CODES AND STANDARDS ENHANCEMENT INITIATIVE (CASE)

Draft Measure Information Template – Office Task Lighting Plug Load Circuit Control

2013 California Building Energy Efficiency Standards

California Utilities Statewide Codes and Standards Team, March 2011

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Measure Information Template – Office Task Lighting and Plug Loads Circuit Controls

2013 California Building Energy Efficiency Standards

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FIGURES

[redacted]

1. Purpose

This Codes and Standards Enhancement (CASE) report addresses office task lighting controls, and associated controls of other plug loads.

Task lightings and other plug loads are becoming a major electricity end-use in office buildings. These loads are significant in term of both power density and power consumption. This is due to both increased practices of low ambient lighting designs, which lead to increased task lighting usage, and increased use of computer and other office electronic equipment.

According to the California Commercial End-Use Survey (CEUS) released in March 2006, interior lighting represents 26.4% of the electricity energy consumption in California office floor space, which is the highest electricity end-use. Office buildings compliant with the 2008 Title 24 minimum requirements can be assumed to have 0.9W/sf of installed overhead lighting and 0.2W/sf of installed task lighting. Hence, about 18% of the interior lighting power density is due to task lighting. In low ambient lighting designs, this ratio is much higher. When further considering overhead lighting controls required by 2008 Title 24, the ratio of power consumption by task lightings to that of overhead lightings can be even higher.

Office equipment represents the third highest electricity end-use in California; it accounts for about 19.2% of the total building electricity consumption. Despite penetration of newer and more efficient technologies, this electricity end-use is steadily increasing as the use of personal computers and other electronics devices in offices continues to grow. Forecasts by the Energy Information Administration's 2010 annual energy outlook predict a 36% increase in PC office equipment energy consumption from 2010 to 2030, and a 65% increase for non-PC office equipment energy consumption.

Although the growth in office equipment use is difficult to control, office equipment use patterns give room for energy savings. This CASE study investigates potential requirements of applying automatically shut-off controls to circuits serving task lightings and certain plug loads, so that they can be switched off when not in use. These control technologies are already required by 2008 Title 24 for general lightings in nonresidential buildings. Therefore, they can be easily implemented with fewer technical barriers.

2. Overview

a. Measure Title	Office Task Lighting and Plug Load Circuit Controls
b. Description	This proposal investigates the feasibility and cost-effectiveness of requiring automatic shut-off controls of electric circuits that serve task lightings and certain plug loads in office buildings. These controls enable connected task lights and plug loads to be automatically switched off when they are not in use. Electric energy savings are achieved through reduction in power consumption of connected task lights and plug loads. The proposal requests an expansion of 2008 Title 24 automatic shut off controls for general lighting to cover circuits serving task lighting. The same type of controls, timer controls and occupancy sensor controls, which are currently required for general lightings, are proposed to be applied to circuits for task lighting and certain plug loads. Uncontrolled circuits should still be provided for plug loads that cannot be disrupted. Receptacles connected to controlled circuits should be marked differently from those connected to uncontrolled circuits. The proposed code changes do not impose any requirement on how task lighting and other plug loads should be connected or used. Rather, they ensure office buildings to be equipped with the proper control system to allow reduction of unnecessary power consumption by task lighting and plug loads.
c. Type of Change	The proposed requirements are mandatory for all office buildings. As mandatory measures, these requirements do not affect the performance method and trade-off calculations. Similar to general lighting control requirements, they would require an acceptance test to ensure controls are correctly installed and wall receptacles are properly marked.

<table>
<tr>
<td>d. Energy Benefits</td>
<td>
Energy savings are calculated for two prototype office buildings. As task lighting and plug load circuit controls are not required in 2008 Title 24 and are rarely installed in California market, baselines for energy savings calculation were assumed to have no task lighting and plug load circuit controls. Energy savings calculations are discussed in details in section 0.
The CASE study investigated three levels of control requirements. The final code change recommendation is based on the Level 2 control requirement. Electricity savings corresponding to this level of requirements are provided in the table below for whole office building and for unit floor area. Electricity savings are not affected by climate zones. TDV electricity savings vary slightly among different climate zones. The proposed change does not have any natural gas savings.
<table>
<tr><th></th><th>Electricity Savings (kwh/yr)</th><th>Demand Savings (kw)</th></tr>
<tr><td>Per Small Office Prototype[2] (10,000 sf)</td><td>4,900</td><td>1.97</td></tr>
<tr><td>Savings per square foot[3] (Small Office)</td><td>0.49</td><td>1.97E-04</td></tr>
<tr><td>Per Large Office Prototype[2] (175,000 sf)</td><td>107,000</td><td>23.6</td></tr>
<tr><td>Savings per square foot[3] (Large Office)</td><td>0.61</td><td>1.35E-04</td></tr>
</table>

For description of prototype buildings refer to Methodology section below.
Applies to office buildings only.

</td>
</tr>
<tr>
<td>e. Non-Energy Benefits</td>
<td>Reducing power consumption will reduce the use of the fuels that produce the needed electricity resulting in a positive statewide impact on power plant emissions. Air quality will improve, related illnesses will be reduced and community health will be improved in general, which in turn should have an impact on the demand for health care services. The economic side benefit that results from cleaner air is increased commerce (productivity), which benefits everyone. This also reduces the amount of land and resources that must be dedicated to a larger electricity infrastructure.</td>
</tr>
</table>

f. Environmental Impact

The potential adverse environmental impacts of this measure are negligible. Task light and plug load circuit controls requires additional wiring and control equipment (occupancy sensors and control panels), thus slightly more copper and plastic usages.

The measure will contribute to reduction of power generation and size of the transmission and distributions system. This leads small reduction in mercury emissions from coal-burning power plants, water consumption, the amount of land and resources that must be dedicated to a larger electricity infrastructure. The emission reductions of this measure are calculated by multiplying the electricity savings (kWh) by the hourly emissions factors. The results are presented in the following table for both prototype office buildings.

Emission Impacts:

Prototype	NOX (lb/yr)	SOX (lb/yr)	CO (lb/yr)	PM10 (lb/yr)	CO2 (lb/yr)
Per Small Office	1	5	1	0	2,844
Per Large Office	17	101	25	8	61,804

There is no significantly impact to water consumption and water quality by this measure.

g. Technology Measures

Measure Availability:

This measure requires control equipment already installed in office buildings per 2008 Title 24 general lighting control requirements. In all cases, compliance to the proposed code changes would only require capacity expansion of the same control equipment used to meet general the lighting requirements.

Useful Life, Persistence, and Maintenance:

Lighting control equipment typically has an useful life of 15 years. Energy savings from this measure will persist for the life of the installed control systems and for the life of the building, if proper control equipment is replaced in future. Lighting control equipment required by the proposed changes does not require maintenance.

h. Performance Verification of the Proposed Measure

This measure will require acceptance tests that can be included in the currently established permitting and site inspection process, similar to those for general lighting controls. Specific requirements include:

- Verify that both controlled and uncontrolled receptacles are installed in the required spaces, and they are marked differently;
- In office building open spaces, verify that circuit wire leads for future workstation furniture connection are marked as controlled and uncontrolled;
- Verify required shut off controls function properly, following the acceptance test procedures for general lighting controls

Once the initial acceptance tests are passed, consistent energy savings are expected.

i. Cost Effectiveness

Life cycle costs (LCC) per building floor area were calculated using the California Energy Commission Life Cycle Costing Methodology posted on the 2013 Standards website for each proposed measure. The measure life for each control level is 15 year. The post-adoption measure costs are not likely to decrease much, and therefore are not shown in the results of the analysis summarized in the table below. No maintenance costs were considered. Details of the analysis are included in Section **Error! eference source not found.**.

a	b	c	f	g
	Measure Life (Years)	Additional Costs[1]– Current Measure Costs (Relative to Basecase) ($)	PV of[4] Energy Cost Savings (PV$)	LCC c-f Based on Current Costs
Per Small Office Prototype[2] (10,000 sf)	15	$2,638	$9,433	($6,796)
Savings per square foot[3] (Small Office)	15	$0.26	$1	($0.68)
Per Large Office Prototype[2] (175,000 sf)	15	$33,250	$206,373	($173,123)
Savings per square foot[3] (Large Office)	15	$0.19	$1	($0.99)

j. Analysis Tools	Task lighting and plug load energy consumption is not covered by any Title 24 Standards reference methods. A spreadsheet tool was developed following energy analysis method described in the Methodology section to assess measure energy savings. The proposed measure is a mandatory requirement, therefore, whole building energy simulation tool was not needed to quantify energy savings for performance trade-off calculations.
k. Relationship to Other Measures	This measure is related to all other lighting control measures that affect lighting controls in office buildings as task lighting and plug load circuit controls are likely to be integrated with the rest of the building lighting control systems. This measure is also important to measures that encourage low ambient lighting strategies. This measure will make sure energy savings achieved with low ambient lighting are not offset by increased task lighting left on when occupants are away from their desk.

3. Methodology

This section describes the methodology that we followed to assess control strategy feasibility, energy savings, incremental costs, and cost effectiveness of the proposed code change. The key elements of the study methodology are as follow:

- Task lighting and plug loads usage characteristics study
- Control technologies market study and industry practice survey Prototype building development
- Energy Savings Analysis
- Cost Analysis
- Cost-effectiveness and Statewide Savings
- Stakeholder Meeting Process

3.1 Task Lighting and Plug Load Characteristics Study

The first step of the study was to understand the characteristics of office task lightings and plug loads in terms of installed power densities and operation patterns. Such information was needed to determine if and how plug loads can be controlled and the amount of power that can potentially be reduced through controls. The CASE study team conducted literature reviews in order to collect relevant information. Different sources were reviewed and analyzed in order to provide a comprehensive understanding of the subject.

3.2 Market Assessment

The general code change proposal concept is to require task lighting and plug loads to be controlled by time switchers or occupancy sensors to achieve automatic shut off controls. To demonstrate the feasibility of this concept, the CASE study conducted market studies to identify commercially available control products and to explore control system design options. Market study results were used to develop compliance options, and collected product costs supported the cost analysis of the proposed control requirements.

This market assessment encompassed two efforts:

- Control technologies market study
- Industry practice assessment

The market study started with literature research to understand existing practices and technology development associated with plug load controls. This effort was carried out in conjunction with literature research on office plug load characteristics study.

Many plug load control studies focused on soft-wired control technologies, e.g. task lighting with embedded occupancy sensor and power strips with occupancy sensor or timer control capabilities. These are effective control strategies and are especially cost effective for plug load control in existing buildings. They are not, however, suitable for Title 24 regulation. This CASE study investigates the implementation of hardwired control strategies in new construction buildings.

The literature study and initial survey revealed that hardwired plug controls had very small market penetration and that little was published on this topic. In response, the CASE project team shifted market study efforts towards product research and control strategy development by interviewing industry practitioners. A broad range of lighting control and circuit control products were reviewed. The project team conducted extensive discussion with lighting control and system furniture manufacturers to examine how hardwired plug load circuit controls can be implemented. The CASE team further surveyed electrical designers, contractors, and system furniture manufacturers using an online survey or through phone calls. The survey aimed at collecting industry consensus on following issues:

- Lighting and circuit control practices and products
- Feasibility of potential control requirements
- Office electric circuit wiring design practices
- Integration of plug load controls with office furniture systems

The project staff further interviewed authors of relevant studies and projects to obtain detailed technical information, to seek additional control strategies and design options, and to identify implementation and operation issues.

3.3 Building Prototype Development

The CASE team developed two building prototypes (a small office building and a large office building) to assess the energy savings, cost, and cost-effectiveness of the proposed task lighting and plug load control requirements. The CASE team built on the two office building prototypes from the Database for Energy Efficient Resources (DEER), which classified the office building stock into two categories, small and large, using a building square footage threshold of 30,000 sf. An office layout was developed for each prototype based on typical office building design and was checked by registered architects.

3.4 Energy Savings Analysis

Once task lightings and other controllable plug loads are plugged into receptacles that are connected to controlled circuits, they can be automatically shut off when they are not in use. The amount of energy savings depends on three elements: how many task lights and plug loads are connected to controlled receptacles, when they can be switched off, and the average power status when they are switched off.

Types of controllable plug loads and installation densities of controllable plug loads were determined based on task lighting and plug load characteristics study. The number of plug loads installed for each building prototype was further estimated based on prototype building sizes and detailed configurations, such as number of private offices and conference rooms.

Control schedule depends on office operation and occupancy presence schedule, as well as on control technology. Central timer control can shut off plug load power according to a fixed schedule when all occupants are expected to be out of office, e.g. during non-business hours. In the case of occupancy sensor control, additional savings can be achieved when an occupant is not at his/her desk during business hours, which includes two scenarios, away from desk and out of office. Similarly, occupancy sensor control in conference rooms can achieve additional savings when the conference room is vacant. Control schedules were developed based on assumptions of average office operation schedules.

Power status of task lighting and other controllable plug loads during all control schedule periods, i.e. business and non-business hours were also based on information collected through task lighting and plug load characteristics study, described in section 0.

The CASE team evaluated energy savings for both the small and large office building prototypes. Three levels of control were considered, which used different combinations of central timer control and occupancy sensor controls.

State-wide energy savings were calculated by multiplying unit energy savings (savings per square foot) by the CEC's forecast of square footage of office building new construction. Peak demand savings were estimated as the average load (kW) reduction during summer peak hours, which are defined as 12pm – 6 pm in July through September, according to CPUC treatment of demand savings for IOU energy efficiency programs.

3.5 Cost Analysis

This code change proposal seeks to expand existing lighting control systems for general lighting in office buildings to implement task lighting and plug load controls. Based on 2008 Title 24 general lighting automatic shut off control requirements , general lighting control compliance options were investigated to develop baseline designs. Task lighting and plug load control compliance options were developed as an upgrade to these general lighting control systems. The CASE study assessed the incremental cost of the proposed code changes by comparing the cost of the baselines to the cost of the corresponding task lighting and plug load control compliance options.

System upgrade costs were estimated for each compliance option with the consideration of following components:

- Cost of control equipment upgrade, installation, configuration, and maintenance
- Cost of additional wiring, if any

This approach also provided realistic compliance examples to effectively demonstrate code change feasibility.

Control equipment costs depend on the number of task lighting and plug load circuits to be controlled, which were determined based on prototype office building configurations. Different office building wiring practices were considered to generate a range of cost estimate.

Control equipment costs were obtained from manufacturers' distributors as part of the efforts of market study of control technologies previously discussed. Labor and material costs for installation, configuration and additional wiring were estimated based on RS Means Cost Works Online Construction Cost Data.

3.6 Cost Effectiveness Analysis

The CASE team calculated lifecycle cost analysis using methodology explained in the California Energy Commission report *Life Cycle Cost Methodology 2013 California Building Energy Efficiency Standards*, written by Architectural Energy Corporation, using the following equation:

$$\Delta LCC = Cost\ Premium - Present\ Value\ of\ Energy\ Savings$$ [1]

$$\Delta LCC = \Delta C - (PV_{TDV\text{-}E} * \Delta TDV_E + PV_{TDV\text{-}G} * \Delta TDV_G)$$

Where:

ΔLCC	change in life-cycle cost
ΔC	cost premium associated with the measure, relative to the base case
$PV_{TDV\text{-}E}$	present value of a TDV unit of electricity
$PV_{TDV\text{-}G}$	present value of a TDV unit of gas
ΔTDV_E	TDV of electricity
ΔTDV_G	TDV of gas

A 15-year lifecycle was used as per the LCC methodology for nonresidential lighting control measures. LCC calculations were completed for two building prototypes, in all sixteen (16) climate zones analyzed, for high, low, and average load shed rates. This provided a range of cost effectiveness to accommodate for varying scenarios.

3.7 Stakeholder Meeting Process

All of the main approaches, assumptions and methods of analysis used in this proposal have been presented for review at public Stakeholder Meetings.

At each meeting, the utilities' CASE team invited feedback on the proposed language and analysis thus far, and sent out a summary of what was discussed at the meeting, along with a summary of outstanding questions and issues.

Records of the Stakeholder Meeting presentations, summaries and other supporting documents can be found at www.calcodes.com. Stakeholder meetings were held on the following dates and locations:

- Control and DR Stakeholder Meeting: July 7th, 2010, San Ramon Conference Center, San Ramon, CA
- Lighting Stakeholder Meeting: February 24th, 2011, UC Davis Alumni Center, Davis CA

In addition to the Stakeholder Meetings, the CASE team contacted representative of diverse organizations involved in projects or code proposals related to plug load control such as ASHRAE and NBI.

[1] The Commission uses a 3% discount rate for determining present values for Standards purposes.

4. Analysis and Results

This section presents the data collected and results of analysis according to approaches laid out in the methodology section.

4.1 Task Lighting and Plug Load Characteristics Study

The CASE team identified and reviewed a list of publications related to office task lighting and plug loads. Detailed references of these reports are provided in the Bibliography and Other Research section. Even though numerous studies have been conducted regarding energy consumption of office equipment and home electronics, they are relatively old (from 1998 to 2002) and usually not specific to office buildings. In particular, after-hours equipment power status and equipment density are scarce information. Two studies, one from the Lawrence Berkeley National Laboratory (LBNL) and one from ECOS Consulting, provided the most comprehensive, updated and valuable data on office plug load energy consumption, status, usage and density in commercial offices.

LBNL conducted series of field measurement studies and analysis of equipment density, powers, and usage patterns of miscellaneous office equipment. The study focused on characterizing after-hour power states of office plug loads. It was published in two papers, "After-hours Power Status of Office Equipment and Energy Use of Miscellaneous Plug-Load Equipment." and "Field Surveys of Office Equipment Operation Patterns". This study is referred to as the LBNL Study in following sections. The other study is the PIER research conducted by ECOS Consulting (referred to as the ECOS Study in following sections), which monitored power consumption and status of plug load devices in 25 commercial offices in 2007 and 2008. The research metered plug load devices and recorded power, current, voltage, and power factor over a two-week period at one-minute intervals. In total, the team inventoried nearly 7,000 plug load devices and collected meter data from 470 plug load devices.

The following information and analysis on office task lighting and plug load characteristics are based on these two studies.

4.1.1 Office Plug Load Definition

In general, office plug loads include task lighting and other office and personal equipment and devices. Following the Title 24 convention that treats lighting as a dedicated category, this study separates task lighting from other plug loads. However, for control feasibility, energy savings analysis, and cost effectiveness evaluation, they are treated in the same way.

Task lighting devices are commonly used. Their installed density usually varies between 1 and 2 lighting fixtures per office workstation, which is either a private office space or an open-space office cubicle. The 2008 Title 24 has a definition for task light in section 100:

> "Task lighting is lighting that is designed specifically to illuminate a task location, and that is generally confined to the task location."

There is no specific Title 24 requirement for task lighting. It is generally assumed for Title 24 compliance that installed task lighting power density is about 0.2 W/sf when overall lighting power density is 0.9 W/sf to reach the maximum allowed power density of 1.1 W/sf. Low ambient lighting strategies, which reduce the overhead lighting power density, tend to increase task light densities and usages.

For the purpose of this CASE study, data and taxonomy from the LBNL Study and ECOS Study were used. According to the LBNL Study, office plug loads can be broken into two categories: office equipment and miscellaneous equipment.

Office equipment refers to electronics products found in any type of offices and are primarily designed for office work. The ECOS Study further sorts office equipment into computers and monitors, and office electronics categories. For the purpose of this analysis, it was further classified into the following categories:

- Task lighting:

  Under-cabinet light, table lamp

- Computer & Monitor:

  Computers: desktop, laptop (notebook or mobile), thin clients

  Monitors: cathode ray tube (CRT), and liquid crystal display (LCD)

- Office electronics

  Imaging: printers (inkjet, laser, wide format), fax machines, copiers, scanners, multi-function devices (inkjet, laser)

  Computer Peripheral: computer speakers

Miscellaneous equipment refers to plug load devices that are typically portable, often occupant-provided units whose number, power consumption and usage patterns depend more on occupants. Combining the results from the ECOS Study and LBNL Study, the most common and important ones in term of energy consumption are listed below:

- Audio/Visual: television, DVD player, video projector, speakers, subwoofers, CD player, portable stereo, portable CD player, table radio
- Telephone: speakerphone, answering machine, phone jack
- Kitchen Equipment: coffee maker, coffee grinder, toaster oven, microwave oven, vending machine, water dispenser, hot beverage dispenser
- Others: portable fan, portable space heater, stapler, electric typewriter, shredder, adding machine

4.1.2 Controllable and Non-controllable Plug Loads

Title 24 cannot and should not regulate installation and usages of office plug loads. Energy savings should come from active controls, i.e. to shut off plug-load devices when they are not in use. Some plug-load devices cannot be switched off even during non-business times due to business operation requirements. They are classified as non-controllable plug load. Controllable plug loads are plug loads that can be switched off during certain times of office operation, e.g. when the occupant is away from the workstation or the office is closed for business. Controllability of certain plug loads is hard to be determined. For example, battery chargers can be switched off when the connected battery is fully charged, however, it is not feasible to require the control to determine if the charging is complete. For energy savings evaluation, this CASE study took a conservative assumption and only classified as controllable plug loads those that can be safely switched off without affecting any intended functions.

Figure 1 provides a list of non-controllable equipment. They are not included in the energy savings analysis.

Plug Loads	**Rationale**
Desktop, laptop, and thin client computers	Need to stay on for remotely access and/or for software update during non-business hours
Ethernet hub or switch	Need to support connected computers
Phone, fax	Need to receive messages/fax all the time
Refrigerator, clock, battery chargers	Need to provide continuous operation

Figure 1 Examples of Non-controllable Plug Loads

Figure 2 provides a detailed list of controllable plug loads, which include task lightings. The figure also indicates control technologies that can be applied to these plug loads. It depends on where in the office building the plug load can be found: workstation (private office or cubicle), conference room, copy room or kitchen. Workstations and conference rooms allow for a finer grain controls using an occupancy sensor where devices can be switched off whenever the space is unoccupied, while kitchen and copy room appliances cannot be disrupted during business hours even without presence of any occupants. Shut off controls of plug loads in these spaces are better to set to be during non-business hours achieved with a time switch control. Detailed discussion on control technologies will be provided in following sections.

The general concept for plug load control is to provide two separate sets of receptacles in office spaces for task lighting and other plug loads. The electric circuits connected to one set of receptacles are controlled to achieve automatically shut off, similar to general lighting circuit shut off control. This set of receptacles is called controlled receptacles and are marked differently from others. When controllable plug loads are connected to controlled receptacles, energy savings are expected. Non-controllable plug loads are connected to un-controlled receptacles so that their services will not be disrupted. Similar to general lighting shut off controls, building occupants should have easy access to manual switches to override the shut off controls.

In practice, building occupants have the choice to decide which plug loads are to be plugged into controlled receptacles.

Plug Load	**Time Switch Control**	**Occupancy Sensor Control**	
		Private Office / Cubicle	**Conference Room**
Task Lighting			
Under Cabinet Light	Y	Y	
Table Lamp	Y	Y	
Monitor			
CRT	Y	Y	
LCD	Y	Y	
Printing/Imaging Equipment			
Laser MFD	Y		
Inkjet MFD	Y		
Laser printer	Y		
Inkjet printer	Y		
Wide Format Printer	Y		
Document Scanner	Y		
Audio /video			
Television, LCD	Y		Y
DVD player	Y		Y
Video Projector	Y		Y
Speakers	Y		Y
Subwoofer	Y		Y
CD Player	Y		Y
Computer Speakers	Y	Y	Y
Portable Stereo	Y	Y	
Portable CD player	Y	Y	
Table Radio	Y	Y	
Other			
Adding machine	Y		
Shredder	Y		
Stapler	Y		
Typewriter, Electric	Y		
Fan, portable	Y	Y	

Space heater, portable	Y	Y	
Kitchen Appliance			
Coffee Grinder	Y		
Coffee Maker	Y		
Toaster oven	Y		
Microwave oven	Y		
Water dispenser	Y		
Vending machine	Y		
Hot beverage dispenser	Y		

Figure 2 Plug Loads that can be controlled by a Time Switch or by an Occupancy Sensor

4.1.3 Operation Mode / Power Status

Most office equipment has different operational modes, or power states, which are related to their operational mode. This study adopts the ECOS Study definitions of five different power states, listed below:

- **Disconnected:** In this state, the device is not drawing any power. This could occur when a device is unplugged, turned off with a hard switch, or turned off via a surge protector or plug strip.
- **Standby:** This state corresponds to the lowest steady power drawn, and usually occurs when the device doesn't perform its primary function or when it is switched off with a soft switch but is still plugged.
- **Sleep**: This mode defines a power state between standby and idle. It is only assigned if the device has these two other power modes, and is mostly use for product types with power-saving features.
- **Idle**: A product operates in idle when it is prepared to perform its intended function, but is not doing so.
- **Active**: The device is performing its intended function. In some cases, products may have more than one intended function and therefore a wide range of active mode power. For example, a multifunction device demands different power levels for scanning, printing, and copying; however, when it is performing any of these functions, the device is in active mode.

In the ECOS Study, a product was considered to be in a power state when it spent a significant and continuous period with its power consumption in a narrow range. An operating mode could include one or more power states, and may have also included fluctuating power levels that were not considered power states.

Figure 2 provided average power, as well as typical installation density in small and large offices (defined by a 30,000 square footage threshold), for each controllable plug load based on data provided by the LBNL Study and the ECOS Study. The equipment density reflects averaged number of devices installed per occupant. These data were used for energy savings analysis.

Plug Loads	Active (W)	Idle (W)	Sleep (W)	Standby (W)	Density (unit/person)		Power Density (w/sf)	
					Small Office	Large Office	Small Office	Large Office
Task Lighting								
Lamp, Desk attachment	35.4	23.2		0.57	0.5	0.5	0.06	0.07
Lamp, Table	41.7	13.4		0.91	1	1	0.14	0.17
Monitor								
CRT	70.6	64.2	45.9	2.6	0.21	0.23	0.05	0.07
LCD	34.2	26.4	6.19	0.88	0.99	1.07	0.11	0.15
Printing/Imaging								
Laser MFD	75.7	26.1	5.44	5.45	0.01	0.01	0.00	0.00
Inkjet MFD	26.0	11.1		4.66	0.04	0.04	0.00	0.00
Laser printer	130.1	19.0		11.4	0.26	0.26	0.11	0.14
Inkjet printer	64.0	6.75	4.68	2.69	0.24	0.2	0.05	0.05
Wide Format Printer	86.8	28.6		5.62	0.048	0.04	0.01	0.01
Document Scanner	10.1			4.03	0.05	0.05	0.00	0.00
Audio /video								
Television, LCD	58.2			3.14	0.04	0.04	0.01	0.01
DVD player	80.0			1.28	0.02	0.04	0.01	0.01
Video Projector	181.9		9.76	4.56	0.02	0.04	0.01	0.03
Speakers	32.0	10	3	1	0.04	0.08	0.00	0.01
Subwoofer	200.0	6.96			0	0.01	0.00	0.01
CD Player	8.3			2.06	0	0.02	0.00	0.00
Computer Speakers	6.0	2.43		1.66	1	1	0.02	0.02
Portable Stereo	7.5	3.31		0.88	0.02	0.01	0.00	0.00
Portable CD player	18.0	2.95		1.27	0.02	0.01	0.00	0.00
Table Radio	2.8			1.4	0.2	0.2	0.00	0.00
Other								
Adding machine	3.6	3.57		1.58	0.04	0.04	0.00	0.00
Shredder	78			0.77	0.04	0.02	0.01	0.01
Stapler	2	0.81		1.22	0.04	0.02	0.00	0.00

Typewriter, Electric	7			3.38	0.02	0.02	0.00	0.00
Fan, portable	30			0.63	0.1	0.2	0.01	0.03
Space heater, portable	938			1.03	0.1	0.2	0.31	0.78
Kitchen Appliance								
Coffee Grinder	120.0	1.25		0.21	0.2	0.01	0.08	0.01
Coffee Maker	464	40.3		1.77	0.1	0.01	0.15	0.02
Toaster oven	1058			0.03	0.04	0.02	0.14	0.09
Microwave oven	1620			3	0.08	0.02	0.06	0.14
Water dispenser	90			1	0.08	0.01	0.00	0.00
Vending machine	205			1	0.04	0.01	0.00	0.01
Hot beverage dispenser	1650			75	0	0.01	0.03	0.07

Figure 3 Plug Load Power States and Typical Installation Density

4.2 Market Assessment

The goal of the market study was to demonstrate feasibility and product availability of the proposed task lighting control and plug load control requirements. The market study also provided information to develop baseline designs for the cost analysis. Different levels of controls were investigated to test the stringency level of code requirements that can still be cost effectively achieved.

4.2.1 Plug Load Control Standards

Both ASHRAE 90.1 and International Green Construction Code (IgCC) have adopted codes for plug load controls. The ASHRAE 90.1 Lighting Subcommittee developed a CMP to 90.1-2007, modifying Addendum "bs" section 8.4.2, labelled "Automatic Receptacle Control". The IgCC technical requirement was developed in the framework of soft-wire control technologies such as timer or occupancy sensor on plug strips or smart strips rather than hard wiring control technologies.

Code language for both organizations can be found in Appendix I: ASHRAE and IgCC Plug Load Control Standards.

4.2.2 Control Products

In general, electrical circuits dedicated to task lighting and other plug loads can be shut off in the same way as general lighting shut off controls. Some manufacturers already promote lighting control products for plug load controls to respond to the growing market demand for reduced plug load energy consumption. Electrical designers, contractors, building managers, and building officials are familiar with the design, installation, and operation of circuit controls due to various existing lighting control code requirements. Hence, there are no infrastructure or market or behavior barriers to expand lighting controls to task lighting and plug load circuits/receptacles.

Similar to general lighting controls, task lighting and plug load receptacle controls can be achieved with time switch and occupancy sensor controls technologies. Manually override can be achieved with the same type of dry contact signal or even using the same override switches. The following sections describe control products that are widely available and are commonly used to demonstrate feasibility and product availability. Lists of commercial products are intended as examples of available products. The CASE study does not suggest they are the only ones capable of achieving the proposed control requirements.

Time Switch Control Products

Time switch controls can be achieved with lighting control panels or controllable breaker panels. These control panels are usually centrally located to serve a large zone of the building. Therefore, the CASE study also refers to the control technology as the central timer control, although other non-central control products can also achieve the same function.

Lighting Control Panels

Lighting control panels essentially use relays to switch on and off 120V or 277V lighting circuits. Most manufacturers indicated that they can be used to control plug load circuits, which are 120V. These relays can be controlled by an astronomical timer clock, building management system signal, occupancy sensors or other inputs. Most control panels currently on the market are compatible with BACNet, LonWorks, DMX512, and other building management communication protocols. They all come with manual override to ensure services can be provided whenever needed, and most of them are Title 24 compliant certified. These panels usually come in three sizes, the most common sizes being 8, 30 and 48 channels. Therefore, the number of circuits that can be controlled by one panel ranges from 8 to 48. Many buildings required more than one control panels. In this case, panels can be networked, with only one logic controller for the whole network to avoid controller logic redundancy and to reduce system cost. The number of panels allowed in a network varies from 10 to 128 depending on the manufacturer and the product line. Most of the products can deal with 120V and 277V mixed loads and hence control overhead lighting and plug control at the same time, using a voltage barrier, which is usually a plastic plate to separate 120V and 277V circuits. Task lighting and plug load control can be implemented by increasing the number of relays in the existing overhead lighting control panel.

Controllable Breaker Panels

Controllable breaker panels integrate circuit breakers for power surge protection and switch control into one panel, so the system demands less space for installation. A controllable breaker panel can have mixed number of controlled and uncontrolled channels. Usually, the number of controlled breakers in a panel comes in multiples of four. The number of circuits in a panel ranges from to 4 to 42, the usual panel size being 18, 30 and 42 circuits. Like lighting control panels, they are compatible with BACNet, LonWorks, DMX512, and other common building management communication protocols. They have manual overrides and take the same dry contact signal inputs as lighting control panels. They also can be networked to support a large building or space. The number of panels in a network can go up to 12, with 8 being the average. Some controllable breaker panels can accept mixed loads (120V and 277V). Depending on configuration of general lighting controls, task lighting and plug load control can be implemented by upgrade a regular breaker panel to a controllable breaker panel or by increasing the number of controllable breakers in an existing breaker panel.

Figure 4 lists a sample of both types of control panels to demonstrate product availability.

Product Type	Manufacturer	Model
Lighting Control Panel	Intelligent Lighting Control	Light Master
	Leviton	e EZMax / ZMax
	Lighting Control and Design	GR2400 Quintessence
	Lightholier/Philips	LyteSwitch
	Lutron	LCP128
	Siemens	LCP3000EZ System
	Wattstopper	Lighting Integrator
Controllable Breaker Panel	Cutler Hammer	Power-R-Command
	Lighting Control and design	GR2400 SmartBreaker
	Lutron	XPS
	Schneider Square D	PowerLink
	Siemens	I-3 Control Technology P1 series
	Synergy lighting control	Synergy Controllable Breaker Panel

Figure 4 Examples of Lighting Control and Controllable Breaker Panels

Occupancy Sensor Controls

Occupancy sensor controls have been widely used for general lighting controls. There are no technical barriers to applying this technology to controlled receptacles in the same fashion for general lighting controls.

Most of high-voltage wall occupancy switches are single-pole based. When an occupancy sensor control is already required to control 270V overhead lights, per 2008 Title 24 requirements, such as in private offices and conference rooms, there are three options to accommodate occupancy sensor control of 120V controlled receptacles:

- Add additional high-voltage single-pole occupancy wall switches for the controlled receptacles
- Use a high-voltage 2-pole occupancy sensor, e.g. SensorSwitch WSD-2P-I, with one pole for general lighting and one pole for controlled receptacles
- Use a low-voltage occupancy sensor, but separate relays, for general lighting and controlled receptacles

The cost analysis considered all these options.

Figure 5 lists manufacturers and models of occupancy sensor controls. For occupancy sensor control in open-space with cubicles, the occupancy sensor needs to be mounted on the cubicle furniture, preferably under the desk. Most of occupancy sensors are designed for wall mount and may not be suitable for cubicle furniture mounting. Some cubicle furniture, e.g. Herman Miller and Haworth, already make furniture that includes occupancy sensor controls. They are not considered in the cost analysis as a Title 24 compliance option.

Product Type	Manufacturer	Product Name
High-voltage Wall Occupancy Switch	Cooper Controls Greengate	OMC-P-0450-R
	Enerlites	WOSS15-W
	Heath Zenith Lighting	SL-6107-WH
	Leviton	OSC04-I0W
	Lutron	LOS-CIR-450-WH
	SensorSwitch	CM-9, WSD-2P-I (2-Pole)
	Wattstopper	PW100I
Low-voltage Occupancy Sensor with Relay Box	Legrand Wiremold	Convia
	Lutron	Maestro Wireless
	Wattstopper	Room Controller

Figure 5 Examples of Occupancy Sensor Controls

4.2.3 Level of Controls

Occupancy sensor controls have finer granularity of controls than timer controls as they can capture more time periods when controlled plug loads can switched off. It is, therefore, desirable to use occupancy sensors to control all task lighting and plug loads. The CASE study considered three levels of control, with increased use of occupancy sensor controls, to test the maximum level of occupancy sensor controls that can be feasibly and cost-effectively achieved. The three levels of controls are:

- **Level 1**: No occupancy sensor controls. Central timer controls are used for all controlled receptacles.
- **Level 2**: Occupancy sensor controls are used for controlled receptacles in private offices and conference rooms; central timer controls are used for controlled receptacles in all other spaces including open-space workstations, kitchens, and copy rooms
- **Level 3**: Occupancy sensor controls are used for controlled receptacles located in all building spaces except those in kitchens and copy rooms.

The proposed Level 2 requirements are very similar to 2008 Title 24 shut off control requirements for general lightings. The difference is that the occupancy sensor controls are not applied to kitchens and copy rooms for plug load controls. Certain appliances, such as coffee maker and printers, need to operate without the presence of any occupant. Using occupancy sensor control would lead occupants to plug those appliances into uncontrolled receptacles, which would therefore never be controlled.

4.2.4 Task Lighting and Plug Load Circuit Wiring

The proposed task lighting and plug load controls would require independent circuits to be connected to controlled and uncontrolled receptacles. This may or may not affect building circuit wiring, depending on the control technologies and existing wiring practices. The CASE study evaluated the impact of industry practices on cost and Title 24 compliance.

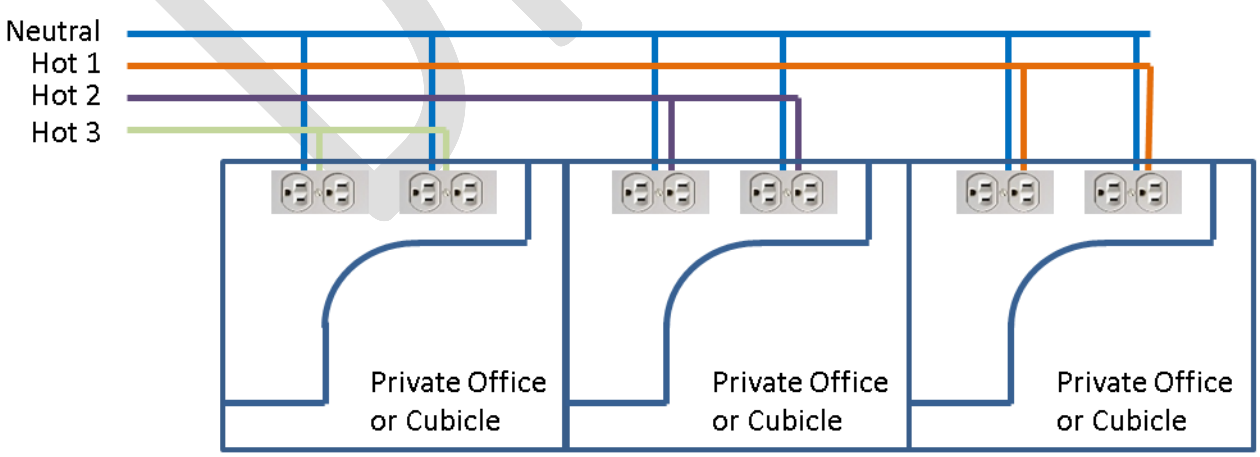
There are two practices regarding general office electrical wiring. One consists of laying out one circuit at a time from the 3-circuits in-feed. The first circuit is laid out in one space, and the next circuit is used to serve the next space. The other practice entails laying out the 3 circuits at the same time. In this case, the 3 circuits will be used to feed the space receptacle

One building 3-circuit in-feed usually serves a group of 4 cubicles, but can serve go up to 8 cubicles depending on the workstation type. Within the system furniture, three to four separate circuits are commonly laid.

Occupancy sensor controls are installed locally. An electric circuit can be split into two branches locally with one branch been controlled by the local occupancy sensor and connected to receptacles marked as controlled, while the other is serving uncontrolled receptacles. More often, multiple circuits are supplied to a workstation or other office spaces, as it is a preferred practice. In this case, one or two circuits can be dedicated to task lighting and other controllable plug loads and will be controlled by an occupancy sensor.

For central timer controls, controlled and uncontrolled circuits need to be separated at the central control panel. Hence, dual circuits are required for all spaces where controlled receptacles are required. According to the industry survey to described in Appendix II: Industry Practice Survey, dual circuit wiring layout is the preferred practice for system reliability and is already used in 46% of office building projects. All system furniture (cubicle) products accommodate multiple circuit inputs and are equipped with receptacles with color-coding to differentiate connected circuits. Contractors are required to clearly mark breakers for each circuit. It requires little additional efforts for electric designers and contractors to mark controlled circuits and make sure they are connected to proper control channels. This is especially true when controllable breaker panels are used. If connection mistakes are made, they can be corrected at the control panel. Therefore, dual circuit wiring does not present any implementation issue according to interviewed electrical designers, contractors and system furniture manufacturers.

Even for single circuit wiring designs, where each workstation is supply with only one circuit to reduce overall wiring cost, the proposed code change will only have minor impact on wiring cost. Figure 6 demonstrates that a wise wiring layout achieves dual circuit design with only a very slight increase of the circuit wiring length.



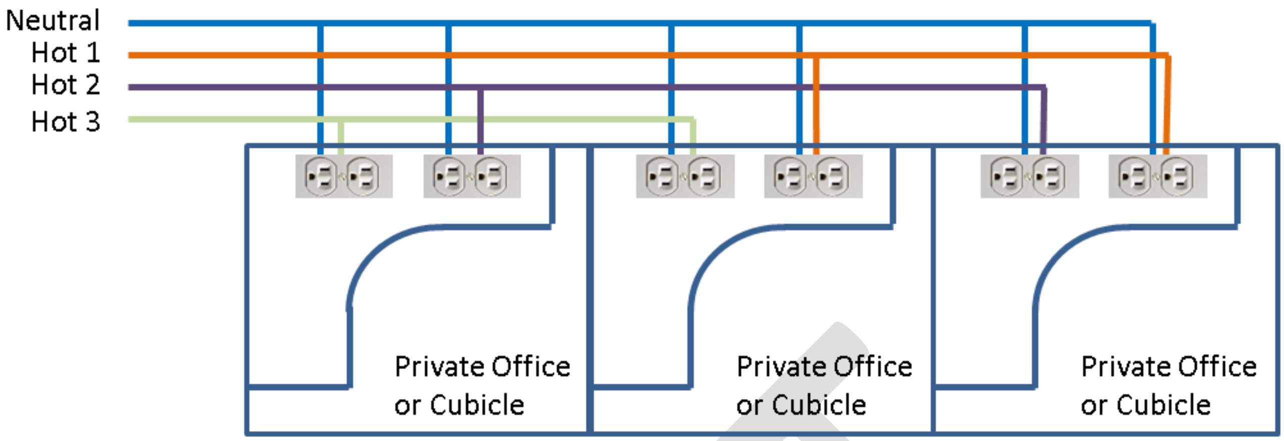


Figure 6 Single circuit (top) versus double circuit (bottom) wiring practice

New construction office buildings may be finished without installation of workstation furniture, which will be added later as part of the tenant improvement (TI) project, possibly along with installation/improvement of overhead lightings. In this case, circuits for workstations will not be connected to any receptacles. For the Title 24 compliance consideration, the proposed code change would require that all unconnected circuits have to be marked to differentiate controlled circuits from uncontrolled one to allow inspection and proper future installation. Local building department may impose inspection during and after TI projects and installation of controlled receptacles can be inspected accordingly.

The number of control channels depends on the number of controlled circuits, which, in turn, are determined by the total power of office task lighting and other controllable plug loads. In general, a 20A circuit can serve plug loads of 2-4 workstations, depending on the expected amount of office equipment installed at each workstation. For cost analysis, the CASE study considered this range of possibility to come up with low and high estimates of control panel upgrade requirements.

4.3 Prototype Buildings Development

The CASE study developed prototypes of small and large office buildings based on the Database for Energy Efficient Resources (DEER). The detailed space layouts are provided in Appendix III: Office Building Prototypes.

The DEER small office building prototype has two stories, with a rectangular footprint (50ft×100ft) and total floor area of 10,000 sf. The building was estimated to have thirty three (33) occupants with nine (9) private offices and one conference room on each floor.

The DEER large office building prototype has ten stories, 175,000 sf building, with a rectangular footprint (175ft×100ft) and total floor area of 175,000 sf. It was estimated there were seven hundred and thirty (730) occupants working in this building. All floors have a similar layout, which includes 19 private offices, 54 cubicles, 2 conference rooms, 2 copy rooms, kitchen and restrooms.

	Type	Area (Square Feet)	Number of Stories
Prototype 1	Small Office	10,000	2
Prototype 2	Large Office	175,000	10

Figure 7 Office Building Prototype Summary

4.4 Energy Savings Analysis

The analysis goal is to provide energy savings estimate for the three levels of task lighting and plug load controls for both prototype office buildings. The general analysis methodology is explained in Section 3.3.

Following sections provide detailed description of data sources and assumptions used for three major components needed for energy savings calculation:

- Controllable plug load density
- Control schedule
- Controllable plug load power status

4.4.1 Energy Savings Analysis Assumptions

Controllable Plug Load Density

Controllable plug loads definition and installation density were discussed in details in 4.1 Task Lighting and Plug Load Characteristics Study. The results are presented in Figure 2 and Figure 3, respectively.

Control Schedule

Office business hours are based on general office working schedules. For private office and open-space cubicle, the CASE team considered average away-from-desk time for events such as lunch break, meetings, early leave, etc., and out-of-office time for events such as vacation, sick leave, business travels, work at home, jury duty, and other personal leaves. For conference room occupancy, assumptions were made on the average unoccupied hours during business hours. Figure 8 lists all assumptions of office operation schedules and occupant working schedules.

Plug Load Power Status

The LBNL Study and ECOS Study are the only data sources that provide relative comprehensive usage pattern statistics of task lighting and plug loads. The LBNL Study measured nighttime operation status of computer and office printing equipment. The ECOS Study provided averaged daily usage statistics for all plug loads. Based on the two studies, the CASE team developed power state statistics for each controllable plug load during three control periods (also referred as control schedule in this report): non-business hours, business hours with the occupant away from desk, and empty conference room during business hours. The latter is applicable to controllable plug load in conference rooms. The results are shown in Figure 9, Figure 10 and Figure 11. The percentages in these figures represent probability that a plug load staying at a corresponding power state. Plug load power state statistics during out-of-office hours was assumed to be same as those during non-business hours.

Annual Office Hours	
Number of weekend days	104
Number of holiday	10
Number of business days	251
Average business hours/day	12
Business hours	3012
Non-business Hours (Timer control hours)	5748
Annual Private Office/Work Station Hours	
Number of vacation days	15
Number of sick/personal leave days	8
Number of business travel/work-at-home days	5
Annual in-office days	223
Annual out-of-office hours	336
Average hour in office per day	9
Average lunch/break hours/day	1
Average away-from-desk meeting hours/day	1
Annual away-from-desk hours	1115
Annual OC controlled hours	1451
Annual Conference Room Hours	
Average occupied hours per day	5
Annual un-occupied hours during business hours	1757

Figure 8 Office Operation and Occupant Working Schedule Assumptions

The detailed calculation formulas are as following:

The average power of a controllable plug load, *i*, is the average of its power states, weighted by the probabilities of power states.

$$Average\_Power_{i,j} = \sum_{PS} Power_{i,PS} \times PS\_Probability_{i,PS,j}$$

PS = {Active, idle, sleep, standby}

The probabilities depend on following control schedule, *j*:

1. Non-Business hours

Business hours, the occupant is away from desk;

Business hours, the occupant is out of office

Business hours, empty Conference room (for conference room plug loads only)

Figure 9, Figure 10, and Figure 11 provide power state probabilities for all relevant plug load at the four control schedules. A central time control only has scenario 1, while an occupant control has all control scenarios.

The total power linked to a control, *k*, is the sum of power from all connected plug load. This is the amount of power reduction that can be achieved by the corresponding control, a central control panel or an occupancy senor.

$$Power\_Reduction_{j,k} = \sum_{i} Average\_Power_{i,j} \times Number\_of\_Connected\_Load_{i,k}$$

Then, hourly energy savings were estimated based on office operation schedule provided in Figure 8.

During non-business hours, energy savings are achieved for every hour. The corresponding building energy savings (kWh) at each non-business hour are:

$$Savings_{non-busi\_hour} = \sum_{k=all\ control} \sum_{j=non-business\ hour} Power\_Reduction_{j,k}$$

For occupancy sensor controls, additional savings can be achieved during the three business hour control scenarios. The office operation schedule shown in Figure 8 provides total number of hours for each control scenario. We assumed that they were evenly distributed among the range of business hours, with the exception that lunch hours were assumed to only from 12pm to 1pm. This approach provided probabilities of circuit shut off, $P\_Shutoff_{j,k}$, at each business hour. The corresponding total building energy savings are:

$$Savings_{busi\_hour} = \sum_{k=all\ oc\ sensor} \sum_{j=\ business\ hour\ scenarios} Power\_Reduction_{j,k} \times P\_Shutoff_{j,k}$$

For both central timer control and occupancy sensor controls, personal fans and heaters were assumed to be used in summer and winter months, respectively.

Plug Load	Active	Idle	Sleep	Standby	Disconnect
Task Lighting					
Lamp, Desk attachment	5%	0%	0%	5%	90%
Lamp, Table	5%	0%	0%	2%	93%
Monitor					
CRT	10%	15%	0%	35%	40%
LCD	10%	15%	0%	35%	40%
Printing/Imaging Equipment					
Laser MFD	0%	28%	0%	45%	27%
Inkjet MFD	0%	28%	0%	70%	2%
Laser printer	0%	35%	0%	45%	20%
Inkjet printer	0%	0%	0%	60%	40%
Wide Format Printer	0%	0%	0%	75%	25%
Document Scanner	0%	0%	0%	95%	5%
Audio /video					
Television, LCD	0%	0%	0%	34%	66%
DVD player	0%	0%	0%	100%	0%
Video Projector	0%	0%	5%	64%	31%
Speakers	0%	37%	2%	40%	21%
Subwoofer	0%	100%	0%	0%	0%
CD Player	0%	0%	0%	95%	5%
Computer Speakers	0%	90%	0%	4%	6%
Portable Stereo	0%	5%	0%	86%	9%
Portable CD player	0%	8%	0%	75%	17%
Table Radio	0%	0%	0%	84%	16%
Other					
Adding machine	0%	40%	0%	37%	23%
Shredder	0%	0%	0%	60%	40%
Stapler	0%	48%	0%	50%	2%
Typewriter, Electric	0%	44%	0%	50%	6%
Fan, portable	0%	0%	0%	80%	20%
Space heater, portable	0%	0%	0%	99%	1%

Kitchen Appliance					
Coffee Grinder	0%	45%	0%	25%	30%
Coffee Maker	0%	0%	0%	80%	20%
Toaster oven	0%	0%	0%	33%	67%
Microwave oven	0%	0%	0%	100%	0%
Water dispenser	5%	0%	0%	95%	0%
Vending machine	0%	0%	0%	100%	0%
Hot beverage dispenser	0%	0%	0%	100%	0%

Figure 9 Probability of Plug Load Power States –Non-Business Hours

Plug Load	**Active**	**Idle**	**Sleep**	**Standby**	**Disconnect**
Task Lighting					
Lamp, Desk attachment	49%	0%		20%	32%
Lamp, Table	33%	0%		14%	55%
Monitor					
CRT	55%	15%	15%	15%	0%
LCD	55%	15%	15%	15%	0%
Audio /video					
Computer Speakers	4%	87%	0%	4%	5%
Portable Stereo	9%	22%		86%	
Portable CD player	15%	11%		75%	0%
Table Radio	47%			84%	
Other					
Fan, portable	3%			80%	17%
Space heater, portable	3%			99%	

Figure 10 Probability of Plug Load Power States –Away-from-desk

Greyed rows indicated that the corresponding plug loads are not controlled

Plug Load	Active	Idle	Sleep	Standby	Disconnect
Audio /video					
Television, LCD	47%			34%	19%
DVD player				100%	
Video Projector	17%		5%	64%	14%
Speakers	20%	37%	2%	40%	1%
Subwoofer		100%			
CD Player	15%			95%	

Figure 11 Probability of Plug Load Power States – Empty Conference Room

4.4.2 Energy Savings Analysis Results

An EXCEL spreadsheet was developed to performance energy savings analysis based on the algorithms described above. Figure 12 and Figure 13 present life cycle TDV savings benefits and annual TDV energy savings, respectively for each three levels of control. Savings variation among sixteen (16) climate zones is due TDV value differences.

Statewide energy savings were estimated by multiplying these values by office building new construction forecast for 2013 provided by the CEC. The results are summarized in Figure 14.

	Small Office			Large Office		
Climate Zone	**Level 1**	**Level 2**	**Level 3**	**Level 1**	**Level 2**	**Level 3**
1	$0.71	$0.86	$0.98	$0.94	$1.05	$1.32
2	$0.73	$0.87	$0.98	$0.97	$1.07	$1.31
3	$0.75	$0.89	$0.99	$1.00	$1.10	$1.33
4	$0.79	$0.92	$1.02	$1.06	$1.15	$1.36
5	$0.82	$0.93	$1.03	$1.09	$1.17	$1.38
6	$0.83	$0.94	$1.03	$1.11	$1.18	$1.38
7	$0.87	$0.97	$1.06	$1.15	$1.23	$1.42
8	$0.86	$0.96	$1.05	$1.15	$1.22	$1.40
9	$0.87	$0.96	$1.04	$1.15	$1.22	$1.40
10	$0.86	$0.96	$1.04	$1.15	$1.22	$1.39
11	$0.86	$0.97	$1.05	$1.15	$1.22	$1.40
12	$0.85	$0.96	$1.04	$1.13	$1.21	$1.40
13	$0.83	$0.94	$1.04	$1.11	$1.19	$1.39
14	$0.80	$0.92	$1.01	$1.07	$1.15	$1.36
15	$0.77	$0.90	$1.00	$1.02	$1.11	$1.34
16	$0.74	$0.88	$0.99	$0.98	$1.08	$1.32

Figure 12 Present Values of Life Cycle Energy Savings ($/sf)

	Small Office			Large Office		
Climate Zone	**Level 1**	**Level 2**	**Level 3**	**Level 1**	**Level 2**	**Level 3**
1	7.96	9.67	11.03	10.61	11.82	14.81
2	8.18	9.73	10.97	10.90	12.00	14.72
3	8.46	9.95	11.14	11.26	12.33	14.95
4	8.93	10.31	11.41	11.89	12.88	15.30
5	9.16	10.48	11.55	12.20	13.14	15.48
6	9.33	10.58	11.58	12.42	13.31	15.52
7	9.73	10.94	11.91	12.95	13.82	15.96
8	9.71	10.84	11.75	12.93	13.74	15.74
9	9.73	10.83	11.71	12.95	13.74	15.68
10	9.70	10.81	11.69	12.91	13.71	15.66
11	9.69	10.85	11.78	12.90	13.73	15.78
12	9.55	10.76	11.73	12.72	13.58	15.71
13	9.35	10.61	11.63	12.45	13.35	15.58
14	8.99	10.32	11.40	11.97	12.92	15.27
15	8.64	10.07	11.22	11.50	12.53	15.05
16	8.28	9.83	11.08	11.03	12.13	14.87

Figure 13 Annual TDV Energy Savings (kBtu/sf/yr)

	Small Office			**Large Office**			**Statewide Energy Savings**	
	kWh/sf/yr	MW/sf	NC Floor Area (Msf)	kWh/sf/yr	MW/sf	NC Floor Area (Msf)	GWh	MW
Level 1	0.42	0		0.56	0		17.09	0
Level 2	0.49	0.197	8.5	0.61	0.236	24.2	18.93	4.94
Level 3	0.55	0.356		0.74	0.839		22.46	14.62

Figure 14 Statewide Energy Savings

4.5 Cost Analysis

The proposed code changes involve two types of control strategies, time switch control and occupancy sensor control. The three levels of control defined in section 4.2.3 build on different combinations of the two control technologies. The following section presents baseline and compliance options using the two control technologies and the incremental costs of the three levels of controls.

4.5.1 Baselines and Compliance Options

Time Switch Control

For time switch control, the baseline in term of existing overhead lighting controls was developed assuming the common practice of using either central lighting control panels or central controllable breaker panels to control general lighting , per 2008 Title 24 requirements. The CASE team considered four baseline designs with different configurations of circuit breaker panels and lighting control panels. These configurations consider that overhead lighting can be on 277V circuits and task lighting and other plug loads are on 120V circuits. Therefore, separate breaker panels are usually needed to host the two sets of circuits. The following diagrams and tables present the four baseline designs and their corresponding upgrade options for tasking lighting and plug load controls.

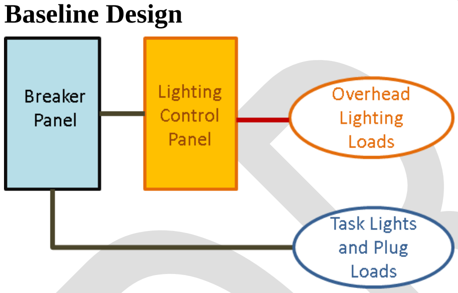
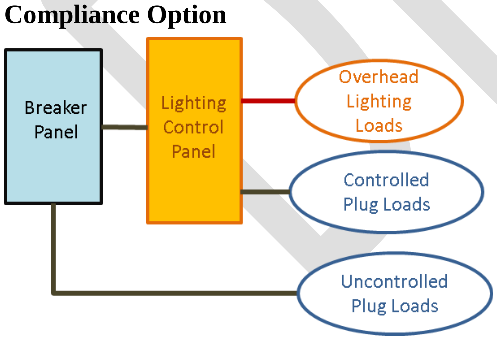
Design A	**Breaker Panel**	**Lighting Control Panel**
Baseline Design 	A single 120V breaker panel for both general lighting and plug loads.	A lighting control panel for overhead lighting (120V)
Compliance Option 	No Change	Increase number of control channels to accommodate controlled plug load circuits; potentially a large panel is needed

Figure 15 Central Timer Control Baseline and Compliance Options – Design A

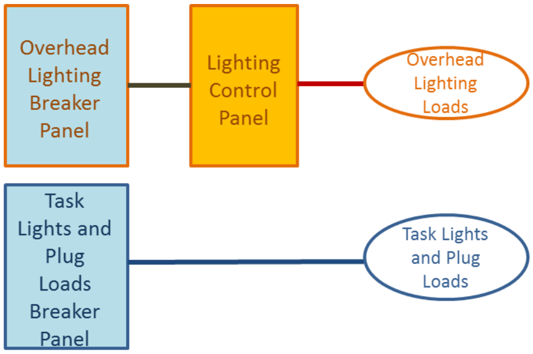
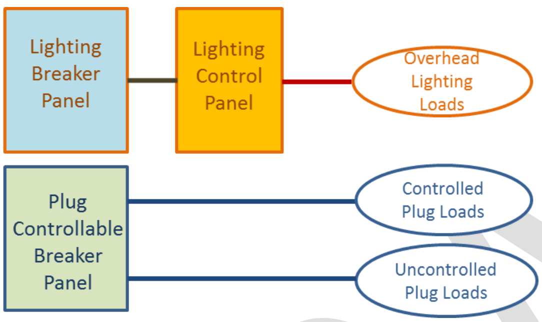
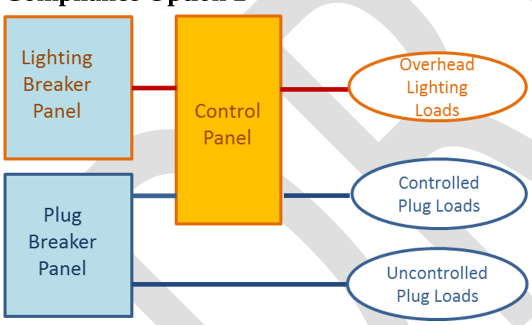
<table>
<tr><th>Design B</th><th>Breaker Panel</th><th>Lighting Control Panel</th></tr>
<tr><td>Baseline Design

</td><td>Separate breaker panels for overhead lighting and plug loads, including task lighting; overhead lighting could be 120V or 277V</td><td>A lighting control panel for overhead lighting (120V or 277V)</td></tr>
<tr><td>Compliance Option 1

</td><td>Upgrade the regular breakers to a controllable breaker panel; only control circuits serving controlled receptacles</td><td>No change</td></tr>
<tr><td>Compliance Option 2

</td><td>No change</td><td>Increase number of control channels to accommodate controlled plug load circuits; potentially a large panel is needed; a voltage barrier is needed if overhead light and plug loads have different voltage</td></tr>
</table>

Figure 16 Central Timer Control Baseline and Compliance Options – Design B

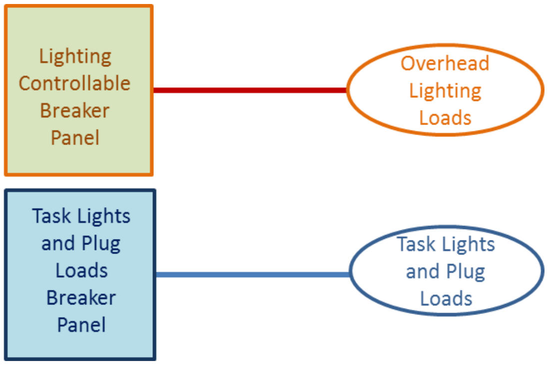
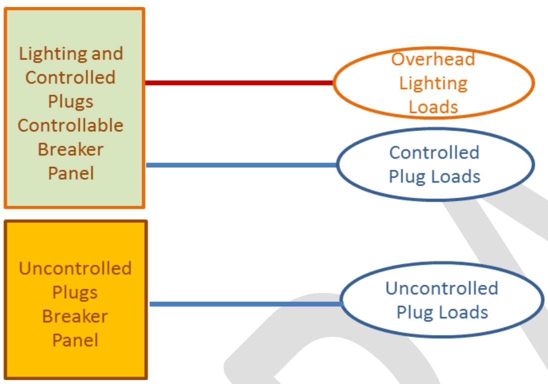
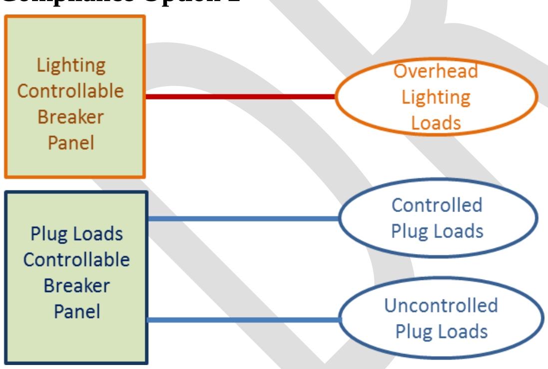
Design C	**Breaker Panel**	**Lighting Control Panel**
Baseline Design 	Separate breaker panels for overhead lighting and plug loads; the breaker panel for overhead lighting is controllable, 120V or 277V	None
Compliance Option 1 	Use a larger controller breaker panel for both overhead lighting and plug load	No change
Compliance Option 2 	Upgrade the break panel for plug loads to be a controllable breaker panel	No change

Figure 17 Central Timer Control Baseline and Compliance Options – Design C

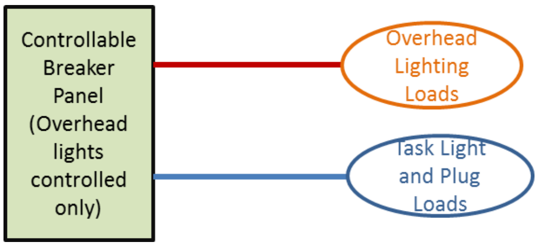
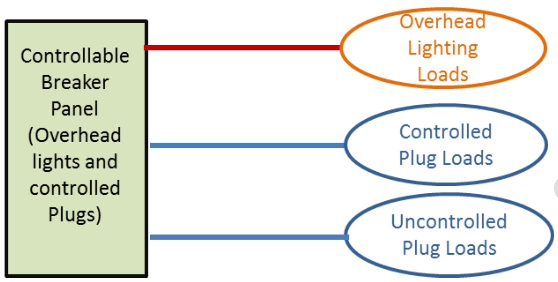
Design D	Breaker Panel	Lighting Control Panel
Baseline Design 	One controllable breaker panel for both overhead lighting and plug loads; only overhead lighting circuits are controlled	None
Compliance Option 	Upgrade circuit channels for controlled receptacles to be controllable	No change

Figure 18 Central Timer Control Baseline and Compliance Options – Design D

Industry practice survey indicated that the dual circuit wiring design, which brings at least two independent circuits into workstations, represents 46% of the market practice. Hence, the baseline is a weighted average of dual circuit wiring and single circuit wiring. The cost for upgrading to a dual circuit design was estimated for the two office building prototypes based on the method described in section 4.2.4.

Occupancy Sensor Control

For occupancy sensor controls, the baselines for existing overhead lighting control are based on the 2008 Title 24 requirement of occupancy sensor shut off controls for general lighting in office spaces less than 250 sf which effectively covers private offices, and in conference rooms. System upgrades needed for meeting the proposed changes are:

- When a **high**-voltage occupancy sensor is used for 2008 Title 24 compliance, another high-voltage occupancy sensor is installed to support controlled receptacles.
- When a **low**-voltage occupancy sensor is used for 2008 Title 24 compliance, the corresponding lighting control or relay box needs to be upgraded to include an additional channel to support controlled receptacles.

The two scenarios above are illustrated in Figure 19. For the first scenario, a 2-pole occupancy sensor can be used to support both general lighting and task lighting shut off controls. The cost would be slightly lower. Since the majority of high-voltage occupancy sensors are single pole based, the use of 2-pole occupancy sensor was not included for cost analysis.

For open-space workstations, there is no baseline for control requirements. The proposed changes, as in the level 3 control, can be met by installing a high-voltage occupancy sensor located under the desk.

Occupancy sensor controls do not require dual circuit wiring from breaker panels. The incoming circuit can be split locally to support both controlled and uncontrolled receptacles.

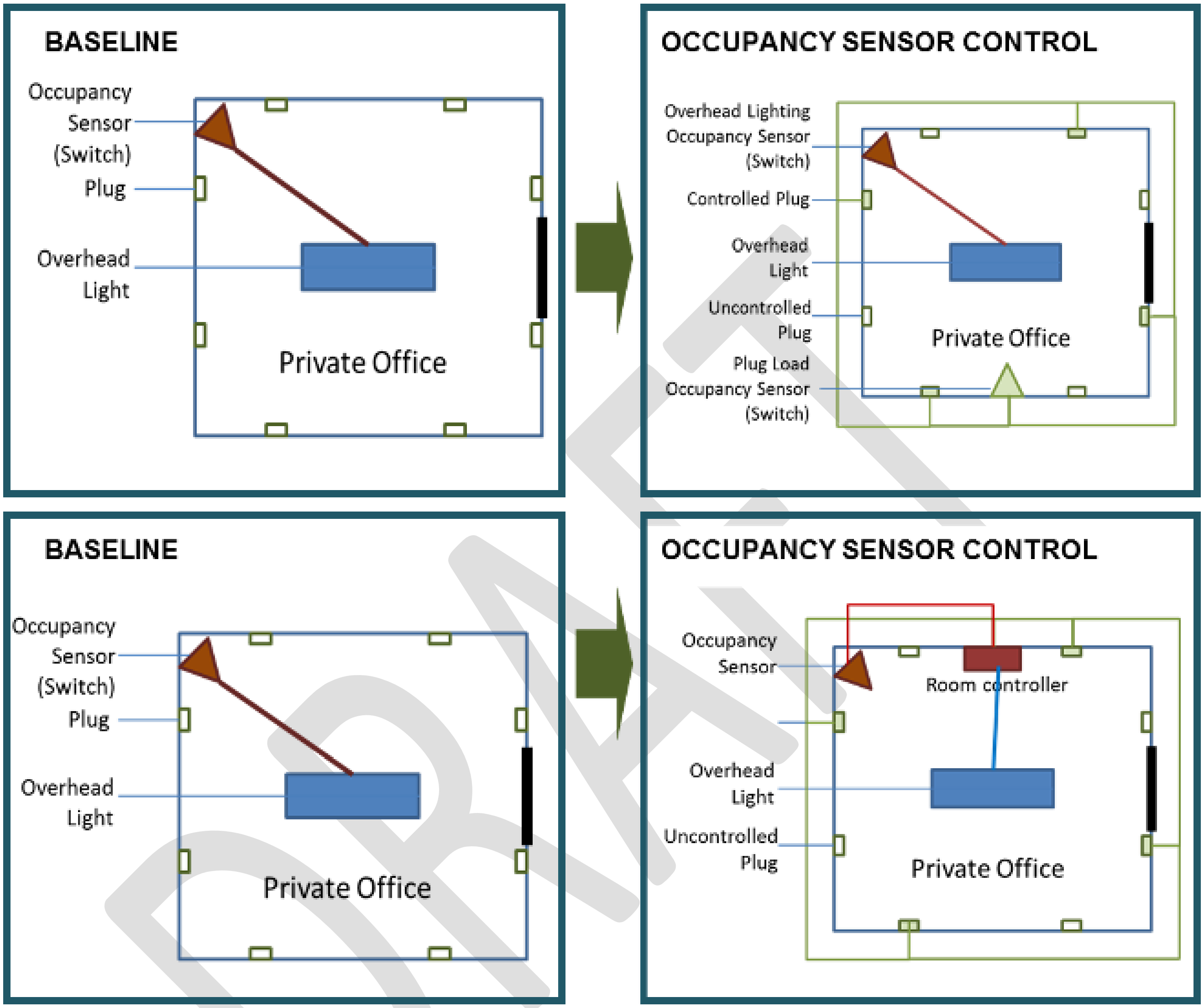


Figure 19 Baselines and Compliance Options for Occupancy Sensor Controls (top: high-voltage; bottom: low-voltage)

4.5.2 Incremental Cost of Three Levels of Controls

The section provides detailed incremental cost estimation for the three levels of task lighting and plug load controls, as described in section 4.2.3.

First, the general electric systems for both the small and large office building prototypes were assessed. The small office was assumed to have a central location for control panel on each floor, with the first floor hosting the master panel with the controller logics networked to the second floor. The large office building had to have two control panel locations on each floor, due to the 120-ft maximum wiring length limitation used by the industry to prevent excessive voltage drop. Two master control panels were used to serve two control-panel networks, one for each side of the building so network wiring can be easily routed along vertical electrical shafts.

Second, the total number of circuits for overhead lighting, task lighting, and other plug loads were determined based on the building configurations. This information was used to determine control panel sizes. The number of overhead lighting circuits was determined based on a lighting power density of 1.1 W/sf. The number of 120 V plug load circuits was estimated based on the office layout as well as on electric system design practices. The analysis considered two levels of assumption of number of circuits used to serve each space type, as shown in Figure 20, to cover the range of possible design practices.

Load Type	Space Type	More Circuits	Less Circuits
Task Lighting and Other Plug Loads	Private Office	1 circuit/private office	1/2 circuit/private office
	Open Space Cubicle	½ circuit/cubicle	¼ circuit/cubicle
	Copy Room	1 circuit/copy room	
	Lobby, Corridor	1 circuit	
	Kitchen	2 circuits/kitchen	
	Mechanical Room	2 circuits/mechanical room	
Overhead Lighting	Overhead lighting	1.1 W/sf LPD, 3 amp/circuit	1.1 W/sf LPD, 4 amp/circuit

Figure 20 Number of Circuits per Space Type

A 20% extra capacity was used for panel sizing to accommodate for future expansion, as commonly done.

Third, the total incremental costs were estimated based on system upgrade requirements as described in the prior section for each baseline design case. Figure 21 provides costs of central control panels for several standard sizes, obtained from manufacturer surveys. Master panels include control logics while slave panels can only receive control signals. The cost for control panel installation and configuration is assumed to be 2 hr per control panel. Wiring material and labor costs were assessed using RS Means data as 1.27 hr/ 100ft of wire. Electric contractor hourly labor rate was assumed to be 86.11 /hr. Figure 22 provides cost estimate for each occupancy sensor option.

Panel Type	Type	8 relays /breakers	24 relays /breakers	42 relays /breakers
Lighting Control Panel	**Master**	$2,305	$3,085	$3,960
	Slave	$1,495	$2,305	$3,215
Controllable Breaker Panel	**Master**	$1,090	$2765	$4,650
	Slave	$930	$2,335	$3,915

Figure 21 Central Timer Control Panel Cost

Options	**Unit Price**	**Installation Time/unit**	**Labor Cost /unit**
One High-voltage Wall Switch	$25	0.35	$ 30
One additional Relay Channel for Low-voltage Occupancy Sensor Control	$100	0.7	$ 60

Figure 22 Occupancy Sensor Control Cost

Level 1 Control Incremental Cost

This level of control requires all task lighting and plug loads to be controlled by central timer controls. The system upgrade requirements are summarized in Figure 23 for each compliance option. The additional wiring length to support dual circuit wiring is shown in Figure 24. Unit office area incremental costs are summarized in Figure 25. For an initial electric system design using minimum number of circuits, more wiring upgrade is required to support the controllable receptacle requirement. Total incremental cost also depends on incremental cost associated with control panel upgrade schedule. As shown in Figure 25, some scenarios of "Less Circuits" show slightly higher incremental cost than corresponding "More Circuits" scenarios.

Baseline	**Option**	**Small Office**		**Large Office**	
		Less Circuits	**More Circuits**	**Less Circuits**	**More Circuits**
A	**1**	Add 6 relays control panel	Add 8 relays to control panel	Add 9 relays to control panel	Add to 15 relays to control panel
B	**1**	Change task/plug loads breaker panel by controllable breaker panel			
	2	Add to 6 relays control panel	Add to 8 relays to control panel	Add to 9 relays to control panel	Add to 15 relays to control panel
C	**1**	Increase controllable breaker panel by 6 controlled breakers and 14 breakers No task/plug breaker panel	Increase controllable breaker panel by 8 controlled breakers and 16 breakers No task/plug breaker panel	Increase controllable breaker panel by 9 controlled breakers and 16 breakers No task/plug breaker panel	Increase controllable breaker panel by 15 controlled breakers and 23 breakers No task/plug breaker panel
	2	Change task/plug loads breaker panel by controllable breaker panel			
D	**1**	Replace 6 regular breakers by controllable breakers in the controllable breaker panel	Replace 8 regular breakers by controllable breakers in the controllable breaker panel	Replace 9 regular breakers by controllable breakers in the controllable breaker panel	Replace 15 regular breakers by controllable breakers in the controllable breaker panel

Figure 23 Control System Upgrade Requirement – Level 1 Control

	Small Office		Large Office	
	Less Circuits	**More Circuits**	**Less Circuits**	**More Circuits**
Additional Wiring Length (ft)	252	120	3,250	2,340

Figure 24 Additional Wiring Length for Dual Circuit Wiring Support– Level 1 Control

Baseline	**Central Timer Control Option**	**Small Office**		**Large Office**	
		Less Circuits	**More Circuits**	**Less Circuits**	**More Circuits**
A	1	$0.25	$0.26	$0.17	$0.23
B	1	$0.55	$0.55	$0.29	$0.33
	2	$0.29	$0.29	$0.18	$0.25
C	1	$0.18	$0.17	$0.12	$0.15
	2	$0.52	$0.51	$0.27	$0.31
D	1	$0.17	$0.14	$0.11	$0.14

Figure 25 System Incremental Cost – Level 1 Control ($/sf)

Level 2 Control Incremental Cost

In this control level, central timer control is used for task lights and plug loads serving open-space workstations, kitchens, and copy rooms and occupancy sensor controls are used in private offices and conference rooms. Central control panel upgrade requirements are summarized in Figure 26. Level 2 control requires less additional wiring since controllable receptacles are used in private offices. Figure 28 shows the unit are system upgrade incremental cost for each prototype. Similar to the level 1 control, when an office electric system has relatively less number of circuit, more system upgrade might be needed, therefore having a higher incremental cost.

Baseline	Option	Small Office		Large Office	
		Less Circuits	More Circuits	Less Circuits	More Circuits
A	1	Add 1 relay control panel	Add 3 relays to control panel	Add 5 relays to control panel	Add 9 relays to control panel
B	1	Change task/plug loads breaker panel by controllable breaker panel			
	2	Add 1 relay control panel	Add 3 relays to control panel	Add 5 relays to control panel	Add 9 relays to control panel
C	1	Increase controllable breaker panel by 1 controlled breaker and 17 breakers No task/plug breaker panel	Increase controllable breaker panel by 3 controlled breakers and 23 breakers No task/plug breaker panel	Increase controllable breaker panel by 5 controlled breakers and 21 breakers No task/plug breaker panel	Increase controllable breaker panel by 9 controlled breakers and 29 breakers No task/plug breaker panel
	2	Change task/plug loads breaker panel by controllable breaker panel			
D	1	Replace 2 regular breakers by controllable breakers in the controllable breaker panel	Replace 3 regular breakers by controllable breakers in the controllable breaker panel	Replace 8 regular breakers by controllable breakers in the controllable breaker panel	Replace 9 regular breakers by controllable breakers in the controllable breaker panel

Figure 26 Control System Upgrade Requirement – Level 2 Control

	Small Office		Large Office	
	Less Circuits	More Circuits	Less Circuits	More Circuits
Additional Wiring Length (ft)	100	50	1,500	1,000

Figure 27 Additional Wiring Length for Dual Circuit Wiring Support– Level 2 Control

Baseline	**Central Timer Control Option**	**Occupancy Sensor Control Option**	**Small Office**		**Large Office**	
			Less Circuits	**More Circuits**	**Less Circuits**	**More Circuits**
A	1	Low-voltage	$0.27	$0.26	$0.18	$0.23
		High-voltage	$0.42	$0.41	$0.27	$0.32
B	1	Low-voltage	$0.64	$0.65	$0.34	$0.37
		High-voltage	$0.79	$0.80	$0.43	$0.46
	2	Low-voltage	$0.30	$0.30	$0.20	$0.24
		High-voltage	$0.45	$0.45	$0.29	$0.29
C	1	Low-voltage	$0.28	$0.28	$0.17	$0.20
		High-voltage	$0.43	$0.43	$0.26	$0.29
	2	Low-voltage	$0.61	$0.61	$0.32	$0.37
		High-voltage	$0.76	$0.76	$0.41	$0.46
D	1	Low-voltage	$0.22	$0.20	$0.13	$0.17
		High-voltage	$0.37	$0.35	$0.22	$0.26

Figure 28 System Incremental Cost – Level 2 Control ($/sf)

Level 3 Control Incremental Cost

The level 3 control requires occupancy sensor controls to be installed in private offices, open-space cubicles, and conference rooms and central timer control is applied to controllable plug loads in kitchens and copy rooms. Figure 29 shows the number of occupancy sensor controls needed for each prototype building. It is assumed that open-space cubicles will use high-voltage switch type of occupancy sensor.

Baseline	Central Timer Control Option	Occupancy Sensor Control Option	Small Office		Large Office	
			Less Circuits	More Circuits	Less Circuits	More Circuits
A	1	Low-voltage	$0.25	$0.27	$0.28	$0.29
		High-voltage	$0.40	$0.42	$0.37	$0.38
B	1	Low-voltage	$0.65	$0.67	$0.48	$0.50
		High-voltage	$0.80	$0.82	$0.57	$0.59
	2	Low-voltage	$0.27	$0.29	$0.29	$0.30
		High-voltage	$0.42	$0.44	$0.38	$0.45
C	1	Low-voltage	$0.30	$0.33	$0.32	$0.36
		High-voltage	$0.45	$0.48	$0.41	$0.45
	2	Low-voltage	$0.63	$0.66	$0.47	$0.51
		High-voltage	$0.78	$0.81	$0.56	$0.60
D	1	Low-voltage	$0.22	$0.25	$0.26	$0.27
		High-voltage	$0.37	$0.40	$0.35	$0.36

Figure 30 shows the system upgrade incremental costs per square foot for each prototype.

	Small Office		Large Office	
	High-voltage OC sensor in Private Office & Conference room	Low-voltage OC sensor in Private Office & Conference room	High-voltage OC sensor in Private Office & Conference room	Low-voltage OC sensor in Private Office & Conference room
Number of High-voltage Wall Switch	33	13	750	540
Number of Low-voltage Occupancy Sensor	0	20	0	210

Figure 29 Number of Occupancy Sensor Control – Level 3 Control

Baseline	Central Timer Control Option	Occupancy Sensor Control Option	Small Office		Large Office	
			Less Circuits	More Circuits	Less Circuits	More Circuits
A	1	Low-voltage	$0.25	$0.27	$0.28	$0.29
		High-voltage	$0.40	$0.42	$0.37	$0.38
B	1	Low-voltage	$0.65	$0.67	$0.48	$0.50
		High-voltage	$0.80	$0.82	$0.57	$0.59
	2	Low-voltage	$0.27	$0.29	$0.29	$0.30
		High-voltage	$0.42	$0.44	$0.38	$0.45
C	1	Low-voltage	$0.30	$0.33	$0.32	$0.36
		High-voltage	$0.45	$0.48	$0.41	$0.45
	2	Low-voltage	$0.63	$0.66	$0.47	$0.51
		High-voltage	$0.78	$0.81	$0.56	$0.60
D	1	Low-voltage	$0.22	$0.25	$0.26	$0.27
		High-voltage	$0.37	$0.40	$0.35	$0.36

Figure 30 System Incremental Cost – Level 3 Control ($/sf)

4.6 Cost Effectiveness Analysis

Results of energy savings and cost analysis were combined to produce LCC as defined in section 3.5. The results are shown in Figure 31, Figure 32 and Figure 33 . As energy savings variation among different climate zones are small, averaged TDV energy savings among all sixteen (16) climate zones were used. The results clearly indicate all three levels of proposed controls have negative LCC values. Therefore, the proposed measures are cost effective.

Baseline	Central Timer Control Option	Small Office		Large Office	
		Less Circuits	More Circuits	Less Circuits	More Circuits
A	1	($0.58)	($0.57)	($0.92)	($0.86)
B	1	($0.28)	($0.28)	($0.80)	($0.76)
	2	($0.54)	($0.54)	($0.91)	($0.84)
C	1	($0.65)	($0.66)	($0.97)	($0.94)
	2	($0.31)	($0.32)	($0.82)	($0.78)
D	1	($0.66)	($0.69)	($0.98)	($0.95)

Figure 31 LCC – Level 1 Control

Baseline	Central Timer Control Option	Occupancy Sensor Control Option	Small Office		Large Office	
			Less Circuits	More Circuits	Less Circuits	More Circuits
A	1	Low-voltage	($0.67)	($0.68)	($0.99)	($0.94)
		High-voltage	($0.52)	($0.53)	($0.90)	($0.85)
B	1	Low-voltage	($0.30)	($0.29)	($0.83)	($0.80)
		High-voltage	($0.15)	($0.14)	($0.74)	($0.71)
	2	Low-voltage	($0.64)	($0.64)	($0.97)	($0.93)
		High-voltage	($0.49)	($0.49)	($0.88)	($0.88)
C	1	Low-voltage	($0.66)	($0.66)	($1.00)	($0.97)
		High-voltage	($0.51)	($0.51)	($0.91)	($0.88)
	2	Low-voltage	($0.33)	($0.33)	($0.85)	($0.80)
		High-voltage	($0.18)	($0.18)	($0.76)	($0.71)
D	1	Low-voltage	($0.72)	($0.74)	($1.04)	($1.00)
		High-voltage	($0.57)	($0.59)	($0.95)	($0.91)

Figure 32 LCC – Level 2 Control

Baseline	Central Timer Control Option	Occupancy Sensor Control Option	Small Office		Large Office	
			Less Circuits	More Circuits	Less Circuits	More Circuits
A	1	Low-voltage	($0.78)	($0.76)	($1.09)	($1.08)
		High-voltage	($0.63)	($0.61)	($1.00)	($0.99)
B	1	Low-voltage	($0.38)	($0.36)	($0.89)	($0.87)
		High-voltage	($0.23)	($0.21)	($0.80)	($0.78)
	2	Low-voltage	($0.76)	($0.74)	($1.08)	($1.07)
		High-voltage	($0.61)	($0.59)	($0.99)	($0.92)
C	1	Low-voltage	($0.73)	($0.70)	($1.05)	($1.01)
		High-voltage	($0.58)	($0.55)	($0.96)	($0.92)
	2	Low-voltage	($0.40)	($0.37)	($0.90)	($0.86)
		High-voltage	($0.25)	($0.22)	($0.81)	($0.77)
D	1	Low-voltage	($0.81)	($0.78)	($1.11)	($1.10)
		High-voltage	($0.66)	($0.63)	($1.02)	($1.01)

Figure 33 LCC – Level 3 Control

5. Recommended Language for the Standards Document, ACM Manuals, and the Reference Appendices

The CASE study investigated three levels of controls. All of them can be achieved cost effectively. Lighting control products are widely available to support field implementation. It is desirable to require the level 3 control to maximize energy savings. However, occupancy sensor control at open-space cubicles may not be easily enforced through existing office building permitting and inspection process, since many office buildings are built for future lease and do not have specific cubicle layout plan upon construction completion. Therefore, the CASE study recommends that the level 2 control, which is very similar to 2008 Title 24 general lighting control requirements, be adopted for task lighting and plug load circuit controls.

We propose to add Section 131(h) for task lighting shut off controls.

In the following proposed language, additions are shown underlined and deletions are shown in strikeout.

SECTION 131 – INDOOR LIGHTING CONTROLS THAT SHALL BE INSTALLED

(h) Task lighting. In all buildings, both controlled and uncontrolled receptacles shall be provide in each private office, open office space, conference room, kitchen, and copy room. Controlled receptacles will allow automatic shut off control of connected task lighting and plug loads. Controlled receptacles shall meet the following requirements:

1. Electric circuits serving controlled receptacles shall be equipped with automatic shut-off controls following the requirements prescribed in section 131(d) for general lighting; and

2. At least one controlled receptacle shall be installed within 1 foot from each uncontrolled receptacles; and

3. Controlled receptacles shall be located and marked to differentiate them from uncontrolled receptacles, and

4. For open office spaces, controlled circuits shall be provided and marked to support installation and configuration of office furniture with receptacles that comply with section 131 (h) 1, 2, and 3.

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7. Appendix I: ASHRAE and IgCC Plug Load Control Standards

This section presents the ASHRAE 90.1 and the International Green Construction Code (IgCC) language regarding plug load controls.

7.1 ASHRAE 90.1

The ASHRAE Lighting Subcommittee developed CMP to 90.1-2007, modifying Addendum "bs"section 8.4.2, labelled "Automatic Receptacle Control". The revised language is as follows:

> "At least 50% of all 125 volt 15- and 20-Ampere receptacles, including those installed in modular partitions, installed in the following space types:
>
> > Private offices
> >
> > Open offices
> >
> > Computer Classrooms
>
> shall be controlled by an *automatic control device* that shall function on:
>
> > a. a scheduled basis using a time-of-day operated control device that turns receptacles off at specific programmed times - an independent program schedule shall be provided for areas of no more than 25,000 ft2 but not more than one floor - or
> >
> > b. an *occupant sensor* that shall turn receptacles off within
> >
> > 30 minutes of all occupants leaving a space or
> >
> > c. a signal from another control or alarm system that indicates the area is unoccupied.
>
> **Exceptions:** Receptacles for the following shall not require an *automatic control device:*
>
> > <u>Receptacles specifically designated for equipment requiring 24 hour operation.</u>
> >
> > Spaces where an automatic shutoff would endanger the safety or security of the room or building occupant(s)."

7.2 International Green Construction Code (IgCC)

The IgCC also developed plug load control requirements. This is a technical requirement which doesn't specify implementation means. It was thought rather in the framework of soft-wire control technologies such as timer or occupancy sensor on plug strips or smart strips rather than hard wiring control technologies. The code language is the following:

"**609.6 Plug load controls.** Receptacles and electrical outlets controlled by an *occupant sensor* or *time switch* shall be provided in accordance with all of the following:

> 1. In Group B office spaces without furniture systems incorporating wired receptacles, at least one switched receptacle shall be provided for each 50 square feet.

2. In Group B office spaces with furniture systems incorporating wired receptacles, at least one switched circuit shall be provided at each electrical outlet used for powering furniture systems.

3. In classrooms in Group B and Group E occupancies, at least four switched receptacles shall be provided in each classroom.

4. In copy rooms, print shops, and computer labs, not less than one switched receptacle shall be provided for each data jack.

5. In spaces with an overhead cabinet above a counter or work surface, not less than one switched receptacle shall be provided for each work surface.

609.6.1 Distribution and marking. Controlled receptacles and electrical outlets shall be distributed in a reasonably uniform pattern throughout each space. Controlled receptacles shall be marked to differentiate them from uncontrolled receptacles.

609.6.2 Furniture systems. Furniture systems incorporating wired receptacles shall include at least two receptacles at each workstation that are connected to a controlled circuit.

609.6.3 Computer office equipment. Computer monitors, plug in space heaters, air purifiers, radios, computer speakers, coffee makers, fans, and task lights located in spaces with controlled receptacles shall be plugged into controlled receptacles.

609.6.4 Audio and visual systems. Displays, projectors, and audio amplifiers in Group B and Group E classrooms, conference and meeting rooms, and multipurpose rooms shall be controlled by an *occupant sensor*.

609.6.5 Water dispensers. Water dispensers that utilize energy to cool or heat drinking water shall be controlled by *time switch controls*.

609.6.6 Refrigerator and freezer cases. Lighting integral to vending machines and refrigerator and freezer cases shall be controlled by an *occupant sensor* or a *time switch*."

8. Appendix II: Industry Practice Survey

This section is presenting the online surveys sent to electrical designer, electrical contractor and system furniture manufacturers.

8.1 CASE Office Task Lighting and Plug Loads, Designer and Contractor survey

8.1.1 Survey Form

The California Investor Owned Utilities (IOUs) are actively supporting the California Energy Commission (CEC) in developing the state's building energy efficiency standard (Title 24, Part 6). Their joint intent is to achieve significant energy savings through the development of reasonable, responsible, and cost-effective code change proposals for the 2011 code update. Codes and Standards Enhancement (CASE) Studies are conducted by IOUs to assess technical potential, cost-effectiveness, and feasibility of proposed regulation improvement.

The Office Tasking Lighting Control CASE study aims to develop requirements of automatic controls of task lighting and other plug loads. Possible control strategies include central timer controls of task lighting/plug load circuits or occupancy sensor controls at individual work station/private office.

As part of the CASE study effort, we invite you to fill out this survey to provide necessary information to guide the code change development. The following questions are related to office space electrical wiring design practices and challenges associated with plug load controls. Intended audience for this survey is office building electrical system designers and contractors.

General Information

1. Please select the profile(s) that best describes you:

- ☐ Designer / Electrical Engineer
- ☐ Contractor
- ☐ Other (please specify)

2. How many office electrical wiring design/installation projects have you worked on?

- ☐ More that 100
- ☐ 50 – 100
- ☐ 10 – 50
- ☐ Less than 10

3. What geographic areas do you serve (check all areas that apply):

- ☐ North Coast
- ☐ Sacramento area
- ☐ Bay area
- ☐ Central Valley
- ☐ Central Coast
- ☐ Los Angeles area
- ☐ San Diego area

Wiring Practice

To implement task lighting and plug load controls, workstations/private offices need to be supplied with more than one independent circuit so that essential office equipment, e.g. computers, fax machines, can be connected to a circuit that will not be interrupted while other plug load circuits are controlled.

4. In how many projects did you bring two or more independent circuits to a private office?

- ☐ more than 75%
- ☐ 50 - 75%
- ☐ 25 - 50%
- ☐ less than 25%

Comments

5. In how many projects did you bring two or more independent circuits to a workstation (cubicle)?

- ☐ more than 75%
- ☐ 50 - 75%
- ☐ 25 - 50%
- ☐ less than 25%

Comments

6. Is it a preferred practice to bring at least two independent circuits to a workstation/private office?

- ☐ Yes, always
- ☐ No, it doesn't really matter
- ☐ It depends

If it depends, please explain

Plug load control strategies

The CASE study plans to propose task lighting and plug load control requirements based on two types of control strategies, central timer controls and local occupancy sensor controls. The former will be installed at circuit breaker/control panel to turn off circuits for task lighting and non-essential plug loads during certain non-business hours. A manual override will be provided. The latter can be implemented at each cubicle and private office to achieve maximum electricity consumption reduction.

In both strategies, circuits for essential office equipment will not be controlled.

7. Are there any issues associated with central timer controls of task lighting and plug load?

8. Are there any issues associated with local occupancy sensor controls of task lighting and plug load?

9. In how many projects did you design/install these task lighting/plug load control strategies in office buildings?

Control Type	Never	1 - 5	5 - 10
Central timer control			
Local occupancy sensor			

10. What other control strategy(ies) would you recommend?

11. Please provide any comment or concern not covered by the previous questions.

12. Providing contact information is always optional. All survey results will always remain anonymous, but if our CASE authors have follow up questions, they would like to be able to contact you.

Name:

Company:

Email Address:

Phone Number:

8.1.2 Survey Answers

Respondent Profile

The pool of electrical designers and contractors surveyed was diversified. Half of the respondents were electrical designers, while the other half were electrical contractors, operating in every area of California. The total number of participants was 12. Half of them have worked on more than 100 office wiring projects, and 65% have worked on more than 50 office wiring projects. The other respondents were also experienced in office wiring (they worked on 10 to 50 office wiring projects).

Wiring practice

Bringing two separate circuits to a private office is done in about a quarter of the office projects wired this way. The main reason for feeding private offices with only one circuit is typically budget constraint. The general rule for private office wiring is to bring 3 circuits to feed 3 to 4 offices. Workstations in open spaces are very rarely served by two independent circuits (only 25% of them are). Most of the respondents agreed that bringing two circuits to a private office or a workstation is a better practice. They argued that it provides flexibility in terms of which equipment can be used at the workstation, and that putting computers and printers on a separate circuit is preferable.

Circuit Controls

No major concerns were voiced about implementation of central timer for task light and plug control. Designers and contractors noted that some circuits would have to remain uncontrolled. Some stressed that this solution may not be widely adapted for businesses which require flexibility, for instance businesses not on a 8am-5pm schedule, or when some workstations need to be switched on while others can be turned off. One respondent was worried about additional cost and complexity while doing business in California, and would rather see this requirement adopted at the federal level.

Apart from cost concerns, comments on the occupancy sensor control strategy are related to implementation considerations. Survey respondents stressed the importance of the equipment quality, in order to detect slight movements and adjust the time delay to avoid disruption. They also suggested that the receptacles would have to be color-coded, and that clocks and some other equipment would have to remain uncontrolled.

While there was little resistance to this proposal, these strategies are not commonly put into practice in the field. Forty two percent (42%) of the respondent replied having experience installing central timer control for office plug loads. The occupancy strategy seemed more common, as 67% of respondents reported having experience with it in office spaces.

In addition to applying central control or occupancy control, some respondents recommended using personal controlled outlet (with either a timer or an occupancy sensor) or occupancy sensor integrated into the task light to avoid wiring configuration change as alternatives.

8.2 CASE Office Task Lighting and Plug Loads, System furniture manufacturer survey

8.2.1 Survey Form

The California Investor Owned Utilities (IOUs) are actively supporting the California Energy Commission (CEC) in developing the state's building energy efficiency standard (Title 24, Part 6). Their joint intent is to achieve significant energy savings through the development of reasonable, responsible, and cost-effective code change proposals for the 2011 code update. Codes and Standards Enhancement (CASE) Studies are conducted by IOUs to assess technical potential, cost-effectiveness, and feasibility of proposed regulation improvement.

The Office Tasking Lighting Control CASE study aims to develop requirements on automatic controls of task lighting and other plug loads. Possible control requirements include central timer controls of task lighting/plug load circuits and occupancy sensor controls at work station/private office levels.

As part of the CASE study effort, we invite you to fill out this survey to provide necessary information to guide the code change development. The following questions are related to office workstation wiring and design practices in California, as well as strategies of task lighting/plug load controls. Intended audiences for this survey are system furniture manufacturers, distributors, and office furniture system designers.

General Information

1. Please select the type of system furniture you manufacture/sell/specify:

- ☐ New
- ☐ Refurbished
- ☐ Both

2. Please select the area(s) which best defines the geographic area(s) you serve:

- ☐ North Coast
- ☐ Sacramento area
- ☐ Bay area
- ☐ Central Valley
- ☐ Central Coast
- ☐ Los Angeles area
- ☐ San Diego area

3. What percentage of your system furniture is delivered with attached task lighting fixtures (under cabinet lighting or other types)?

- ☐ More than 75%
- ☐ 50% - 75%
- ☐ 25% - 50%
- ☐ less than 25%

Comments

System Furniture Wiring Practices

To implement task lighting and plug loads controls, workstations need to be supplied with more than one independent circuit so that essential office equipment, e.g. computers, fax machines, can be connected to a circuit that will not be interrupted while other plug load circuits are controlled.

4. What percentage of furniture is installed with at least two independent circuits brought to a workstation?

	more than 75%	50% -75%	25% - 50%	less than 25%
Cubicles furniture				
Private office furniture				

NA (please specify)

5. Do you usually recommend to have more than one circuit connected to a workstation, without considering task lighting and plug load control?

- ☐ Yes
- ☐ No
- ☐ It depends on application

If depends on application, please specify

6. For the system furniture you are providing, do you label receptacles to differentiate the circuits they are connected to?

- ☐ Yes, if multiple circuits are to be connected to the system furniture
- ☐ Yes, upon customer requests
- ☐ No

Comments:

Workstation Occupancy Sensor Control

Occupancy sensor control at workstations can help to maximize the reduction of electricity consumption by task lighting and office plug loads. Operation of essential office equipment will not be controlled.

7. Do you provide system furniture that is equipped with occupancy sensor control or can be configured to allow occupancy sensor control?

	Yes, we are providing such system furniture	Not now, but we plan to provide such system furniture in the near future	No, we don't plan to provide such system furniture
New system furniture			
Refurbished system			

Comments

8. What percentage of the system furniture you delivered was working with occupancy sensors?

- ☐ more than 30% of the delivered system furniture
- ☐ 20 - 30%
- ☐ 10 - 20%
- ☐ 5 - 10%
- ☐ less than 5%

Comments

9. Are there any issues related to implementing occupancy sensor controls in office system furniture?

10. What other control strategy(ies) would you recommend for office task lighting and plug load controls in offices?

11. Providing contact information is always optional. All survey results will always remain anonymous, but if our CASE authors have follow up questions, they would like to be able to contact you. Thank you!

Name:

Company:

Email Address:

Phone Number:

9. Appendix III: Office Building Prototypes

This section presents detailed information on the two office prototypes developed for this case study. These prototypes were developed to overcome limitations of the CASE analysis prototypes. They are based on the DEER (Database for Energy Efficient Resources) office building models. The same assumptions regarding office prototype physical shape, occupant density, and building space activity breakdown are kept, and a space layout was created based on these inputs and some typical office space layouts.

9.1 Small Office

The DEER small office building prototype used for energy savings and cost-effectiveness calculation is a two-story 10,000 sf building, with a rectangular footprint (50ft×100ft). Based on the space breakdown in Figure 34, it was estimated that the office building could host 33 occupants. The first floor is made of a lobby with reception desk, stairs and elevator, a large open-space with 6 cubicles in the building core surrounded by 9 private offices and a conference room located at the perimeter of the building. The restrooms, copy room, kitchen and mechanical room can be found along the building perimeter. The first floor hosts 15 occupants. The second floor has a similar configuration, with an additional cubicle in the core of the building, hence hosting 16 employees. The floor layout, shown in Figure 35, was developed based on common office floor plans and was checked by registered architects.

Office Areas (Private office and open-space cubicle)	70%
Corridor & Lobby	15%
Conference Room	4%
Copy Room	2%
Restrooms	5%
Mechanical/Electrical Room	4%

Figure 34 Small Office Area Breakdown

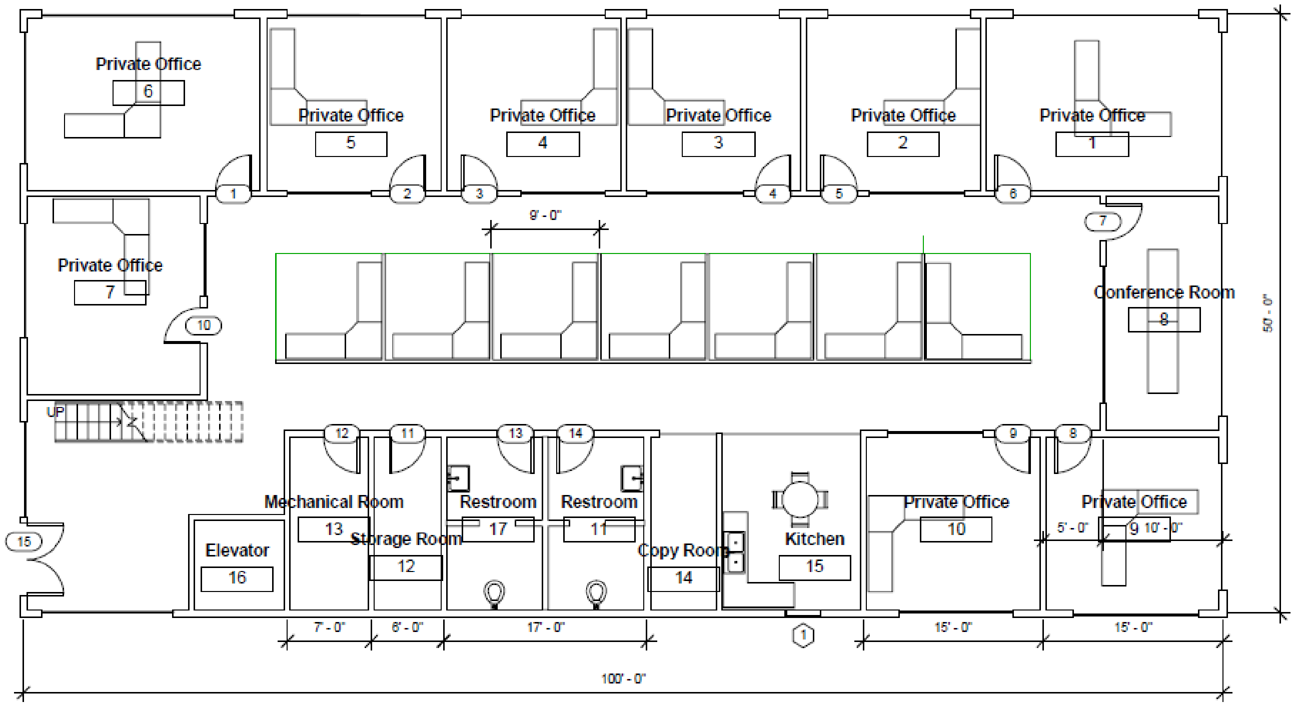

Figure 35 Small Office Floor Plan

9.2 Large Office

The DEER prototype building used for energy savings and cost-effectiveness analysis purpose is a 10 story 175,000 sf building. Its shape is rectangular (175ft×100ft), and all floors have a similar layout. Based on the space breakdown in Figure 36 and floor plan in Figure 37, it was assumed that the building would host seven hundred and thirty (730) people. Each floor hosts seventy-three (73) employees. A typical floor is made of 19 private offices, 54 cubicles, 2 conference rooms, 2 copy rooms, kitchen and restrooms. Each East and West perimeters host 10 private offices and a large conference room while the North and South perimeter spaces are open offices with 27 cubicles in stack of 6 or 3 at each orientation. A lobby with elevators and stairs is located in the building core, with kitchen, mechanical room and restroom on both sides. Another 9 private offices can be found in the building core. The office layout was developed based on the office buildings floor plan provided in the WattStopper "Lighting control best practice guide: Office Buildings" and were checked by a registered architect.

Office Areas (Private office and open-space cubicle)	70%
Corridor & Lobby	15%
Conference Room	4%
Copy Room	2%
Restrooms	5%
Mechanical/Electrical Room	4%

Figure 36 Large Office Area Breakdown

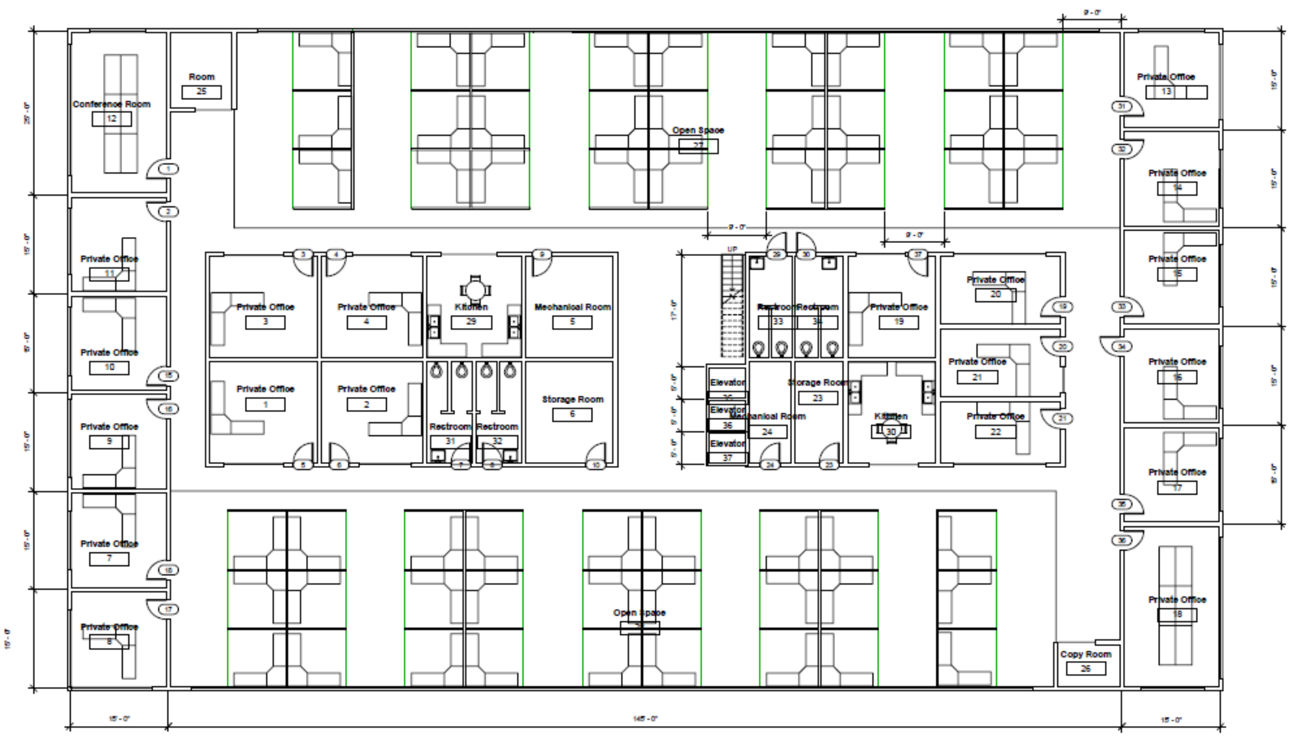

Figure 37 Large Office Floor Plan