic shutoff controls of general service lights. These code requirements are the starting point for integrated plug load control designs. In general, there are three types of automatic shut off controls: time switch controls, occupancy sensor controls, and photo sensor controls. A time switch control turns off lights using a fixed control schedule; an occupancy sensor control turns off lights when the occupant is absent; and a photo sensor control turns off lights when enough daylighting is detected. All these controls are required to be accompanied with a manual override to ensure building occupants have direct access to electrical lights, if needed. Both time switch controls and occupancy sensor controls can be expanded to cover plug load controls, since they are based on status of occupant presence. The same manual override for lighting controls can be used to override plug load controls. Photo sensor controls rely on availability of daylighting in a building space, not occupant presence. Therefore, they are not applicable to plug load controls.

In the following sections, we provide detailed analysis of design strategies to demonstrate that integrated plug load control can be achieved by common lighting control products, not just a few specialized products. However, the amount of energy savings achieved will depend on the level of integration.

Time Switch Controls

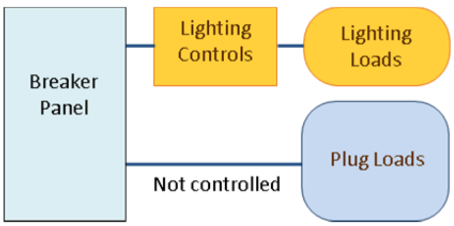
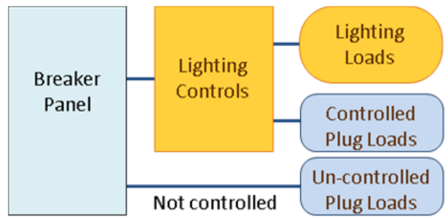
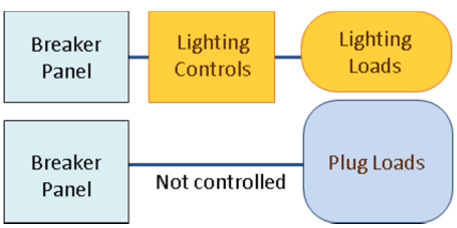
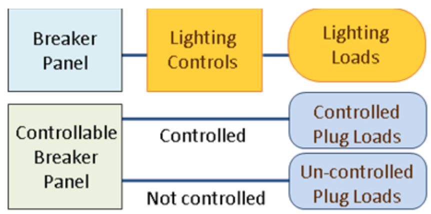
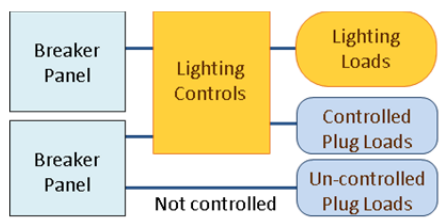
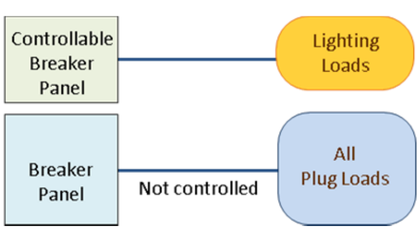
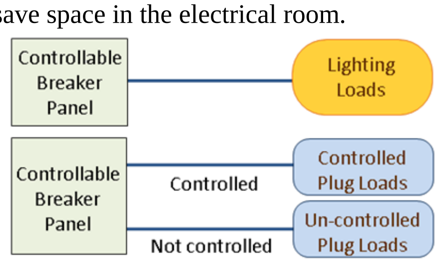
Time switch controls are usually configured to automatically turn off lights during non-business hours, when no occupants are to be expected in the controlled space. Controllable plug loads should also be able to be turned off during the same time since they are not in service. Since there is no fundamental difference between lighting circuits and plug load circuits, using the same lighting controls for plug load control is a natural choice. Lighting controls will include additional control channels to accommodate circuits connected to controlled receptacles, while configurations of control schedules will stay the same.

Among different control technologies, controllable breaker panels deserve some special attention in integrated designs. Circuit breakers are required for all building circuits for overload or short circuit protections. A controllable breaker includes the additional function of circuit shut off controls. By combining the function of breaker protection and circuit control into one panel, total equipment size is reduced and total equipment cost may also be reduced. For plug load controls, using a controllable breaker panel would eliminate additional wiring efforts needed for setting up controls. Electrical system designers and/or installers do need to pay attention to make sure that only controlled circuits are connected to controllable breakers. This is hardly an additional requirement, because installers need to keep track of the mapping between breaker channels and circuits in the building for breaker panel configuration anyway. Just as with lighting control technologies, controllable breaker panels can be interconnected and connected to other building management systems to achieve building control integration.

Many lighting control products have their unique features and advantages that cannot be replaced by a controllable breaker panel or a centralized lighting control system. For plug load control integration, lighting system designers have the option to use their preferred lighting control technologies and simply expand the number of control channels to cover plug load circuits. Alternatively, they can use their preferred lighting control technologies for lighting control and use controllable breaker panels exclusively for plug load circuits. In Table 1, several paths for integrated designs are provided based on baseline design configurations, where plug load controls are not considered. It should be noted that schematic illustrations in Table 1 do not suggest that lighting control panels need to be centrally located along with the breaker panel for plug load controls. However, locations of lighting controls may be constrained by wiring requirements imposed by plug load circuits.

Often, lighting circuits are on 277V power lines, instead of on 120V power lines used by plug loads. Most lighting control products can deal with 120V and 277V mixed loads. Circuits with different voltage ratings are separated by a voltage barrier, usually a plastic plate, inside a lighting control panel.

Table 1. Integrated Time Switch Controls

	Baseline - Lighting Control Only	**Integrated Control**
A	Lighting circuits are 120V based and share the same breaker panel with plug load circuits.  	Expand the lighting control to cover controllable plug loads. 
B	Separate breaker panels are used for lighting and plug load circuits because they use different voltages (277V vs. 120V), or because one breaker panel is not enough to accommodate all circuits.  	B1: Use a controllable breaker panel for plug load controls  B2: Expand the lighting control to cover controllable plug loads. 
C	A controllable breaker panel is used for lighting control.  	C: Use controllable breaker panel for plug load controls as well. The two breaker panels may be combined into one to save space in the electrical room. 

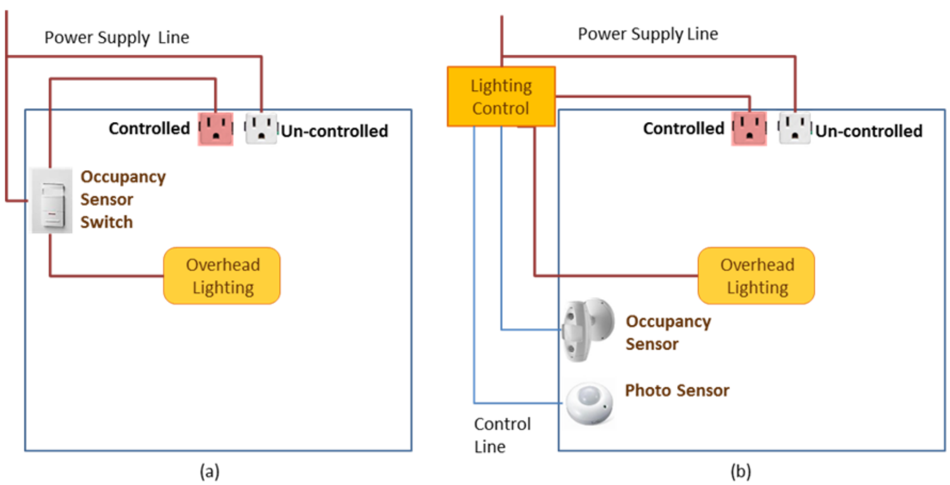
Occupancy Sensor Controls

While time switch controls aim to shut off lighting and controllable plug load during scheduled, non-business hours, occupancy sensor controls can further shut off these circuits when occupants are away from the controlled space during business hours. Since occupancy sensors are installed locally, changes in electrical wiring needed for plug load controls are minimal. Figure 1 illustrates two types of occupancy sensor control configurations. In configuration (a), a wall-mounted occupancy sensor switch is used to directly control lighting and controllable plug load circuits. In configuration (b), a lighting control, with input from an occupancy sensor and a photo sensor, is used to achieve localized control of lighting and controllable plug loads. The second approach may only make economic sense when daylighting control is also needed, or when a wall-mounted occupancy sensor is inadequate. Otherwise, the first approach would lower equipment and installation cost.

When the lighting uses 277V power supply, three design options exist for integrated designs:

- Use approach (a) in Figure 1 and install separate wall-mounted occupancy sensor switches for lighting and controllable plug loads.
- Use approach (a) in Figure 1 and install a 2-pole occupancy sensor switch with one pole for lighting and one pole for controllable plug loads.
- Use approach (b) in Figure 1 and install a lighting control that can handle mixed 277V and 120V loads

Figure 1. Integrated Occupancy Sensor Control



Applicability of occupancy sensor controls for lighting is not always the same as those for plug load controls. In private offices and small conference rooms, occupancy sensor controls can be applied to both lighting and plug loads. In office copy rooms and kitchenettes, occupancy sensor control may be applicable only to lighting control. This is because certain appliances in these spaces, e.g. coffee makers, copy machines, and printers, need to have continuous services without the presence of any occupant. If these appliances are connected to receptacles that are controlled by occupancy sensors, continuous services would not be guaranteed. Occupants will more likely to plug these appliances into uncontrolled receptacles to avoid service interruption during business hours. This would eliminate energy savings that could be generated with a time switch control for turning off these appliances during non-business hours.

In open office areas, it is better to implement occupancy sensor control at each workstation (cubicle) to maximize the opportunities of shutoff controls. System furniture (cubicle) is usually equipped with more than one internal electrical circuit and some of these circuits can be dedicated for controllable plug loads. Electrical circuit connectors for system furniture are modularized and, therefore, the split between controlled and uncontrolled circuits has to be made at a junction box. If external occupancy sensor switches are used, they all need to be wired to the corresponding junction box and the overall system wiring is complicated. In addition, off-the-shelf occupancy sensors are designed to be mounted on walls, not onto system furniture. For the above reasons, office furniture with embedded occupancy sensor controls are the ideal choice for occupancy sensor controls in open office areas.

Electrical Wiring for Plug Load Controls

Hardwired plug load controls require the installation of both controlled and uncontrolled receptacles, which, in turn, require two sets of electric circuits, or dual circuits, to support the two sets of receptacles. The impact by this requirement to building electrical wiring practices depends on control technology. Occupancy sensor controls are usually installed locally, so controlled and uncontrolled electrical circuits can be formed by splitting an electrical feed locally so that the building electrical system does not need to have dual circuits starting from the central breaker panel. In time switch controls, controlled and uncontrolled circuits need to be separated starting from the control panel. If control panels are centrally located next to the breaker panel or if controllable breaker panels are used, a dual-circuit design in the whole controlled space is needed.

This study surveyed twelve (12) office electrical system designers and contractors in California, who collectively have worked on more than 740 office building electrical system design or installation projects. The survey indicated that dual-circuit wiring was the preferred design practice and presented about 46% of new construction market. Computers and other key office appliances need to have more reliable and stable power supplies than other non-essential appliances and they are preferred to be on circuits with dedicated grounding. This is also why most office system furniture has multiple internal circuits (three or four) and an electrical connection adaptor that supports multiple feeds of electrical circuits. Receptacles in office system furniture have different markings to indicate the connected circuit and these markings can help occupants to distinguish controlled receptacles from uncontrolled ones.

It takes little effort to convert a single-circuit design to a dual-circuit design. In general, a 20A circuit can serve 2-4 workstations, depending on the expected plug load capacity at each workstation. In a single-circuit design, each group of 2-4 workstations shares one electrical circuit. To convert to a dual-circuit design, two circuits are allocated to two groups of workstations (4-8) and are split and routed to each workstation. Total number of circuits in the building stay the same. Total wiring length may increase slightly if workstations sharing the same circuits are not located close to each other.

Levels of Plug Load Control Integration

Occupancy sensor controls can capture more opportunities to shut off controllable plug loads than can time switch controls. Therefore, it is desirable to install occupancy sensor controls wherever possible. However, they do increase system cost due to additional control hardware and installation effort. This study considered three levels of control, with increased use of occupancy sensor controls as shown in Table 2, to demonstrate the cost effectiveness of these three integrated design options.

Table 2. Levels of Plug Load Control

	Occupancy Sensor Control	**Time Switch Control**
Level 1	**None**	**All spaces**
Level 2	Private offices and conference rooms	All other spaces including open office spaces, kitchenettes, and copy rooms
Level 3	Private offices, conference rooms, and open office spaces	Kitchenettes and copy rooms

Factors Determining Plug Load Control Savings Potentials

Energy savings potential of plug load controls depends on three primary factors:

- Control schedule - when controlled receptacles can be turned off
- Plug load density - how many plug loads are connected to controlled receptacles
- Power status – average power consumption of plug loads before being turned off

Control Schedule

Plug load control schedules depend on building operation schedules and occupant work schedules. There are four scenarios when controllable plug load can be turned off: non-business hours, out-of-office hours, away-from-desk hours, and empty conference room. Time switch controls are only effective for non-business hours, while occupancy sensor controls work for all four scenarios. The scenario of empty conference room is only applicable to plug load controls in conference rooms. This study developed assumptions of common work schedules and calculated annual hours of the four control schedules. Table 3 presents the assumptions and the detailed calculation steps.

Plug Load Density

For the subject of hardwired plug load controls, only controllable plug loads were considered. Office equipment such as computer servers, network hub/switches, telephones, fax machines, refrigerators, clocks, and battery chargers, are considered as non-controllable plug loads in this study. To be conservative, this study treated desktop computers and docked laptops as non-controllable plug loads. In practice, occupants may choose to plug them into receptacles controlled by time switch controls to allow them being turned off during non-business hours.

Several studies (Kawamoto 2000, 2001; Moorefield, Frazer & Bendt 2011; Roberson 2002, 2004; Roth 2002, 2004; Sanchez 2007; Webber 2001, 2005) provide the most comprehensive information on office plug load types, installation densities, usage patterns, and power states based on field surveys and monitoring. Based on the results from these studies, we develop assumptions of installation densities for all controllable plug loads, which are provided in Table 4.

Power Status

A study by ECOS (Moorefield, Frazer & Bendt 2011) categorized the operation of office appliances into the following five power states:

- Disconnected: An appliance is unplugged or turned off and does not draw any power.
- Standby: An appliance is connected, but is not performing its primary functions. This state corresponds to the lowest steady power drawn of the appliance.
- Sleep: This mode defines a power state between standby and idle. It exists for devices with power-saving features.
- Idle: An appliance is prepared to perform its intended functions, but is not doing so.
- Active: An appliance is performing its intended functions.

Not all appliances have all five power states and a power state can have different levels of power consumption. The average power consumption of all controlled plug loads right before shutoff control activation determines the amount of power reduction by controls. For each type of plug load, the average power consumption is calculated by averaging power consumptions of the five power states weighted by percentages of plug loads in each power state. Field studies conducted by Lawrence Berkeley National Laboratory (Kawamoto 2000, 2001; Roberson 2002, 2004; Sanchez 2007; Webber 2001, 2005) provided statistics of power states for key plug loads during non-business hours. Since no other study results were available, this study made assumptions of power state statistics for other controllable plug loads under the four control schedules listed in Table 3. The average power consumption of each type of plug load and under each control schedule was calculated accordingly. The results are shown in Table 4.

Table 3. Plug Load Control Schedules

Control Scenarios	Day	Hour
Non-Business Hours		
Annual non-business days = Weekend days (104) + Holidays (10)	114	
Annual non-business hours in non-business days = 24 × Annual non-business days		2736
Annual non-business hours in business days = Non-business hours per day (12) × Annual business days		3012
Annual non-business hours = Annual non-business hours in non-business days + Annual non-business hours in business days		5748
Out-of-Office Hours		
Annual out-of-office days (vacation, business travel, sick, and work from home)	28	
Annual out-of-office hours = Business hours per day (12) × Annual out-of-office days		336
Away-from-Desk Hours		
Annual in-office days = 365 - non-business days - out of office days	223	
Un-occupied hours in a business day (meetings, breaks, early leaves, late arrivals)		5
Annual away-from-desk hours = Un-occupied hours during business hours per day × Annual in-office days		1115
Hours of Empty Conference Room		
Annual business days = 365 - non-business days	251	
Average un-occupied hours during business hours per day		7
Annual hours of empty conference room = Average un-occupied hours during business hours per day × Annual business days		1757

Table 4. Characteristics of Controllable Plug Loads

	Plug Load Type	Density (/person)		Average Power Consumption (Watt)			
		Small Office	Large Office	Non-Business Hours	Out-of-Office	Away-from-Desk	Empty Meeting Room
Task Ligh	Desk attached lamp	0.5	0.5	1.80	1.80	17.30	NA
	Table lamp	1	1	1.78	1.78	11.61	NA
Mon itor	Monitor, CRT	0.21	0.23	7.22	7.22	23.01	NA
	Monitor, LCD	0.99	1.07	7.22	7.22	23.01	NA
Printing/Imaging	Laser MFD	0.01	0.01	6.76	NA	NA	NA
	Inkjet MFD	0.04	0.04	6.90	NA	NA	NA
	Laser printer	0.26	0.26	8.38	NA	NA	NA
	Inkjet printer	0.24	0.2	0.34	NA	NA	NA
	Wide Format Printer	0.048	0.04	0.43	NA	NA	NA
	Document Scanner	0.05	0.05	0.54	NA	NA	NA
Audio/Video	Television, LCD	0.04	0.04	0.19	NA	NA	0.89
	DVD player	0.02	0.04	0.57	NA	NA	0.57
	Video Projector	0.02	0.04	0.36	NA	NA	0.72
	Speakers	0.04	0.08	8.82	NA	NA	7.13
	Subwoofer	0	0.01	23.21	NA	NA	23.21
	CD Player	0	0.02	0.54	NA	NA	5.68
	Computer Speakers	1	1	20.91	20.91	21.78	NA
	Portable Stereo	0.02	0.01	1.65	1.65	8.69	NA
	Portable CD player	0.02	0.01	2.28	2.28	8.10	NA
	Table Radio	0.2	0.2	0.48	0.48	14.48	NA
Others	Adding machine	0.04	0.04	9.49	NA	NA	NA
	Shredder	0.04	0.02	0.34	NA	NA	NA
	Stapler	0.04	0.02	11.43	NA	NA	NA
	Typewriter, Electric	0.02	0.02	10.50	NA	NA	NA
	Fan, portable	0.1	0.2	0.49	0.49	1.42	NA
	Space heater	0.1	0.2	0.60	0.60	1.52	NA
Kitchen	Coffee Grinder	0.2	0.01	10.59	NA	NA	NA
	Coffee Maker	0.1	0.01	0.46	NA	NA	NA
	Toaster oven	0.04	0.02	0.19	NA	NA	NA
	Microwave oven	0.08	0.02	0.57	NA	NA	NA
	Water dispenser	0.08	0.01	2.31	NA	NA	NA
	Vending machine	0.04	0.01	0.57	NA	NA	NA
	Beverage dispenser	0	0.01	0.57	NA	NA	NA

Cost Effectiveness Analysis

Prototype Buildings

This study investigated cost effectiveness of integrated plug load controls in new construction office buildings. This study used a small and a large office building prototype, based on the prototypes provided in California Database for Energy-Efficient Resources (DEER2008). This study developed detailed office space partitions based on common design practices to determine the number of private offices, cubicles, and conference rooms in each office space. This detailed office design information was then used to estimate the total number of installed plug loads and to determine control equipment capacity and wiring length. General design information of the two prototypes is presented in Table 5.

As discussed in the previous section, there are three levels of lighting and plug load integration, with increased use of occupancy sensor controls. We analyze the cost effectiveness of all three levels of plug load controls.

Table 5. Prototype Buildings

	Area (Sqft)	Number of Stories	Number of Private Offices	Number of Conference Rooms	Number of Cubicles	Number of Occupants
Small Office	10,000	2	18	2	15	33
Large Office	175,000	10	190	20	540	730

Energy Savings Calculation

First, energy savings from each type of plug load, e.g. table lamps, under each control schedule were calculated using the following equation:

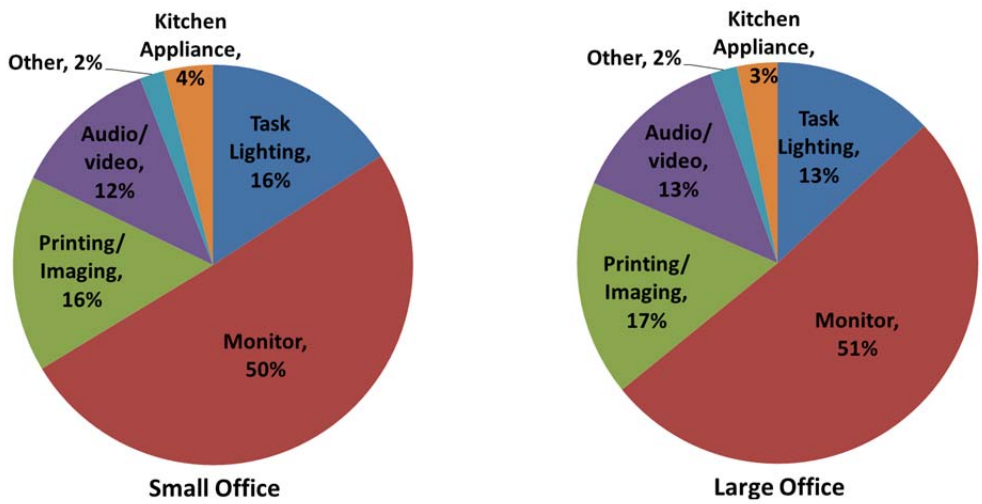
$$Savings_{i,j} = Installed\ Units_i \times Control\ Hours_{i,j} \times Average\ Power_{i,j}$$

Where i and j are the index of plug load type and control schedule, respectively. Installed units in a building prototype were calculated as the product of plug load density (Table 4) and number of occupants (Table 5). Control hours were obtained from (Table 3). The three levels of controls have different involvement of occupancy sensor controls and would have different amounts of control hours for applicable plug loads. Average power of a plug load depends on control schedule and they are listed in Table 4

Total energy savings of a building prototype were obtained by summing up energy savings from each type of plug load. Table 7 shows the estimated energy savings from three levels of controls for both prototype buildings. The results indicate that energy savings increase from level 1 to level 3, with increased use of occupancy sensors. Energy savings from level 3 control is 30% more than those of level 1 control for prototype buildings. The large office prototype has higher energy savings because the design assumptions for the large office prototype lead to a higher occupant density, therefore higher plug load densities, than those of the small office prototype. Breakdowns of energy savings in Figure 2 further show that about half of the energy savings come from shutoff controls of monitors, and that the savings components are quite similar between small and large offices.

For energy savings assessment, the study assumes that all controllable plug loads were plugged into controlled receptacles. Some building occupants may not feel comfortable to have some or all of their plug loads being controlled. Further studies are needed to assess occupant acceptance of plug load controls. Future outreach efforts are probably also needed to increase the market acceptance of plug load controls.

Figure 2. Breakdown of Energy Savings by Plug Load Category (Level 2)



Cost Analysis

The incremental cost of integrated plug load designs includes those from control equipment upgrades, additional wiring requirements, and additional installation labor hours. Equipment and wiring costs are proportional to the number of controllable plug load circuits, which depends on the number of workstations served by an electrical circuit. This study considered both the low-end design of four (4) workstations per circuit and the high-end design of two (2) workstations per circuit in order to capture the range of costs. Cost of time switch controls included four design options (Table 1) and occupancy sensor controls included two design options (Figure 1). Therefore, there were eight cost scenarios for level 1 integration and sixteen cost scenarios for level 2 and level 3 integration.

This study collected costs of lighting control equipment through a survey of distributors and manufacturers. The survey found that standard breaker panels cost about $25 per circuit channel. Costs of lighting control panels and controllable breaker panels are summarized in Table 6. Incremental cost for panel installation and configuration was assumed to be two (2) hours per control panel. Using RS Means (RS Means 2010), the electric contractor labor rate was estimated to be $86.11/hr and wiring costs (material and labor) were estimated to be $1.27/100ft.

The incremental cost for an occupancy sensor switch control (Figure 1 (a)) was estimated to be $55 each and the incremental cost for an occupancy sensor enabled lighting control (Figure 1 (b)) was estimated to be $160 per control channel.

Table 6. Costs of Control Panels

	Type	8 Channel	24 Channel	48 Channel
Lighting Control Panel	Slave	$2305	$3085	$3960
	Master	$1495	$2305	$3215
Controllable Breaker Panel	Slave	$1090	$2765	$4650
	Master	$930	$2335	$3915

Cost Effectiveness

Combining the results of energy savings and incremental costs, simple payback years of the three levels of integrated designs were calculated and shown Table 7. The price of electricity was assumed to be $0.15/kWh. Wide ranges of payback period were obtained because cost analysis considered many possible combinations of design options. Simply payback for all three levels of controls are less than ten (10) years. Since most lighting control equipment are expected to have an useful life longer than 10 years, all three levels of controls are cost effective. For certain combinations of lighting control equipment and electrical wiring designs, payback years are less than four (4) years.

Table 7. Cost Effectiveness of Hardwired Plug Load Controls

	Small Office			Large Office		
	Level 1	**Level 2**	**Level 3**	**Level 1**	**Level 2**	**Level 3**
Annual Electric Energy Savings (kWh/sqft)	0.42	0.49	0.55	0.56	0.61	0.74
Incremental Cost ($/SQFT)	0.17 ~ 0.52	0.26 ~ 0.70	0.29 ~ 0.82	0.12 ~ 0.33	0.17 ~ 0.46	0.28 ~ 0.60
Simple Payback (Years)	2.7 ~8.3	3.5 ~ 9.5	3.5 ~ 9.9	1.4 ~ 3.9	1.9 ~ 5.0	2.5 ~ 5.4

Conclusion

The concept of hardwired plug load control is to install controlled receptacles next to regular un-controlled receptacles to allow certain office equipment to be controlled. This study demonstrated that this concept can be easily implemented by expanding lighting controls to cover plug load circuits. Multiple design options for time switch controls and occupancy sensor controls were provided to indicate that integrated designs could be achieved with all types of lighting control technologies that satisfy the existing code requirements on automatic lighting shutoff control. In particular, the study investigated three levels of control integration with increased use of occupancy sensor controls. These design options can serve as a general guideline for integrated plug load control designs.

The study developed a method to calculate energy savings from plug load controls. This method includes the consideration of three factors, i.e. control schedules, densities of controllable plug loads, and power status of controllable plug loads. The study collect data from existing studies and developed assumptions to provide quantitative estimates of these three factors for further energy savings assessment. Future field studies are needed to provide better information of plug load power status under different control schedules.

The study used a large and a small office building prototype to assess the costs of integrated designs for plug load controls and the corresponding energy savings. The estimated annual energy savings were in the range of 0.42 – 0.74 kWh/sqft, depending on plug load densities and the level of integration of occupancy sensor controls. Maximizing the use of occupancy sensor controls can increase plug load control savings by 30%. About 50% of the savings came from shutoff controls of monitors. Further field studies on occupant behaviors are needed to further refine our understanding of plug load control opportunities.

Depending on design preference, the cost for integrated designs can vary widely. However, payback years for all design options are cost effective within the expected life of lighting control equipment. Simple payback of less than four (4) years can be achieved with certain combinations of lighting control equipment and electrical wiring designs.

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