Requirements for Controllable Lighting

2011 California Building Energy Efficiency Standards

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1. Purpose

In practical terms, controllable lighting means that the auxiliary electrical gear associated with modern high efficacy light sources must be a special type of ballast or driver that permits the light source to be dimmed from full output, with commensurate energy savings. Controllable light sources enable a wide range of lighting controls strategies capable of significant energy savings such as daylighting, scheduling, tuning, adaptation compensation, workstation-specific control and manual dimming. In addition, controllable light sources permit active management of lighting for other purposes such as demand response and real-time pricing.

However, despite being part of the Title 24 development agenda for over 20 years, the cost of controllable lighting has been continually cited as the primary obstacle to incorporating these features into lighting applications and to be adopted within the Building Energy Efficiency Standards. Recently, the concurrent falling prices for electronics and rising costs of energy have finally made it desirable to employ controllable lighting, and now controllable lighting can meet the statutory cost effectiveness tests for formal Standards adoption.

Therefore, this CASE report proposes the adoption of mandatory requirements for controllable light sources. It is anticipated that mandating controllable lighting will further accelerate the ongoing market transformation, continuing to reduce the cost of this technology.

Moreover, this CASE report has significant ramifications for other CASE proposals. If controllable lighting can be assumed, proposed requirements for daylighting and other control-related strategies likely will also pass cost effectiveness tests.

2. Overview

a. Measure Title	Requirements for Controllable Lighting
b. Description	This proposed measure modifies the minimum requirements in Section 131 for multi-level lighting controls in non-residential buildings. The measure requires additional control steps beyond the existing requirements, specified according to light source. The measure also reduces the maximum lighting power density that is exempt from multi-level control.
c. Type of Change	**Mandatory Measure -** The measure modifies the mandatory code requirements for multi-level lighting control. The Section will be re-named. The proposed change does not modify the current scope of the Standards. It does, however, impose new requirements on lighting systems. Currently, only a single lighting control step is required for all applications that are not exempt from the multi-level control requirements. To comply with the proposed measure, lighting applications will be required to employ ballast or driver technologies that permit significantly increased granularity of lighting control at the level of the individual luminaire. This will replace current requirements that permit switching alternate luminaires or rows of luminaires. There are presently many choices of suitable ballasts, drivers and control devices available in the marketplace. Section 131 (b) will be modified to include a table that specifies, by light source type, revised minimum required multi-level control steps including acceptable methods of achieving functional illuminance. Compliance manuals will be adapted to reflect the new requirements. The ACM will need to be adjusted to accommodate controllable lighting on all systems. Section 134 will be modified to ensure that tuning has been employed if called for, with a corresponding place on compliance forms.

d. Energy Benefits	The following is a list of the generally-accepted lighting controls strategies for energy savings. **Those benefitting from controllable lighting are shown in bold:**

Daylighting	**Lighting is dimmed or extinguished in response to daylight sensors indicating the availability of adequate daylight.**
Small zone occupancy/ vacancy sensing	Motion sensors extinguish lights when the space is unoccupied without regard for adjacent rooms or workstations. The difference between occupancy and vacancy is that vacancy sensing requires manual activation of lighting, and occupancy sensing activates lighting automatically.
Large zone motion/vacancy sensing	Motion sensors may be interconnected to control a larger space, and for which there is consideration for adjacent rooms and/or workstations
User dimming	**A manual control device allows individual occupants or work clusters to control lights affecting their task.**
Tuning	**The ability to set maximum light levels at a lower level than full lighting power, thus always saving energy in a manner to which the space occupants are generally not aware. Tuning is usually justified as saving the energy associated with the normal slight overdesign of lighting, but it can also be used when lower light levels are generally called for.**
Predictable Scheduling	**Predictable schedules such as the opening for business of a store or school can be used to activate or extinguish lighting. With controllable lighting, light levels can be predictably varied as a function of either clock time or solar time.**
Adaptation compensation	**Interior lights are dimmed at night to ease adaptation of the eye and harvest energy savings at night.**
Demand management and response	**Overall building energy use is monitored and lighting is reduced in response to energy cost or grid emergencies. Lighting is especially suited for indefinite power reduction because for most people, a 25% reduction in light level is barely perceptible, especially if occurring slowly.**

	In summary, controllable lighting is an enabling technology for all of most control-related strategies. While not every strategy applies to every building or every space, a building equipped with controllable lighting can utilize strategies determined on a space by space basis.
e. Non-Energy Benefits	A significant non-energy benefit anticipated from this measure is increased lighting quality as a result of the capability to individually tune each lighting fixture. In current lighting design practice, non-residential spaces are often over-lighted initially in order to account for lamp lumen depreciation over time and to meet minimum maintained illuminance requirements. After the lighting is installed, tuning allows for precise adjustments of lighting levels to create a more optimally illuminated environment. Additionally, controllable lighting gives end users more individual control over the lighting in their space, enabling them to adjust light levels according to their own needs and preferences.
F. Environmental Impact	There is no material environmental impact other than the energy savings.

g. Technology Measures	**Measure Availability** *Identify the principal manufacturers/suppliers who make the measure (product, technology, design strategy or installation technique), and their methods of distribution. Is the measure readily available from multiple providers? Comment on the current ability of the market to supply the measure in response to the possible Standards change and the potential for the market to ramp up to meet demand associated with the possible Standards change. If the measure needs further development and refinement in response to possible Standards changes, comment on if the measure will be available from several manufacturers by the effective date of the Standards. Identify competing products.* The industry presently offers many suitable products including the ballasts, drivers and control systems to operate them. As stated previously, their limited share of the marketplace has been largely held back by the high cost of dimmable fluorescent ballasts. As recently as 2005, fluorescent dimming ballasts were priced at about $25 per lamp OEM, which translates roughly into $50 per lamp end-user. However, in 2010, low cost dimming ballasts were introduced at LightFair with OEM prices of under $10 per lamp by GE, Sylvania, and Advance. Additionally, Lutron introduced a new generation of DALI-like wide range dimming ballasts (Ecosystem) with an OEM per lamp cost under $25 per lamp. Following are noteworthy manufacturers of various applicable products: **Fluorescent dimming ballasts 0-10 volt**: Lutron, Advance, Universal, GE, Sylvania, Tridonic **Fluorescent dimming ballasts - DALI or DALI-style**: Lutron, Leviton, Sylvania, Advance, Tridonic, Universal, Lumenergi **Fluorescent dimming ballasts - phase cut**: Lutron, Advance, Sylvania **HID Lighting - controllable ballasts:** GE, Acuity Holophane, Delta **HID Lighting - step control for magnetic ballasts:** Wattstopper, Hunt **LED Drivers, dimmable (system style):** Lutron, ATCO Tridonic, Advance **Compatible Lighting Control Systems** ***Analog/hybrid means digital signaling using 0-10 volt analog ballasts.*** Lutron Grafik (analog/hybrid), Lutron Ecosystem (digital), Leviton Sector (digital), Leviton (analog), Lumenergi (digital), Philips Dynalite (digital or analog), Crestron (digital or analog hybrid), Wattstopper (analog hybrid), Acuity LC&D (analog hybrid, digital), Starfield (digital), Encelium (analog hybrid), Convia (analog hybrid), many others.

	Useful Life, Persistence, and Maintenance: Controllable lighting permits unprecedented opportunity to save energy, but to achieve that goal, lighting control systems must be properly installed, commissioned and maintained. Persistent savings will be affected by any failure among these operational steps. However, when fully realized the savings can be substantially greater than predicted herein. Mandatory acceptance testing in Title 24 will be modified to add a step to certify tuning. Other energy saving measures for which controllable lighting will be important are already subject to acceptance testing.
h. Performance Verification of the Proposed Measure	The tuning of a controllable ballast can consist of a manual adjustment or an electronic adjustment. Both are inspectable and should be part of acceptance certification as proposed herein.
i. Cost Effectiveness	***Overview*** Because controllable lighting is an enabling technology, the combination of controllable lighting *and* a suitable initiating signal are needed to determine both the first cost and the energy savings. This research team was keenly aware of efforts to develop CASE studies specifically for several specific lighting control applications. A method was devised to attribute the costs of controllable lighting including ballasts or drivers and the associated wiring to a control hub to the controllable lighting system, and to attribute the costs of the control application including its sensor, sending device and programming or response circuit to the application case study. In the discussion, one application stood out that had no specific external supporter – tuning. As it turns out, tuning is applicable to just about every project. It was decided that the energy savings attributed to tuning would be used to justify controllable lighting, and that the incremental energy savings attributed to other applications would be used to determine cost effectiveness of those specific applications. Cost effectiveness of controllable lighting is determined for each of a number of prototype buildings using the format prescribed by the CEC. In general, for each building the incremental cost of controllable lighting is compared to a "breakeven point" determined for each prototype building. The results are presented in Section 4, Table 6. Among high LPD buildings, only schools fail to meet the breakeven point, largely due to the summer recess and short days. For this reason, a special code exception is proposed.

	Cost Breakdown Any lighting controls application employing controllable lighting must as a minimum have a certain number of components, regardless of application: • Dimmable ballast(s) or driver(s) for the light source(s). At present, dimmable ballasts and drivers break down into two primary groups, ***intelligent devices*** capable of memory and bi-directional communications, and ***basic devices*** that can receive and act as directed by a signal. • A means to "turn on" and "turn off" the lighting system. Many intelligent devices can do this internally, whereas most simple devices require an external power switch or relay. • A means to get signals from a source to the dimmable ballast/driver. This includes wiring and a circuit device that must allow one to "tune" the ballast or driver. To determine the approximate cost of this provision, comparable digital systems (DALI, etc.) and analog systems (0-10 volt) were priced and normalized. Assuming an office occupancy with one ballast or driver about 80-100 square feet and including the cost of commissioning, the approximate cost of the controllable lighting portion was determined to be about $0.61/sf (2011). Three other additions to the above provisions create the minimum system needed for lighting control as follows: • In order to respond to a signal calling for demand reduction, whether generated by the utility or a local computer, a lighting control network must be installed including as a minimum a control origination source and wiring capable of interpreting a request and translating it into a signal upon which ballast(s) and driver(s) can react. This is about $0.35/sf. • In order to respond to daylighting, a daylight sensor must be provided and commissioned, and connected to the minimum wiring system that will convey the signal. This is about $0.57/sf. • In order to respond to other commands such as manual on/off or user dimmer settings, the additional cost of providing and commissioning the added devices and the device must be connected to the minimum wiring system that will convey the signal. This is about $0.18/sf. The "Controllable Lighting" value is used in Life Cycle studies presented later in this report. The other values were assigned to other CASE reports. Note that different values were determined for different building types. This is largely due to a difference in ballast or driver density caused by light level differences or differences in how lighting is used. These are all included in the following analyses.

j. Analysis Tools	This measure is proposed as mandatory and will not require the use of analysis tools, because the measure is not subject to whole building trade-offs.
k. Relationship to Other Measures	See the prior discussion about resolving the costs of controllable lighting and systems among the energy efficiency strategies and various energy code alternatives. Following is a reprise of the values used to analyze the cost effectiveness of lighting controls as assigned to various reports.

Report	***Cost per SF***	***Pays for (including commissioning)***
Controllable Lighting	$0.61	Controllable ballasts and drivers including essential communications bus and load connections to fixtures
Demand Response	$0.35	Communication network from initiating device to controllable lighting bus
Daylighting	$0.57	Daylighting sensors
Other	$0.18	Additional features, e.g emergency interface, non mandatory dimming features, etc.

3. Methodology

The overall intent of this investigation was to demonstrate the cost-effectiveness of mandatory requirements for controllable lighting in non-residential spaces. As the cost of installed lighting systems varies widely in practice depending on the technologies used and the control strategies applied, we chose to develop a standard cost and energy savings model based on a controllable lighting system that employs tuning as the sole proposed lighting control strategy beyond current code requirements. Our approach was to identify the cost/benefit break-even point for each of the prototypes analyzed and determine whether life-cycle cost-effectiveness could be achieved using the models we developed.

3.1 Developing the Base Case

We used the current control requirements of Title 24 as the basis for determining lighting system costs and the estimated energy savings from application of the proposed measure. The following sections describe the assumptions and methodology used to develop the base case for our analysis.

3.1.1 Review of Current Title 24 Code

We reviewed the current 2008 Title 24 Building Code to determine the standard lighting control configuration and minimum required technology to achieve code compliance in non-residential buildings. Using this information, we performed our cost-effectiveness analysis by calculating the costs and benefits of this proposal as incremental values beyond the current code requirements (i.e., the additional costs vs. the energy saved by installing a controllable lighting system that is capable of tuning each individual luminaire).

3.1.2 Developing Building Energy Use Profiles

To estimate the potential energy savings from this proposal, it was necessary to develop a model of current energy use in 2008 Title 24-compliant non-residential buildings. We chose to create and analyze nine different building prototypes that represent the majority of non-residential building end-uses in California. The following section describes in more detail our process for creating these prototypes.

3.1.3 Developing the Building Prototypes

The building prototypes were created based on a combination of the project team's practical design experience and a review of the space types currently defined in Table 146-F of Title 24 for use in the Area Category Method of determining allowed lighting power density. We modeled each prototype by estimating the percentage of floor space that each space type typically occupies within the overall building type.

The prototypes are a mix of physical and conceptual models. In some cases, the breakdown of space types within a building prototype corresponds to the division of space within a single site (for example, a typical office building or warehouse). In other cases where the actual design of each building may vary widely across a building end-use type, we chose to divide the spaces within a prototype according to the estimated percentage each space type occupies within the entire building sector (for example, the percentage of floor space occupied by kitchens within the hospitality sector).

Figure 1 below summarizes the key attributes for each of the prototypes used in our analysis. Detailed tables listing the assumed percentage of floor space according to space type for each building prototype are included in Appendix A.

Prototype Number	**Occupancy Type**	**Area (Square Feet)**	**Number of Stories**	**Other Notes**
Prototype 1	Office	10,000	1	
Prototype 2	Retail (ASHRAE Type 1)	10,000	1	Corresponds to Building Type 1 in ASHRAE Standard 90.1-2010
Prototype 3	Retail (ASHRAE Type 2)	10,000	1	Corresponds to Building Type 2 in ASHRAE Standard 90.1-2010
Prototype 4	Retail (ASHRAE Type 3)	10,000	1	Corresponds to Building Type 3 in ASHRAE Standard 90.1-2010
Prototype 5	Foodstore	10,000	1	
Prototype 6	School (K-12)	10,000	1	
Prototype 7	School (Year-round)	10,000	1	
Prototype 8	Warehouse	10,000	1	Includes both refrigerated and non-refrigerated spaces
Prototype 9	Hospitality (Restaurant/ Hotel Function)	10,000	1	

Figure 1. Building Prototypes Used in Analysis

3.1.4 Determining Energy Use by Building Sector

To profile typical lighting energy use in each of these building prototypes, we consulted the California Commercial End-Use Survey (CEUS), an extensive statewide research effort completed in 2002 that details energy use by commercial building sector and energy end-use. This study provides data on lighting energy use by time of day across twelve specific building sectors, ranked as follows according to total statewide floor space: (1) Miscellaneous; (2) Retail; (3) Large Office; (4) Unrefrigerated Warehouse; (5) School; (6) Small Office; (7) Lodging; (8) Health; (9) College; (10) Restaurant; (11) Food Store; and (12) Unrefrigerated Warehouse.

As the CEUS study reflects energy use across the entire commercial building sector, including pre-Title 24 building stock, we were unable to use the data directly to produce current energy profiles for our prototypes. Instead, we extracted data from the report that could be used to construct an estimated 2008 Title 24-compliant load profile for each building type analyzed.

First, we compared the building sectors in the CEUS report to our nine prototypes to determine their level of correspondence. After reviewing the data, we found that all of our building prototypes could be mapped to one or more of the sectors analyzed in the report. Figure 2 below shows how we matched our classification system to the study to facilitate further analysis.

CASE Building Prototype	Comparable CEUS Building Sector(s)
Office	Large Office, Small Office
Retail - ASHRAE Type 1	Retail
Retail - ASHRAE Type 2	Retail
Retail - ASHRAE Type 3	Retail
Foodstore	Grocery
School (K-12)	School
School (Year-round)	Colleges
Warehouse	Unrefrigerated Warehouse, Refrigerated Warehouse
Hospitality	Restaurant, Lodging

Figure 2. Comparison of CASE Building Prototypes to CEUS Building Sectors

Next, we distilled the CEUS data in order to develop typical occupancy profiles (percentage of the total lighting load used by time of day) for each of our building prototypes. The formula used to determine occupancy at a particular hour of the day is shown in Equation 1:

Equation 1. $Occupancy^{(Hour)} = Lighting\ Load^{(Hour)}/Total\ Lighting\ Load$

To arrive at this value using the CEUS data, we first calculated the average load profile for each of the applicable CEUS building sectors by dividing the total statewide load for that sector by the total floor space occupied by that sector statewide, for each hour of the day (Equation 2) :

Equation 2. $Watts/Square\ Foot^{(Hour)} = Total\ Sector\ Load^{(Hour)}/Total\ Sector\ Floor\ Space$

We then determined occupancy by dividing the load at each hour of the day by the average lighting load per square foot reported for that sector in the CEUS study, according to the occupancy formula above. Where the CEUS building sector corresponded one-to-one with our prototype definition, we performed this calculation directly on the data provided for that sector. If there were two corresponding sectors, we calculated the result by aggregating the sectors using a weighted average of the data (i.e., the percentage of Large Offices vs. Small Offices making up the total Office sector).

3.1.5 Creating the Base Case Load Profiles

Using the occupancy profiles derived from the CEUS data, we constructed a 2008 Title 24-compliant base load profile for each of the nine building prototypes. To determine the overall lighting load for each prototype, we used the Area Category Method of calculating code compliance. We matched each of the space types within our prototypes with the allowed lighting power specified in Table 146-F of Title 24. Two exceptions were the ASHRAE Type 2 and Type 3 prototypes, where additional allowances were made for display lighting according to the Tailored Method of compliance. The total load for each prototype was calculated using a weighted average of the lighting power allowances for each space type. We then calculated the active load for each hour of the day using Equation 3:

Equation 3. $\textit{Lighting Load}^{(Hour)} = \textit{Occupancy}^{(Hour)} * \textit{Total Building Load}$

3.2 Developing the Proposed Standards Case

The following sections describe the methodology we used to develop the CASE proposal for comparison against the base case.

3.2.1 Stakeholder Meetings

The project team hosted a series of stakeholder meetings in order to solicit comments, questions, and concerns from key stakeholders who would be affected by potential changes to the Title 24 requirements for controllable lighting. A stakeholder list was developed that included major lighting and controls manufacturers, utilities administrators, lighting researchers, energy analysts, and California Energy Commission staff. The roundtable meetings were held on April 15, 2009; November 4, 2009; and January 19, 2010. Stakeholders provided important feedback on the technical capability and economic feasibility of currently available products with respect to mandatory requirements for controllable lighting.

3.2.2 Developing Cost Models

Cost models were developed based on consultation with key lighting manufacturers as well as the project team's prior lighting design experience. Primary communication with manufacturers took place at LightFair in May, 2010. The cost of the proposed measure was calculated by comparing the base cost of a 2008 Title 24-compliant prototype with the final cost after adding the control wiring and program capability to allow tuning of the individual luminaires. We used the incremental cost per square foot as the basis for our cost-effectiveness analysis.

3.2.3 Estimating Energy Savings

As stated previously, we chose to estimate energy savings from this proposal using tuning as the only applied lighting control strategy for each building prototype. Tuning is a method of controlling light levels from a luminaire by adjusting the power output of the ballast in order to produce the desired quantity of lumens. In current lighting design practice, spaces typically are over-lighted initially in order to account for lamp lumen depreciation and to maintain minimum illuminance requirements over lamp life. We modeled the energy savings from this measure according to the average percent reduction in power that could be reasonably applied during the initial part of lamp life in order to tune light levels down to the maintained design level required by the application. To determine this value, we used typical lamp lumen depreciation (LLD) factors for the light source types used in each of our prototype applications.

3.3 Life-Cycle Cost Analysis

We demonstrated life-cycle cost-effectiveness using the 2011 Life-Cycle Cost Methodology provided by the California Energy Commission. The results of this analysis are provided in the Analysis and Results section below.

4. Analysis and Results

4.1 Current Code Requirements for Controllable Lighting

The required controls for indoor lighting are specified in Section 131 of the code and represent three progressive levels of control, as follows:

1. *Area Controls.* Each space enclosed by ceiling-height partitions must have an independent switching or control device that can shut off the lighting in that space. This requirement may be met by using a wall switch.

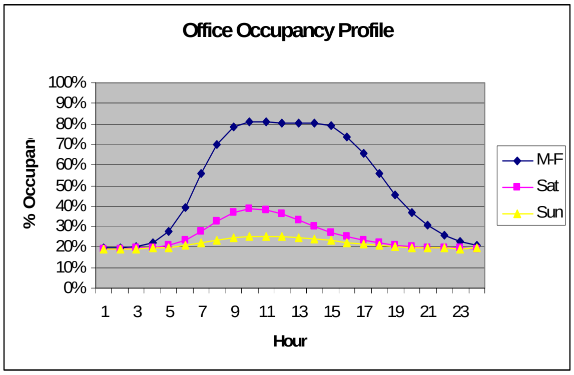
2. *Multi-Level Controls.* The general lighting of any space greater than 100 square feet, with a connected lighting load greater than 0.8 watts per square foot, must have a control device with one control step between 30 and 70 percent of design lighting power and allow the lighting to be manually turned off. This measure requires the use of additional circuitry to allow dimming or switching of individual luminaires.

3. *Automatic Shut-Off Controls.* In addition to the manual controls specified above, all indoor lighting systems must be equipped with separate automatic controls capable of shutting off the lighting. An occupancy sensor, automatic time switch, or daylight sensor may be used to comply with this requirement.

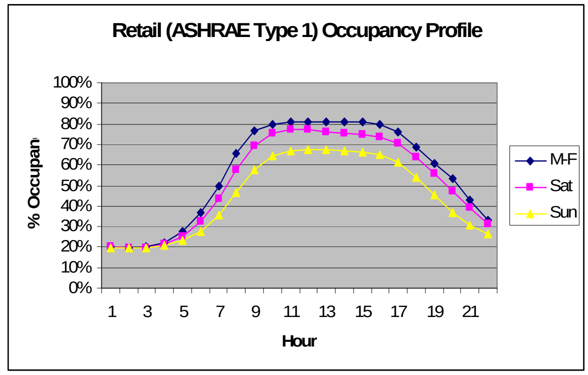
4.2 Baseline Energy Use by Building Prototype

4.2.1 Prototype Occupancy Profiles

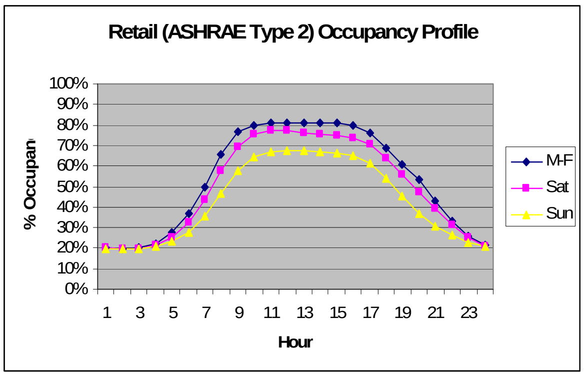
As described in the methodology section above, we derived an occupancy profile for each building prototype using data in the CEUS report for the comparable building sector(s). Figure 3 shows the results of this analysis. The detailed calculations used to produce these occupancy profiles are included in Appendix B.


Office Occupancy Profile
% Occupan
Hour
M-F
Sat
Sun

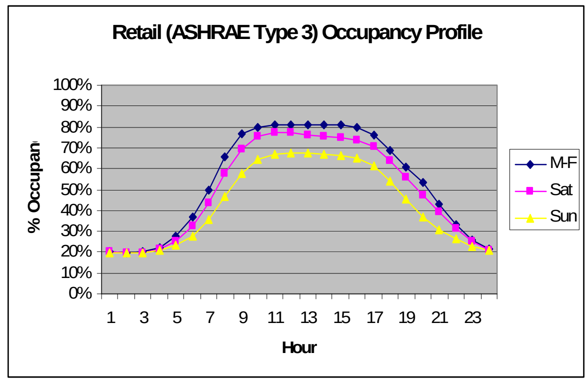
(a)


Retail (ASHRAE Type 1) Occupancy Profile
% Occupan
Hour
M-F
Sat
Sun

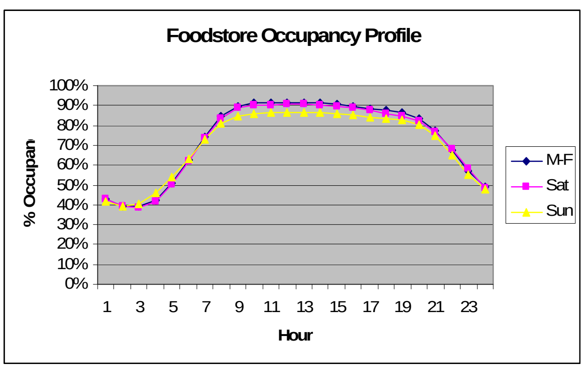
(b)


Retail (ASHRAE Type 2) Occupancy Profile
% Occupan
Hour
M-F
Sat
Sun

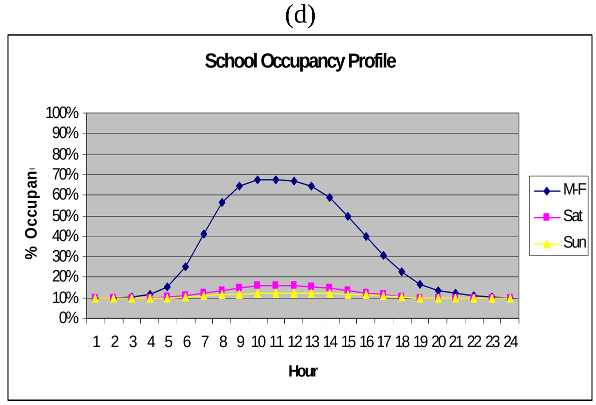
(c)


Retail (ASHRAE Type 3) Occupancy Profile
% Occupan
Hour
M-F
Sat
Sun

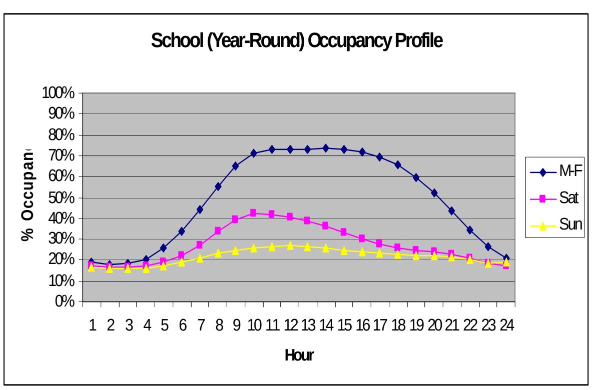
(d)


Foodstore Occupancy Profile
% Occupan
Hour
M-F
Sat
Sun

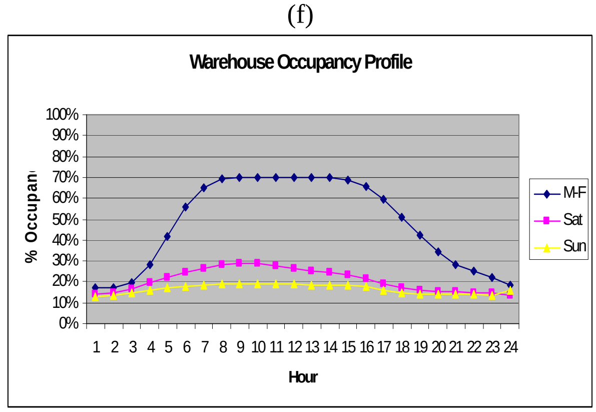
(e)


School Occupancy Profile
% Occupan
Hour
M-F
Sat
Sun

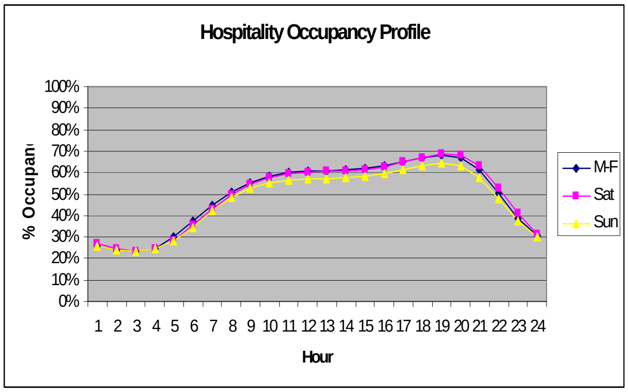
(f)


School (Year-Round) Occupancy Profile
% Occupan
Hour
M-F
Sat
Sun

(g)


Warehouse Occupancy Profile
% Occupan
Hour
M-F
Sat
Sun

(h)

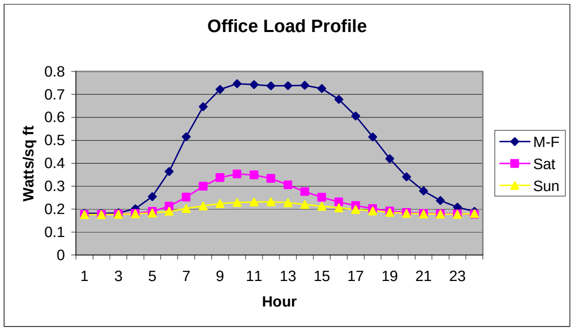


(i)

Figure 3. Occupancy Profiles by Building Prototype

4.2.2 Prototype Load Profiles

We constructed the load profiles for each prototype by multiplying the occupancy at each hour of the day by the estimated load (watts/square foot) for that prototype. Figure 4 shows the results of this analysis. Detailed calculations are included in Appendix C.


Office Load Profile
Watts/sq ft
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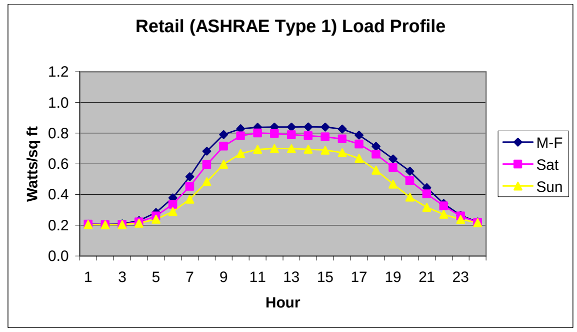
1 3 5 7 9 11 13 15 17 19 21 23
Hour
M-F
Sat
Sun

(a)


Retail (ASHRAE Type 1) Load Profile
Watts/sq ft
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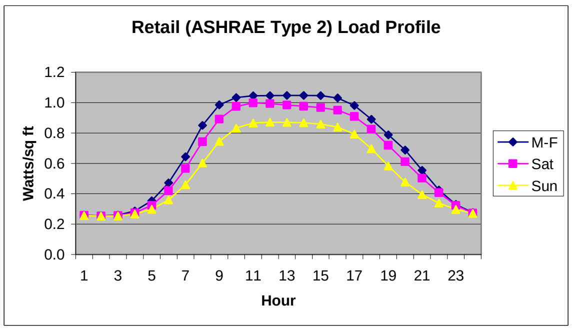
Hour
M-F
Sat
Sun

(b)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Watts/sq ft
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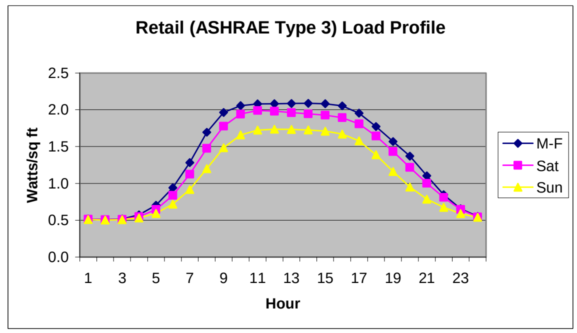
Hour
M-F
Sat
Sun

(c)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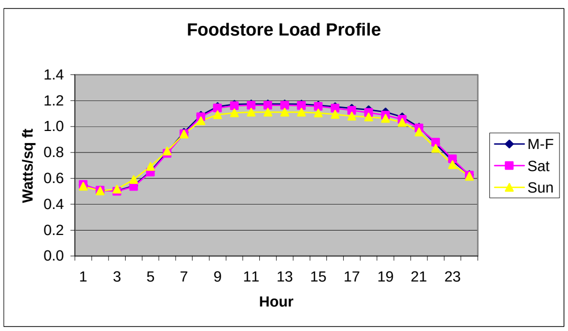
Hour
M-F
Sat
Sun

(d)


Foodstore Load Profile
Watts/sq ft
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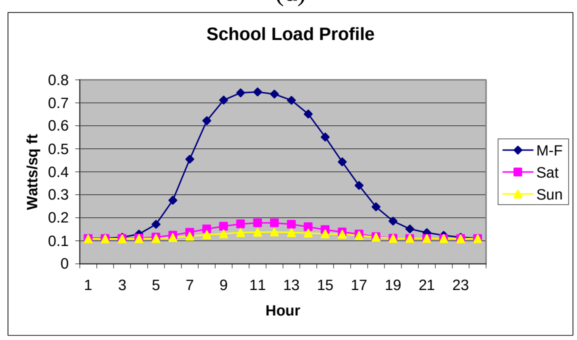
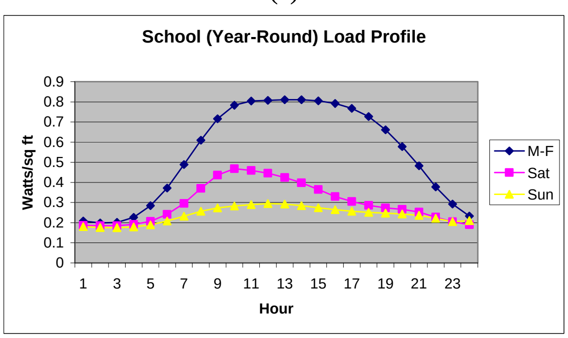
1 3 5 7 9 11 13 15 17 19 21 23
Hour
M-F
Sat
Sun

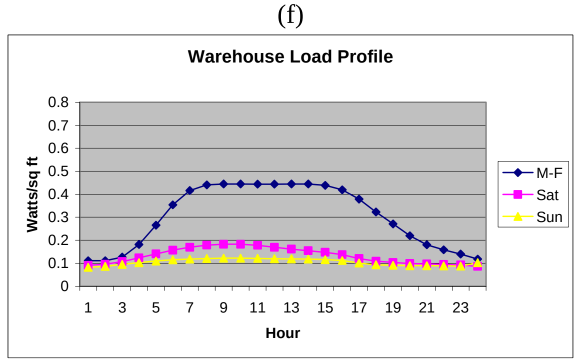
(e)


School Load Profile
Watts/sq ft
0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1 0
1 3 5 7 9 11 13 15 17 19 21 23
Hour
M-F
Sat
Sun

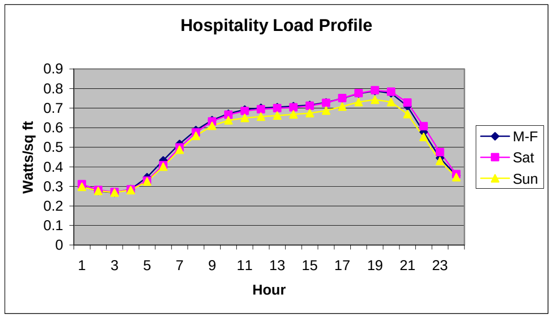
(f)


School (Year-Round) Load Profile
Watts/sq ft
0.9 0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1 0
1 3 5 7 9 11 13 15 17 19 21 23
Hour
M-F
Sat
Sun

(g)


Warehouse Load Profile
Watts/sq ft
0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1 0
1 3 5 7 9 11 13 15 17 19 21 23
Hour
M-F
Sat
Sun

(h)



(i)

Figure 4. Load Profiles by Building Prototype

4.3 Cost Analysis

Cost models were prepared for each of the building prototypes based on the project team's design experience and communication with lighting manufacturers (see attached LightFair memorandum in Appendix F). We calculated the costs of the proposed measure as incremental values per square foot beyond the equipment currently required by code. These values reflect the additional cost of the ballast and digital devices attributed to the use of tuning as a control strategy. Figure 5 below lists this incremental cost for each of our prototypes. Detailed cost calculations are provided in Appendix D.

Prototype	Measure cost per square foot
Office	$0.61
Retail (ASHRAE Type 1)	$0.56
Retail (ASHRAE Type 2)	$1.04
Retail (ASHRAE Type 3)	$2.00
Foodstore	$0.66
School	$0.65
School (Year-Round)	$0.65
Warehouse	$0.37
Hospitality	$0.85

Figure 5. Summary of Incremental Costs by Building Prototype

4.4 Potential Energy Savings

We estimated the potential energy savings from this measure using the methodology described above in Section 3.2.3. Typical lighting installations are designed to provide a higher light level at the start of the lamping cycle, in order to account for lamp lumen depreciation and other light loss factors over lamp life. In addition, the constraints of standard lighting geometries, available luminaire sizes, and lamping usually create a situation in which the lighting designer must specify even higher light levels than are necessary to meet minimum maintained illuminance requirements. Based on these factors, we assume that by tuning lighting to the required level during the initial part of lamp life, a 15% power reduction over the lamping cycle is possible.

As this measure will potentially enable a range of other lighting control strategies besides tuning, additional energy savings beyond those described in this report may be possible if the proposal is adopted.

4.5 Stakeholder Feedback

Several important points were raised during discussion of the proposed measure with stakeholders that ultimately shaped the results of our analysis and the final recommendations provided in this report. These issues can be summarized as follows:

- Stakeholders requested a thorough investigation of the cost of devices, installation and commissioning associated with the proposed code changes.
- The use of dimming systems to comply with the new requirements was widely supported by participants, provided that the low end of the dimming range would not be required to go nominally below 30% of power.
- Cost-effectiveness was not proven for low-usage spaces, such as K-12 schools. As a result, stakeholders recommended that we include an exception in the proposed code language that allows a slightly higher minimum power density for these spaces, exempting them from the controls requirements.

4.6 Cost-Effectiveness Analysis

We performed a cost-effectiveness analysis of the proposed measure using the 2011 Life-Cycle Cost Methodology provided by the California Energy Commission. The results of this analysis are summarized in Figure 6 below. The detailed calculations used to determine cost-effectiveness are included in Appendix E.

Prototype	**Incremental Cost/Square Foot**	**Cost-Benefit Breakeven Point**	**Cost-Effective?**
Office	$0.61	$ 0.81	Yes
Retail (ASHRAE Type 1)	$0.56	$ 1.16	Yes
Retail (ASHRAE Type 2)	$1.04	$ 1.51	Yes
Retail (ASHRAE Type 3)	$2.00	$ 3.28	Yes
Foodstore	$0.66	$ 2.15	Yes
School	$0.65	$ 0.48	No
School (Year-Round)	$0.65	$ 1.01	Yes
Warehouse	$0.37	$ 0.41	Yes
Hospitality	$0.85	$ 1.22	Yes

Figure 6. Summary of Cost-Effectiveness Analysis by Building Prototype

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

5.1 Summary of Recommendations

Based on the above analysis, we recommend the following changes to the current Title 24 requirements for controllable lighting:

1. Modify Section 131(b) to require controllable ballasts for all interior lighting systems with a total lighting power density of greater than 0.5 watts per square foot. The specific control steps required will vary depending on the light source type.

2. Provide an exception to this requirement for classrooms under 0.7 watts per square foot.

5.2 Proposed Language

SECTION 131 - INDOOR LIGHTING CONTROLS THAT SHALL BE INSTALLED

(b) ~~Multi-Level Lighting Controls.~~ Controllable Lighting

The general lighting of any enclosed space 100 square feet or larger, and has a connected lighting load that exceeds ~~0.8~~ 0.5 watts per square foot, shall have ~~multi-level lighting controls~~ controllable lighting~~. Multi-level controls shall~~ complying with the requirements of Table 131-A.~~have at least one control step that is between 30 percent and 70 percent of design lighting power and allow the power of all lights to be manually turned off. A reasonably uniform level of illuminance shall be achieved by any of the following:~~

~~1. Continuous or stepped dimming of all lamps or luminaires; or~~
~~2. Switching alternate lamps in luminaires, alternate luminaires, and alternate rows of luminaires.~~

EXCEPTIONS to Section 131(b):

1. ~~Lights in corridors.~~ Classrooms with a connected general lighting load of 0.7 watts per square foot and less shall have at least one step between 30-70 percent of full rated power.
2. A space that has only one luminaire with no more than two lamps.

Table 131-A. Light Source Controllability and Uniformity Requirements

Luminaire Type	Minimum Required Control Steps:	A reasonably uniform level of illuminance shall be achieved by:
Incandescent, halogen, and LED lamps and LED lighting systems	Continuous dimming - 10%-100% of Full Power	Continuous dimming
Fluorescent linear (including U-bent) lamps > 13 watts; induction lamps >25 watts	Full[1], High[2], Medium[3], Low[4]	Stepped dimming, continuous dimming, switching alternate lamps in a luminaire[5]
Fluorescent CF pin based[6] > 20 watts and Fluorescent GU-24 based > 20 watts	Continuous dimming 20 – 100% of full power	Continuous dimming
Linear fluorescent lamps 13 watts and less, Fluorescent CF pin based[6] 20 watts and less, and Fluorescent GU-24 20 watts and less	One step between 30-70 percent of rated power	Stepped dimming, continuous dimming, switching alternate lamps, switching alternate luminaires
HID and Other Light Sources	One step between 50-70 percent of rated power	Stepped dimming, Continuous dimming, Switching alternate lamps in a luminaire[7]

1. Full: full rated input power of ballast and lamp, corresponding to maximum ballast factor
2. High: between 80% and 85% of rated power
3. Medium: between 50% and 70% of rated power
4. Low: between 20% and 40% of rated power
5. Luminaires with at least four lamps illuminating the same area and in the same manner.
6. Includes, twin tube, multiple twin tube, long twin tube, and spiral lamps
7. Luminaires with at least three lamps illuminating the same area and in the same manner.

SECTION 134 – REQUIRED NONRESIDENTIAL LIGHTING CONTROL ACCEPTANCE

(a) Lighting Control Acceptance. Before an occupancy permit is granted for a new building or space, or a new lighting system serving a building, space, or site is operated for normal use, all indoor and outdoor lighting controls serving the building, space, or site shall be certified as meeting the Acceptance Requirements for Code Compliance. A Certificate of Acceptance shall be submitted to the enforcement agency under Section 10-103(a) of Title 24, Part 1, that:

1. Certifies plans, specifications, installation certificates, and operating and maintenance information meet the requirements of Part 6.
2. Certifies that automatic daylighting controls meet the applicable requirements of Section 119 and Section 131(c) 2D.
3. Certifies that when a multi-level astronomical time switch is used to meet EXCEPTION 3 to Section 131(c)2B all general lighting in the skylit area is controlled by a multi-level astronomical time switch that meets the applicable requirements of Section 119 and that has an override switch that meets the requirements of Section 131(d)2.
4. Certifies that lighting controls meet the requirements of Section 131(a) through Section 131(c), Sections 131(e) and (f), and Section 146(a)2 as applicable.

5. Certifies that automatic lighting controls meet the applicable requirements of Section 119 and Section 131(d).
6. Certifies that occupant-sensors meet the applicable requirements of Section 119 and Section 131(d).
7. Certified that outdoor lighting controls meet the applicable requirements of Section 119 and Section 132.
8. Certifies that lighting system tuning settings are set according to settings specified on (form XXX).

6. Bibliography and Other Research

1. California Energy Commission. (March 2006). *California Commercial End-Use Survey* (CEC Publication #CEC-400-2006-005). Prepared by Itron, Inc. Retrieved from http://www.energy.ca.gov/2006publications/CEC-400-2006-005/CEC-400-2006-005.PDF.

2. Personal communications with vendors at LightFair. See attached memorandum (Appendix F).

7. Appendices

Appendix A. Spatial Breakdown of Building Prototypes

Building Type: OFFICE				
Space Type	**Allowed Ltg Pwr (W/ft^2)**	**% of Floor Space**	**Technology**	**$/watt**
Storage	0.6	5%	T5/T8	$0.440
Corridor	0.6	10%	CFL/LED	$0.880
Toilet	0.6	4%	T5/T8	$0.440
Service	0.7	5%	T5/T8	$0.440
Open Office	0.9	50%	T5/T8	$0.440
Private Office	1.1	15%	T5/T8	$0.440
Conference	1.4	9%	CFL/LED	$0.880
Lobby	1.5	2%	CFL/LED	$0.880
Weighted Average Load	W/sf 0.92		**$/W**	**$0.53**
Spaces with T5/T8		79%		
Spaces with CFL/LED		21%		
Incremental cost/sf	$/watt * watt/sf	$0.49		
Commissioning		$0.08		
TOTAL		**$0.56**		
Technology Classes	**Incremental added cost**			
	$/watt			
T5/T8	0.44			
CFL/LED	0.88			
HID EB				
HID MB				

Figure 7. Office Prototype

Building Type: RETAIL (ASHRAE TYPE 1)				
Space Type	**Allowed Ltg Pwr (W/ft^2)**	**% of Floor Space**	**Technology**	**$/watt**
Storage	0.6	15%	T5/T8	$0.440
Corridor	0.6	5%	CFL/LED	$0.880
Toilet	0.6	3%	T5/T8	$0.440
Service	0.7	4%	T5/T8	$0.440
Malls/Atria	1.2	5%	T5/T8	$0.440
Sales	1.2	64%	T5/T8	$0.440
Dressing Room	0.8	1%	CFL/LED	$0.880
Office	1.1	3%	T5/T8	$0.440
Weighted Average Load	W/sf 1.035		**$/W**	**$0.47**
Spaces with T5/T8		30%		
Spaces with CFL/LED		70%		
Incremental cost/sf	$/watt * watt/sf	$0.48		
Commissioning		$0.08		
TOTAL		**$0.56**		
Technology Classes	**Incremental added cost**			
	$/watt			
T5/T8	0.44			
CFL/LED	0.88			
HID EB				
HID MB				

Figure 8. Retail (ASHRAE Type 1) Prototype

Building Type: RETAIL (ASHRAE TYPE 2)				
Space Type	**Allowed Ltg Pwr (W/ft^2)**	**% of Floor Space**	**Technology**	**$/watt**
Storage	0.6	15%	T5/T8	$0.440
Corridor	0.6	5%	CFL/LED	$0.880
Toilet	0.6	3%	T5/T8	$0.440
Service	0.7	4%	T5/T8	$0.440
Malls/Atria	1.2	5%	T5/T8	$0.440
Sales	1.6	64%	CFL/LED	$0.880
Dressing Room	0.8	1%	CFL/LED	$0.880
Office	1.1	3%	T5/T8	$0.440
Weighted Average Load	W/sf 1.291		**$/W**	**$0.75**
Spaces with T5/T8		30%		
Spaces with CFL/LED		70%		
Incremental cost/sf	$/watt * watt/sf	$0.97		
Commissioning		$0.08		
TOTAL		**$1.04**		
Technology Classes	**Incremental added cost**			
	$/watt			
T5/T8	0.44			
CFL/LED	0.88			
HID EB				
HID MB				

Figure 9. Retail (ASHRAE Type 2) Prototype

Building Type: RETAIL (ASHRAE TYPE 3)				
Space Type	**Allowed Ltg Pwr (W/ft²)**	**% of Floor Space**	**Technology**	**$/watt**
Storage	0.6	15%	T5/T8	$0.440
Corridor	0.6	5%	CFL/LED	$0.880
Toilet	0.6	3%	T5/T8	$0.440
Service	0.7	4%	T5/T8	$0.440
Malls/Atria	1.2	5%	T5/T8	$0.440
Sales	3.6	64%	CFL/LED	$0.880
Dressing Room	0.8	1%	CFL/LED	$0.880
Office	1.1	3%	T5/T8	$0.440
Weighted Average Load		W/sf 2.571	**$/W**	**$0.75**
Spaces with T5/T8		30%		
Spaces with CFL/LED		70%		
Incremental cost/sf	$/watt * watt/sf	$1.92		
Commissioning		$0.08		
TOTAL		**$2.00**		
Technology Classes	**Incremental added cost**			
	$/watt			
T5/T8	0.44			
CFL/LED	0.88			
HID EB				
HID MB				

Figure 10. Retail (ASHRAE Type 3) Prototype

Building Type: FOOD STORE				
Space Type	**Allowed Ltg Pwr (W/ft²)**	**% of Floor Space**	**Technology**	**$/watt**
Storage	0.6	22%	T5/T8	$0.440
Corridor	0.6	1%	CFL/LED	$0.880
Toilet	0.6	2%	T5/T8	$0.440
Service	0.7	6%	T5/T8	$0.440
Grocery Sales	1.6	65%	T5/T8	$0.440
Office	1.1	2%	CFL/LED	$0.880
Kitchen	1.6	2%	T5/T8	$0.440
Weighted Average Load		W/sf 1.286	**$/W**	**$0.45**
Spaces with T5/T8		97%		
Spaces with CFL/LED		3%		
Incremental cost/sf	$/watt * watt/sf	$0.58		
Commissioning		$0.08		
TOTAL		**$0.66**		
Technology Classes	**Incremental added cost**			
	$/watt			
T5/T8	0.44			
CFL/LED	0.88			
HID EB				
HID MB				

Figure 11. Foodstore Space Types

Building Type: SCHOOL (K-12)				
Space Type	**Allowed Ltg Pwr (W/ft²)**	**% of Floor Space**	**Technology**	**$/watt**
Storage	0.6	5%	T5/T8	$0.440
Corridor	0.6	4%	CFL/LED	$0.880
Toilet	0.6	3%	T5/T8	$0.440
Service	0.7	5%	T5/T8	$0.440
Auditorium	1.5	4%	CFL/LED	$0.880
Classroom	1.2	46%	T5/T8	$0.440
Library - Read	1.2	2%	T5/T8	$0.440
Library - Stacks	1.5	4%	T5/T8	$0.440
Office	1.1	6%	CFL/LED	$0.880
Dining	1.1	4%	T5/T8	$0.440
Gymnasium	1.0	8%	T5/T8	$0.440
Kitchen	1.6	2%	T5/T8	$0.440
Laboratory	1.4	4%	T5/T8	$0.880
Locker Room	0.8	3%	T5/T8	$0.440
Weighted Average Load	W/sf 1.105		**$/W**	**$0.52**
Spaces with T5/T8		86%		
Spaces with CFL/LED		14%		
Incremental cost/sf	$/watt * watt/sf	$0.57		
Commissioning		$0.08		
TOTAL		**$0.65**		
Technology Classes	**Incremental added cost** $/watt			
T5/T8	0.44			
CFL/LED	0.88			
HID EB				
HID MB				

Figure 12. School (K-12) Prototype

Building Type: SCHOOL (YEAR-ROUND)				
Space Type	**Allowed Ltg Pwr (W/ft^2)**	**% of Floor Space**	**Technology**	**$/watt**
Storage	0.6	5%	T5/T8	$0.440
Corridor	0.6	4%	CFL/LED	$0.880
Toilet	0.6	3%	T5/T8	$0.440
Service	0.7	5%	T5/T8	$0.440
Auditorium	1.5	4%	CFL/LED	$0.880
Classroom	1.2	46%	T5/T8	$0.440
Library - Read	1.2	2%	T5/T8	$0.440
Library - Stacks	1.5	4%	T5/T8	$0.440
Office	1.1	6%	CFL/LED	$0.880
Break Room	1.1	4%	T5/T8	$0.440
Multipurpose Room	1.0	8%	T5/T8	$0.440
Vending Area	1.6	2%	T5/T8	$0.440
Laboratory	1.4	4%	T5/T8	$0.880
Locker Room	0.8	3%	T5/T8	$0.440
Weighted Average Load	W/sf 1.105		**$/W**	**$0.52**
Spaces with T5/T8		86%		
Spaces with CFL/LED		14%		
Incremental cost/sf	$/watt * watt/sf	$0.57		
Commissioning		$0.08		
TOTAL		**$0.65**		

Technology Classes	**Incremental added cost**
	$/watt
T5/T8	0.44
CFL/LED	0.88
HID EB	
HID MB	

Figure 13. School (Year-Round) Prototype

Building Type: WAREHOUSE				
Space Type	**Allowed Ltg Pwr (W/ft²)**	**% of Floor Space**	**Technology**	**$/watt**
Storage	0.6	85%	T5/T8	$0.440
Corridor	0.6	2%	CFL/LED	$0.880
Toilet	0.6	1%	T5/T8	$0.440
Service	0.7	4%	T5/T8	$0.440
Office	1.1	2%	CFL/LED	$0.880
Low Bay	0.9	3%	T5/T8	$0.440
High Bay	1.0	2%	T5/T8	$0.440
Precision	1.2	1%	T5/T8	$0.440
Weighted Average Load	W/sf 0.637		**$/W**	**$0.46**
Spaces with T5/T8		96%		
Spaces with CFL/LED		4%		
Incremental cost/sf	$/watt * watt/sf	$0.29		
Commissioning		$0.08		
TOTAL		**$0.37**		
Technology Classes	**Incremental added cost** $/watt			
T5/T8	0.44			
CFL/LED	0.88			
HID EB				
HID MB				

Figure 14. Warehouse Prototype

Building Type: HOSPITALITY				
Space Type	**Allowed Ltg Pwr (W/ft^2)**	**% of Floor Space**	**Technology**	**$/watt**
Storage	0.6	5%	T5/T8	$0.440
Corridor	0.6	2%	CFL/LED	$0.880
Toilet	0.6	7%	T5/T8	$0.440
Service	0.7	6%	T5/T8	$0.440
Dining	1.1	30%	CFL/LED	$0.880
Kitchen	1.6	20%	T5/T8	$0.440
Hotel Lobby	1.1	10%	CFL/LED	$0.880
Hotel Function Area	1.5	5%	T5/T8	$0.440
Convention/Multipurpose	1.4	10%	CFL/LED	$0.880
Lounge/Recreation	1.1	5%	T5/T8	$0.440
Weighted Average Load	W/sf 1.156		**$/W**	**$0.67**
Spaces with T5/T8		58%		
Spaces with CFL/LED		42%		
Incremental cost/sf	$/watt * watt/sf	$0.77		
Commissioning		$0.08		
TOTAL		**$0.85**		
Technology Classes	**Incremental added cost**			
	$/watt			
T5/T8	0.44			
CFL/LED	0.88			
HID EB				
HID MB				

Figure 15. Hospitality Prototype

Appendix B. Excerpts from Benya Lighting Design White Paper on Lighting Controls

Lighting Controls for High Performance Buildings

James R Benya, PE, FIES, FIALD, LC

8-26-10

Includes "Are You Using State of the Art Controls" from Architectural Lighting Magazine, February, 2009, by the Author

1. Introduction

Until the mid-1970's, buildings were usually designed without any type of lighting control. In fact, many were designed without heating systems either, because of the enormous heat produced by 24-hour operation of indoor lighting systems. In hot climates, you can imagine how this added to the amount of air conditioning required to cool the whole building. No wonder that since the first energy codes in 1975, switches for every room is a basic requirement.
But even if you're designing super efficient buildings, you will still have to provide lighting. Normally efficient lighting with simple switching will consume 20-40 percent of the total electric energy use of the building, with most of it "on peak" when electricity is most expensive. With the best lamps and ballasts, a super efficient design can save a few more watts. But to significantly reduce lighting energy use, especially on peak, using state-of-the-art lighting controls is probably the most effective way.

But what constitutes state-of-the-art lighting controls? The overarching concept of state-of-the-art lighting controls is to offset the cost of high performance controls by reducing the costs of equipment and wiring, including copper, steel, and labor that are normally associated with lighting controls systems. These systems have the following distinctions:

- Digital communications over a network of interconnected devices.
- Distributed intelligence, although a central computer may be necessary for multi-zone functions.
- Smart dimming ballasts and drivers with the ability to turn themselves on and off and respond to control signals for dimming, and/or smart zone controllers with relays and dimmers to control groups of incandescent lamps and as well as modern sources with dumb ballasts and drivers.
- Reduced line voltage wiring with simple "hot" branch circuits and home runs
- No line voltage control devices such as snap switches, dimmers or line voltage motion sensors.
- No central panels, especially large panels with racks of dimmers or relays.

2. Brains Everywhere

Contemporary light sources used in commercial lighting like LED and fluorescent adapt to digital controls easily. Simple additions to ballast or driver internal electronic circuits permit a wide range of control options including on/off switching, dimming and digital communications. Then brains are added so that ballasts and drivers can remember their current state and perform complex functions like individual addressing, programmed response and the ability to communicate with a central control panel or building[1] management system.
An alternate smart system takes the "brains" out of the ballasts and puts them in zone controllers. Zone controllers are a very useful hybrid; they perform almost all of the duties of a smart ballast, but one controller can drive a large number of conventional lamps and ballasts that all switch and dim at the same time and by the same amount.

What makes all of this possible is the low cost of embedded controllers with memory. In the case of a fluorescent ballast, the added cost of brains and dimming should only cost about $25 to $30 more than a non-dimming "dumb" ballast. Keeping this from becoming reality is the miniscule demand for these types of products, but that is about to change. In 2010, the OEM price for a 2-lamp "smart ballast" dropped below $50, with analog dimming ballasts around $20.

3. State-of-the-art Commercial Lighting Control Options

Today, there are significantly different approaches to commercial building control systems.

DALI-based – Digital Addressable Lighting Interface-based (DALI) systems are based on the international DALI standard. They are simple to the point of elegance. A complete DALI system consists of a bus hub and sensors, ballasts, and input ports connected on a simple 2-wire bus circuit. Programming is stored throughout the circuit's devices. Although DALI buses are limited to 64 nodes per bus, multiple buses can easily be used. A master "overlay" computer server can be added that interconnects buses and enables inter-bus communication and powerful functions.

However, the original DALI standard is flawed. In its original form, DALI lacks modern communication network fundamentals, and a system based on the original "two byte" DALI standard will fail if the network is used for bi-directional communications. NEMA formed a working group and a better "three-byte" DALI is presently being tested at the California Lighting Technology Center.

This effort notwithstanding, there are several systems, such as Lutron's Ecosystem and Leviton's Sector, that are DALI-based but have proprietary improvements. Other systems such as Philips Dynalite and Crestron employ DALI but isolate the bi-directional communications from the DALI bus, minimizing or eliminating the problems in practice.

Zone-based - Zone-based systems are hardware intensive and require a master overlay computer server. For each zone (or a small group of zones) there is a zone controller to which the loads, sensors and input ports are hardwired. Systems include a controller for every zone and a digital network

[1] End user cost premium compared to a generic, non dimming 2 lamp ballast

(usually Ethernet). The master overlay computer connects and communicates with all of the zone controllers. Zone controllers can switch any lamp load and can dim ten volt analog ballasts and drivers.

Wireless - Wireless communication networks are similar to zone-based systems, except that instead of Ethernet, a wireless network is used. In older buildings, wiring is expensive and often almost impossible, and wireless is often seen as the only practical way to provide modern controls. This part of the market is new and comparatively immature, due to the evolving capabilities of the RF lighting controls industry and competing standards such as Zigbee and Z-Wave. However, many industry experts feel that commercial grade wireless systems are just about ready to play a major role. At present, wireless systems seem to work well for small to medium sized buildings.

Legacy-based - Legacy-based systems are hardware and wiring intensive. Because they are based around old-fashioned relay and dimmer panel design, these systems are only marginally described as state-of-the-art. But they can offer the best of the old along with some of the new, giving designers the most options including DALI. Because these systems were developed for networking amidst relay and dimming cabinets, powerful overlay computer controls are standard.

Power-Line Carrier - Once problematic, new power line communications technology makes this approach make sense again – but with limitations. To ensure reliable communications, each controlled circuit must pass through a combination filter and signal generator, which works best in a legacy-type central control cabinet. Downstream ballasts must be compatible power line ballasts, too.

4. Choosing a System

For most projects, the decision to use a full-function lighting control system hinges on its energy cost savings potential. There are eight principal ways that lighting controls save energy cost:

- ***Daylighting*** where lights are dimmed or extinguished in response to daylight.
- ***Small zone motion and/or vacancy detection*** where sensors can see all occupants and extinguish lights when the space is unoccupied.
- ***Large zone motion and/or vacancy detection*** where one or more sensors are often combined with scheduling to provide night security and safety.
- ***User dimming*** where individual occupants can control lights affecting their task.
- ***Tuning*** where maximum light levels can be set to limit lighting power.
- ***Scheduling*** where lights are switched on a fixed or programmed schedule.
- ***Adaptation compensation*** where interior lights are dimmed at night to ease adaptation of the eye and harvest energy savings at night.
- ***Demand management and response*** where overall building energy use is monitored and reduced in response to energy cost or grid emergencies.

Lighting controls are also expected to support function use of the space. The most common of these is the ability to change lighting scenes to support audio, video, and similar functions. From the following chart, the advantage of state-of-the-art systems becomes clear. While it is possible to achieve almost every level of control with conventional lighting controls, the cost and complexity can become profound.

Performance Capabilities of Commercial Lighting Control Systems ★ Performs well at reasonable cost O Performs acceptably with cost or performance limits X Function not possible or unusually expensive and/or difficult ? System might be capable	***Daylighting***	***Small Zone Motion and Vacancy***	***Large Zone Motion and Vacancy***	***User Dimming***	***Tuning***	***Scheduling***	***Adaptation Compensation***	***Demand Management and Response***	***Scenes and AV Interface***	***Cost ($=least $$$$=most)***
State-of-the-art Systems										
DALI-based (stand alone)	★	★	O	★	★	O	X	X	(3)	$$-$$$
DALI-based (with overlay)	★	★	★	★	★	★	O	★	(3)	$$-$$$$
Zone-based with overlay	★	★	★	★	★	★	O	★	X	$$-$$$$
Wireless Zone-based	★	★	★	★	★	★	X	★	X	$$-$$$$
Legacy-based	O	O	★	O	(4)	★	O	★	O	$$-$$$$
Power Line Carrier	O	O	★	X	(4)	★	O	★	O	$$-$$$$
Conventional Lighting Controls										
Stand alone analog system with analog dimming ballasts without central relay panels	O	★	★	O	O	X	X	X	★	$-$$$
Old school relay panels	X	O	O	X	X	★	X	X	X	$-$$
BAS overlay to legacy system with stand alone small zones, D/A outputs and analog dimming ballasts throughout	★	★	★	★	★	★	O	★	X	$$$-$$$$

Notes

(1) When using the DALI option
(2) Systems employing large numbers of relays in central cabinets only
(3) Depends on manufacturer
(4) All ballasts on the same zone can be tuned to the same level

There are now a number of buildings and case studies in which state-of-the-art lighting controls help realize 50-92 percent lighting energy savings when compared to a building with the same lighting but only the simplest controls.

5. The Hidden Costs of Software, Programming, and Commissioning

Programming and commissioning costs should be included in system specifications and factored into estimates. Someone has to do it, and it is best done by trained and experienced personnel. Consider making it a requirement of the manufacturer or a trained agent. The specifier should provide a detailed description of all the functions expected from every luminaire and component, but without a significant investment in their own training, the actual programming and commissioning should be left to others. Also, make sure that the contractors get training in lighting controls bidding, installation and troubleshooting. Unless the contractor believes that installation cost savings will occur, the cost of state-of-the-art systems will be much higher than expected.

6. Specification Considerations

As a result of designing and commissioning systems from a number of vendors, the following are key issues in selecting and specifying systems at this time.

1. **System Simplicity** The ideal system is "plug-program-play". Wiring should be easy and faultless with a minimum of wire stripping or the need to land individual wires. The wiring methods should be simple, repetitive and logical.
2. **Single Point Responsibility** Regardless of how many manufacturers' products are used, there should be a single point of responsibility for the compatibility of the products and for all necessary products being part of the system.
3. **Supplier Start-up, Commissioning and Programming** A company representative or, preferably, a factory engineer should be a integral part of the installation and commissioning team. This person should be well trained and capable of quickly reviewing and fixing installation errors, checking system integrity, placing the system into operating condition, and performing initial programming. This person should teach the owner's personnel how to operate and reprogram the system and should be available on-call throughout a reasonable shake down period.
4. **System Maturity** The system should be well into a third generation of the product if possible. First generation products should only be used on a potential "guinea pig" basis.
5. **System Track Record** Comparable systems in current operation should be able to be reviewed and should have testimonials from several customers
6. **Warranty** The system should have as a minimum a comprehensive labor and material warranty for the first year and a declining value warranty on all parts for at least 5 years.
7. **Company Track Record** The company should have been in the architectural and/or energy lighting controls business for at least 10 years and have annual revenues in lighting controls and similar electrical construction materials of at least $100M in the domestic US market in

2009. The company's reputation for service and parts availability is an essential indicator of the long term viability of the system and is critically important in the decision to use the system

8. **Pricing** The system price should be fair. Hidden markups and other costs without added value should not be tolerated.

9. **Installation Costs** Don't forget to evaluate the cost of cabling and installation of control hardware.

10. **Performance** The system should provide all needed lighting controls functions for both energy management and architectural applications.
11. **Obsolescence** Is the system digital, hybrid or analog? Is it likely to be dropped when new generation systems are introduced? Will future products remain backwards compatible?
12. **Sole source vs. multiple source** Does the manufacturer rely upon the products of other companies (e.g. ballasts)? Is there a risk of finger pointing when things go wrong?
13. **Port and interface to BAS** Does the system provide a BACNET port for high level management?
14. **Data reporting** Does the system provide feedback, e.g. failed lamps and ballasts?
15. **Long term Viability of Company** How large is the Company? What is the likelihood of the Company's future existence? What is their place in the market?
16. **Application** Is this a single building system, an expansion of existing hardware and software, and/or potentially the start of a new campus standard?
17. **Avoidance of Hidden Costs and Pitfalls** Are there unresolved problems with previously installed systems? Is commissioning predictably fast and accurate? Will the company stand behind the product and make it right?

7. Choices (not exhaustive, others may be considered)

**Systems know to have Overlay Manager; others may as well*

DALI-based systems (all have zone-based functions with analog ballasts, too)

- Lutron Ecosystem
- Lutron Ecosystem with Quantum*
- Leviton Sector*
- Starfield Controls CoreNet*
- Lumenergi LMCS*

Zone Based

- Convia*
- Encellium*
- Wattstopper*

- Acuity LC&D*

Legacy

- ETC
- Crestron
- Acuity Synergy
- Lutron Grafik 7000*
- Schneider Square D*
- Crestron Green Light

Wireless

- Adura

Power Line Carrier

- Universal DLC

Appendix C. Occupancy Profiles from CEUS Data

	Office																				1.13	connected load		
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	M-F																							
W/ft^2	0.224	0.222	0.226	0.248	0.312	0.447	0.632	0.793	0.886	0.917	0.912	0.905	0.906	0.908	0.891	0.833	0.745	0.632	0.516	0.419	0.344	0.291	0.256	0.233
Occ %	20%	20%	20%	22%	28%	40%	56%	70%	78%	81%	81%	80%	80%	80%	79%	74%	66%	56%	46%	37%	30%	26%	23%	21%
	Sat																							
W/ft^2	0.217	0.217	0.219	0.223	0.234	0.261	0.31	0.368	0.414	0.433	0.429	0.409	0.376	0.339	0.308	0.284	0.265	0.249	0.235	0.227	0.223	0.221	0.22	0.218
Occ %	19%	19%	19%	20%	21%	23%	27%	33%	37%	38%	38%	36%	33%	30%	27%	25%	23%	22%	21%	20%	20%	20%	19%	19%
	Sun																							
W/ft^2	0.217	0.217	0.218	0.221	0.225	0.235	0.248	0.263	0.275	0.281	0.284	0.285	0.28	0.271	0.262	0.253	0.244	0.236	0.228	0.223	0.22	0.219	0.218	0.222
Occ %	19%	19%	19%	20%	20%	21%	22%	23%	24%	25%	25%	25%	25%	24%	23%	22%	22%	21%	20%	20%	19%	19%	19%	20%

Figure 16. Occupancy Profile for Office Sector

	Retail																				1.34	connected load		
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	M-F																							
W/ft^2	0.269	0.265	0.27	0.298	0.367	0.49	0.668	0.883	1.024	1.072	1.085	1.086	1.087	1.088	1.086	1.071	1.018	0.924	0.818	0.714	0.575	0.441	0.342	0.286
Occ %	20%	20%	20%	22%	27%	37%	50%	66%	76%	80%	81%	81%	81%	81%	81%	80%	76%	69%	61%	53%	43%	33%	25%	21%
	Sat																							
W/ft^2	0.268	0.264	0.267	0.286	0.336	0.436	0.587	0.77	0.926	1.012	1.037	1.032	1.022	1.014	1.004	0.987	0.943	0.857	0.746	0.635	0.522	0.422	0.336	0.283
Occ %	20%	20%	20%	21%	25%	33%	44%	57%	69%	76%	77%	77%	76%	76%	75%	74%	70%	64%	56%	47%	39%	32%	25%	21%
	Sun																							
W/ft^2	0.266	0.262	0.264	0.276	0.309	0.374	0.478	0.626	0.774	0.864	0.899	0.905	0.904	0.9	0.892	0.871	0.822	0.724	0.605	0.496	0.41	0.351	0.308	0.281
Occ %	20%	20%	20%	21%	23%	28%	36%	47%	58%	64%	67%	68%	67%	67%	67%	65%	61%	54%	45%	37%	31%	26%	23%	21%

Figure 17. Occupancy Profile for Retail Sector

	Grocery																			1.34	connected load			
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	M-F																							
W/ft^2	0.571	0.529	0.526	0.566	0.682	0.837	0.996	1.133	1.203	1.222	1.224	1.224	1.225	1.222	1.213	1.201	1.188	1.177	1.159	1.119	1.037	0.902	0.766	0.656
Occ %	43%	39%	39%	42%	51%	62%	74%	85%	90%	91%	91%	91%	91%	91%	91%	90%	89%	88%	86%	84%	77%	67%	57%	49%
	Sat																							
W/ft^2	0.576	0.53	0.521	0.559	0.675	0.826	0.984	1.121	1.191	1.21	1.213	1.213	1.213	1.211	1.204	1.19	1.172	1.155	1.134	1.099	1.03	0.915	0.782	0.651
Occ %	43%	40%	39%	42%	50%	62%	73%	84%	89%	90%	90%	90%	91%	90%	90%	89%	87%	86%	85%	82%	77%	68%	58%	49%
	Sun																							
W/ft^2	0.562	0.524	0.539	0.615	0.721	0.845	0.982	1.088	1.138	1.154	1.157	1.158	1.158	1.157	1.152	1.14	1.127	1.119	1.108	1.075	1	0.867	0.736	0.643
Occ %	42%	39%	40%	46%	54%	63%	73%	81%	85%	86%	86%	86%	86%	86%	86%	85%	84%	84%	83%	80%	75%	65%	55%	48%

Figure 18. Occupancy Profile for Grocery Sector

	School																			1.23	connected load			
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	M-F																							
W/ft^2	0.123	0.124	0.128	0.143	0.191	0.308	0.506	0.693	0.792	0.827	0.832	0.822	0.791	0.725	0.613	0.493	0.379	0.276	0.206	0.169	0.15	0.137	0.128	0.124
Occ %	10%	10%	10%	12%	16%	25%	41%	56%	64%	67%	68%	67%	64%	59%	50%	40%	31%	22%	17%	14%	12%	11%	10%	10%
	Sat																							
W/ft^2	0.122	0.122	0.122	0.124	0.129	0.138	0.152	0.168	0.181	0.193	0.198	0.197	0.191	0.179	0.165	0.154	0.144	0.131	0.124	0.122	0.122	0.122	0.122	0.122
Occ %	10%	10%	10%	10%	10%	11%	12%	14%	15%	16%	16%	16%	16%	15%	13%	13%	12%	11%	10%	10%	10%	10%	10%	10%
	Sun																							
W/ft^2	0.121	0.121	0.121	0.122	0.123	0.127	0.133	0.141	0.145	0.151	0.153	0.154	0.152	0.149	0.145	0.143	0.138	0.129	0.123	0.123	0.122	0.122	0.121	0.122
Occ %	10%	10%	10%	10%	10%	10%	11%	11%	12%	12%	12%	13%	12%	12%	12%	12%	11%	10%	10%	10%	10%	10%	10%	10%

Figure 19. Occupancy Profile for School Sector

	College																				1.04	connected load		
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	M-F																							
W/ft^2	0.196	0.188	0.19	0.213	0.268	0.35	0.46	0.573	0.674	0.737	0.756	0.76	0.762	0.763	0.758	0.745	0.722	0.684	0.622	0.544	0.454	0.356	0.275	0.22
Occ %	19%	18%	18%	21%	26%	34%	44%	55%	65%	71%	73%	73%	73%	73%	73%	72%	69%	66%	60%	52%	44%	34%	26%	21%
	Sat																							
W/ft^2	0.176	0.174	0.174	0.18	0.195	0.227	0.278	0.348	0.411	0.44	0.432	0.42	0.399	0.374	0.343	0.311	0.288	0.27	0.257	0.25	0.238	0.214	0.193	0.179
Occ %	17%	17%	17%	17%	19%	22%	27%	33%	40%	42%	42%	40%	38%	36%	33%	30%	28%	26%	25%	24%	23%	21%	19%	17%
	Sun																							
W/ft^2	0.17	0.166	0.165	0.169	0.178	0.196	0.219	0.241	0.257	0.266	0.273	0.278	0.275	0.268	0.258	0.249	0.241	0.236	0.233	0.229	0.223	0.209	0.193	0.198
Occ %	16%	16%	16%	16%	17%	19%	21%	23%	25%	26%	26%	27%	26%	26%	25%	24%	23%	23%	22%	22%	21%	20%	19%	19%

Figure 20. Occupancy Profile for College Sector

	Warehouse																				0.66	connected load		
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	M-F																							
W/ft^2	0.115	0.115	0.131	0.188	0.275	0.367	0.431	0.457	0.461	0.461	0.46	0.46	0.461	0.461	0.454	0.434	0.392	0.335	0.28	0.228	0.186	0.164	0.144	0.123
Occ %	17%	17%	20%	28%	42%	56%	65%	69%	70%	70%	70%	70%	70%	70%	69%	66%	59%	51%	42%	35%	28%	25%	22%	19%
	Sat																							
W/ft^2	0.094	0.099	0.111	0.128	0.145	0.162	0.175	0.185	0.189	0.189	0.184	0.176	0.168	0.16	0.152	0.143	0.125	0.113	0.107	0.102	0.1	0.098	0.096	0.089
Occ %	14%	15%	17%	19%	22%	25%	27%	28%	29%	29%	28%	27%	25%	24%	23%	22%	19%	17%	16%	15%	15%	15%	15%	13%
	Sun																							
W/ft^2	0.085	0.09	0.098	0.106	0.113	0.119	0.122	0.125	0.126	0.126	0.125	0.124	0.123	0.122	0.12	0.116	0.104	0.096	0.094	0.093	0.093	0.092	0.091	0.106
Occ %	13%	14%	15%	16%	17%	18%	19%	19%	19%	19%	19%	19%	19%	19%	18%	18%	16%	15%	14%	14%	14%	14%	14%	16%

Figure 21. Occupancy Profile for Warehouse Sector

	Restaurant												148892	kSqFt	0.355	Weighting Factor				1.41	connected load			
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	M-F																							
W/ft^2	0.275	0.241	0.225	0.245	0.308	0.399	0.503	0.62	0.763	0.923	1.041	1.095	1.117	1.133	1.142	1.144	1.141	1.122	1.08	1.009	0.866	0.659	0.477	0.355
Occ %	20%	17%	16%	17%	22%	28%	36%	44%	54%	65%	74%	78%	79%	80%	81%	81%	81%	80%	77%	72%	61%	47%	34%	25%
	Sat																							
W/ft^2	0.303	0.257	0.234	0.248	0.305	0.393	0.498	0.61	0.752	0.906	1.022	1.079	1.102	1.116	1.132	1.136	1.141	1.13	1.092	1.03	0.91	0.725	0.547	0.371
Occ %	21%	18%	17%	18%	22%	28%	35%	43%	53%	64%	72%	76%	78%	79%	80%	81%	81%	80%	77%	73%	65%	51%	39%	26%
	Sun																							
W/ft^2	0.268	0.245	0.228	0.241	0.293	0.376	0.47	0.569	0.697	0.835	0.933	0.984	1.009	1.027	1.038	1.04	1.036	1.017	0.972	0.898	0.765	0.59	0.434	0.331
Occ %	19%	17%	16%	17%	21%	27%	33%	40%	49%	59%	66%	70%	72%	73%	74%	74%	73%	72%	69%	64%	54%	42%	31%	23%

Figure 22. Occupancy Profile for Restaurant Sector

	Lodging												270044	kSqFt	0.645	Weighting Factor				0.86	connected load			
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	M-F																							
W/ft^2	0.273	0.258	0.255	0.269	0.321	0.394	0.455	0.491	0.483	0.443	0.407	0.39	0.382	0.381	0.384	0.402	0.433	0.477	0.52	0.542	0.528	0.456	0.367	0.308
Occ %	32%	30%	30%	31%	37%	46%	53%	57%	56%	51%	47%	45%	44%	44%	45%	47%	50%	56%	60%	63%	61%	53%	43%	36%
	Sat																							
W/ft^2	0.273	0.257	0.254	0.266	0.299	0.362	0.432	0.479	0.481	0.444	0.407	0.389	0.383	0.381	0.384	0.402	0.434	0.476	0.519	0.543	0.53	0.461	0.371	0.309
Occ %	32%	30%	30%	31%	35%	42%	50%	56%	56%	52%	47%	45%	45%	44%	45%	47%	50%	55%	60%	63%	62%	54%	43%	36%
	Sun																							
W/ft^2	0.273	0.257	0.255	0.266	0.298	0.36	0.43	0.478	0.479	0.442	0.406	0.387	0.381	0.379	0.382	0.4	0.432	0.475	0.517	0.54	0.526	0.458	0.37	0.308
Occ %	32%	30%	30%	31%	35%	42%	50%	56%	56%	51%	47%	45%	44%	44%	44%	47%	50%	55%	60%	63%	61%	53%	43%	36%

Figure 23. Occupancy Profile for Lodging Sector

	Hospitality (Combined Restaurant + Lodging)																				1.055	connected load		
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	M-F																							
W/ft^2	0.274	0.252	0.244	0.26	0.316	0.396	0.472	0.536	0.582	0.613	0.632	0.64	0.643	0.648	0.654	0.665	0.685	0.707	0.719	0.708	0.648	0.528	0.406	0.325
Occ %	26%	24%	23%	25%	30%	37%	45%	51%	55%	58%	60%	61%	61%	61%	62%	63%	65%	67%	68%	67%	61%	50%	38%	31%
	Sat																							
W/ft^2	0.283	0.257	0.247	0.26	0.301	0.373	0.455	0.526	0.577	0.608	0.626	0.634	0.638	0.643	0.65	0.663	0.685	0.709	0.722	0.716	0.665	0.554	0.434	0.331
Occ %	27%	24%	23%	25%	28%	35%	43%	50%	55%	58%	59%	60%	60%	61%	62%	63%	65%	67%	68%	68%	63%	53%	41%	31%
	Sun																							
W/ft^2	0.272	0.253	0.245	0.257	0.296	0.366	0.444	0.51	0.556	0.581	0.593	0.599	0.604	0.61	0.615	0.628	0.647	0.667	0.679	0.667	0.611	0.505	0.393	0.316
Occ %	26%	24%	23%	24%	28%	35%	42%	48%	53%	55%	56%	57%	57%	58%	58%	59%	61%	63%	64%	63%	58%	48%	37%	30%

Figure 24. Occupancy Profile for Hospitality (Combined Restaurant + Lodging) Sector

Appendix D. Prototype Load Profiles

Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	M-F																							
W	0.182	0.181	0.184	0.202	0.254	0.364	0.515	0.646	0.722	0.746	0.742	0.737	0.738	0.739	0.725	0.679	0.606	0.514	0.420	0.341	0.280	0.237	0.209	0.190
kW	0.00018	0.00018	0.00018	0.00020	0.00025	0.00036	0.00051	0.00065	0.00072	0.00075	0.00074	0.00074	0.00074	0.00074	0.00073	0.00068	0.00061	0.00051	0.00042	0.00034	0.00028	0.00024	0.00021	0.00019
	Sat																							
W	0.177	0.177	0.178	0.181	0.190	0.213	0.252	0.300	0.337	0.353	0.349	0.333	0.306	0.276	0.251	0.231	0.216	0.202	0.192	0.185	0.182	0.180	0.179	0.177
kW	0.00018	0.00018	0.00018	0.00018	0.00019	0.00021	0.00025	0.00030	0.00034	0.00035	0.00035	0.00033	0.00031	0.00028	0.00025	0.00023	0.00022	0.00020	0.00019	0.00019	0.00018	0.00018	0.00018	0.00018
	Sun																							
W	0.176	0.176	0.178	0.180	0.183	0.191	0.202	0.215	0.224	0.229	0.231	0.232	0.228	0.221	0.213	0.206	0.199	0.192	0.186	0.182	0.179	0.178	0.177	0.181
kW	0.00018	0.00018	0.00018	0.00018	0.00018	0.00019	0.00020	0.00021	0.00022	0.00023	0.00023	0.00023	0.00023	0.00022	0.00021	0.00021	0.00020	0.00019	0.00019	0.00018	0.00018	0.00018	0.00018	0.00018

Figure 25. Office Prototype Load Profile

Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	M-F																							
W	0.208	0.204	0.208	0.230	0.283	0.378	0.516	0.682	0.791	0.828	0.838	0.839	0.839	0.840	0.839	0.827	0.787	0.714	0.632	0.551	0.444	0.341	0.264	0.221
kW	0.00021	0.00020	0.00021	0.00023	0.00028	0.00038	0.00052	0.00068	0.00079	0.00083	0.00084	0.00084	0.00084	0.00084	0.00084	0.00083	0.00079	0.00071	0.00063	0.00055	0.00044	0.00034	0.00026	0.00022
	Sat																							
W	0.207	0.204	0.206	0.221	0.260	0.337	0.453	0.595	0.715	0.782	0.801	0.797	0.790	0.783	0.776	0.762	0.728	0.662	0.577	0.490	0.403	0.326	0.259	0.219
kW	0.00021	0.00020	0.00021	0.00022	0.00026	0.00034	0.00045	0.00059	0.00072	0.00078	0.00080	0.00080	0.00079	0.00078	0.00078	0.00076	0.00073	0.00066	0.00058	0.00049	0.00040	0.00033	0.00026	0.00022
	Sun																							
W	0.205	0.202	0.204	0.213	0.239	0.289	0.369	0.484	0.597	0.667	0.694	0.699	0.698	0.695	0.689	0.673	0.635	0.559	0.467	0.383	0.316	0.271	0.238	0.217
kW	0.00021	0.00020	0.00020	0.00021	0.00024	0.00029	0.00037	0.00048	0.00060	0.00067	0.00069	0.00070	0.00070	0.00070	0.00069	0.00067	0.00064	0.00056	0.00047	0.00038	0.00032	0.00027	0.00024	0.00022

Figure 26. Retail (ASHRAE Type 1) Prototype Load Profile

Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	M-F																							
W	0.259	0.255	0.260	0.287	0.353	0.472	0.644	0.851	0.986	1.033	1.045	1.046	1.047	1.048	1.046	1.032	0.981	0.890	0.788	0.688	0.554	0.425	0.329	0.276
kW	0.00026	0.00026	0.00026	0.00029	0.00035	0.00047	0.00064	0.00085	0.00099	0.00103	0.00105	0.00105	0.00105	0.00105	0.00105	0.00103	0.00098	0.00089	0.00079	0.00069	0.00055	0.00042	0.00033	0.00028
	Sat																							
W	0.258	0.254	0.257	0.275	0.324	0.420	0.565	0.742	0.892	0.975	0.999	0.994	0.985	0.977	0.968	0.951	0.908	0.825	0.719	0.611	0.503	0.407	0.323	0.273
kW	0.00026	0.00025	0.00026	0.00028	0.00032	0.00042	0.00057	0.00074	0.00089	0.00098	0.00100	0.00099	0.00098	0.00098	0.00097	0.00095	0.00091	0.00083	0.00072	0.00061	0.00050	0.00041	0.00032	0.00027
	Sun																							
W	0.256	0.252	0.254	0.266	0.298	0.360	0.460	0.603	0.745	0.833	0.866	0.872	0.871	0.867	0.859	0.839	0.792	0.697	0.583	0.478	0.395	0.338	0.296	0.271
kW	0.00026	0.00025	0.00025	0.00027	0.00030	0.00036	0.00046	0.00060	0.00075	0.00083	0.00087	0.00087	0.00087	0.00087	0.00086	0.00084	0.00079	0.00070	0.00058	0.00048	0.00039	0.00034	0.00030	0.00027

Figure 27. Retail (ASHRAE Type 2) Prototype Load Profile

Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	M-F																							
W	0.515	0.508	0.517	0.571	0.704	0.940	1.282	1.694	1.964	2.057	2.081	2.084	2.085	2.087	2.083	2.054	1.954	1.773	1.569	1.369	1.103	0.846	0.656	0.549
kW	0.00052	0.00051	0.00052	0.00057	0.00070	0.00094	0.00128	0.00169	0.00196	0.00206	0.00208	0.00208	0.00209	0.00209	0.00208	0.00205	0.00195	0.00177	0.00157	0.00137	0.00110	0.00085	0.00066	0.00055
	Sat																							
W	0.515	0.506	0.512	0.548	0.645	0.836	1.126	1.478	1.777	1.942	1.990	1.980	1.961	1.945	1.927	1.893	1.809	1.644	1.432	1.218	1.002	0.810	0.644	0.543
kW	0.00051	0.00051	0.00051	0.00055	0.00064	0.00084	0.00113	0.00148	0.00178	0.00194	0.00199	0.00198	0.00196	0.00195	0.00193	0.00189	0.00181	0.00164	0.00143	0.00122	0.00100	0.00081	0.00064	0.00054
	Sun																							
W	0.510	0.502	0.506	0.530	0.593	0.717	0.916	1.201	1.484	1.658	1.724	1.737	1.734	1.727	1.711	1.671	1.577	1.388	1.161	0.951	0.786	0.674	0.590	0.539
kW	0.00051	0.00050	0.00051	0.00053	0.00059	0.00072	0.00092	0.00120	0.00148	0.00166	0.00172	0.00174	0.00173	0.00173	0.00171	0.00167	0.00158	0.00139	0.00116	0.00095	0.00079	0.00067	0.00059	0.00054

Figure 28. Retail (ASHRAE Type 3) Prototype Load Profile

Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	M-F																							
W	0.548	0.508	0.504	0.543	0.655	0.803	0.956	1.087	1.154	1.172	1.175	1.175	1.175	1.173	1.164	1.152	1.140	1.129	1.112	1.074	0.995	0.866	0.736	0.629
kW	0.00055	0.00051	0.00050	0.00054	0.00065	0.00080	0.00096	0.00109	0.00115	0.00117	0.00117	0.00118	0.00118	0.00117	0.00116	0.00115	0.00114	0.00113	0.00111	0.00107	0.00099	0.00087	0.00074	0.00063
	Sat																							
W	0.553	0.508	0.500	0.537	0.648	0.793	0.944	1.076	1.143	1.161	1.164	1.164	1.164	1.162	1.155	1.142	1.125	1.108	1.088	1.055	0.989	0.879	0.750	0.625
kW	0.00055	0.00051	0.00050	0.00054	0.00065	0.00079	0.00094	0.00108	0.00114	0.00116	0.00116	0.00116	0.00116	0.00116	0.00116	0.00114	0.00112	0.00111	0.00109	0.00105	0.00099	0.00088	0.00075	0.00063
	Sun																							
W	0.539	0.503	0.517	0.590	0.692	0.811	0.942	1.044	1.092	1.107	1.110	1.111	1.111	1.111	1.105	1.094	1.081	1.074	1.063	1.032	0.959	0.832	0.706	0.617
kW	0.00054	0.00050	0.00052	0.00059	0.00069	0.00081	0.00094	0.00104	0.00109	0.00111	0.00111	0.00111	0.00111	0.00111	0.00111	0.00109	0.00108	0.00107	0.00106	0.00103	0.00096	0.00083	0.00071	0.00062

Figure 29. Foodstore Prototype Load Profile

Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	M-F																							
W	0.110	0.111	0.115	0.129	0.172	0.277	0.455	0.622	0.712	0.743	0.748	0.738	0.711	0.651	0.551	0.443	0.340	0.248	0.185	0.152	0.135	0.123	0.115	0.111
kW	0.00011	0.00011	0.00011	0.00013	0.00017	0.00028	0.00045	0.00062	0.00071	0.00074	0.00075	0.00074	0.00071	0.00065	0.00055	0.00044	0.00034	0.00025	0.00019	0.00015	0.00013	0.00012	0.00012	0.00011
	Sat																							
W	0.109	0.109	0.110	0.111	0.116	0.124	0.137	0.151	0.163	0.173	0.177	0.177	0.172	0.161	0.148	0.138	0.129	0.118	0.111	0.110	0.109	0.109	0.109	0.109
kW	0.00011	0.00011	0.00011	0.00011	0.00012	0.00012	0.00014	0.00015	0.00016	0.00017	0.00018	0.00018	0.00017	0.00016	0.00015	0.00014	0.00013	0.00012	0.00011	0.00011	0.00011	0.00011	0.00011	0.00011
	Sun																							
W	0.109	0.109	0.109	0.109	0.111	0.114	0.120	0.127	0.130	0.136	0.137	0.138	0.136	0.134	0.130	0.128	0.124	0.116	0.111	0.110	0.110	0.109	0.109	0.110
kW	0.00011	0.00011	0.00011	0.00011	0.00011	0.00011	0.00012	0.00013	0.00013	0.00014	0.00014	0.00014	0.00014	0.00013	0.00013	0.00013	0.00012	0.00012	0.00011	0.00011	0.00011	0.00011	0.00011	0.00011

Figure 30. School (K-12) Prototype Load Profile

Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	M-F																							
W	0.208	0.199	0.202	0.227	0.284	0.372	0.489	0.609	0.716	0.783	0.804	0.808	0.810	0.810	0.805	0.792	0.767	0.727	0.661	0.578	0.482	0.378	0.293	0.233
kW	0.00021	0.00020	0.00020	0.00023	0.00028	0.00037	0.00049	0.00061	0.00072	0.00078	0.00080	0.00081	0.00081	0.00081	0.00081	0.00079	0.00077	0.00073	0.00066	0.00058	0.00048	0.00038	0.00029	0.00023
	Sat																							
W	0.187	0.185	0.185	0.192	0.207	0.241	0.296	0.370	0.437	0.468	0.459	0.446	0.424	0.398	0.365	0.330	0.306	0.287	0.273	0.266	0.253	0.228	0.205	0.190
kW	0.00019	0.00019	0.00019	0.00019	0.00021	0.00024	0.00030	0.00037	0.00044	0.00047	0.00046	0.00045	0.00042	0.00040	0.00036	0.00033	0.00031	0.00029	0.00027	0.00027	0.00025	0.00023	0.00021	0.00019
	Sun																							
W	0.180	0.176	0.175	0.179	0.190	0.208	0.233	0.256	0.273	0.283	0.290	0.295	0.293	0.285	0.274	0.264	0.257	0.251	0.247	0.244	0.236	0.222	0.205	0.211
kW	0.00018	0.00018	0.00018	0.00018	0.00019	0.00021	0.00023	0.00026	0.00027	0.00028	0.00029	0.00030	0.00029	0.00028	0.00027	0.00026	0.00026	0.00025	0.00025	0.00024	0.00024	0.00022	0.00020	0.00021

Figure 31. School (Year-Round) Prototype Load Profile

Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	M-F																							
W	0.111	0.111	0.126	0.181	0.265	0.354	0.416	0.441	0.445	0.445	0.444	0.444	0.445	0.445	0.438	0.419	0.378	0.323	0.271	0.220	0.180	0.158	0.139	0.118
kW	0.00011	0.00011	0.00013	0.00018	0.00027	0.00035	0.00042	0.00044	0.00044	0.00044	0.00044	0.00044	0.00044	0.00044	0.00044	0.00042	0.00038	0.00032	0.00027	0.00022	0.00018	0.00016	0.00014	0.00012
	Sat																							
W	0.091	0.095	0.107	0.123	0.140	0.156	0.169	0.178	0.182	0.183	0.178	0.170	0.162	0.155	0.147	0.138	0.120	0.109	0.103	0.099	0.097	0.095	0.092	0.086
kW	0.00009	0.00010	0.00011	0.00012	0.00014	0.00016	0.00017	0.00018	0.00018	0.00018	0.00018	0.00017	0.00016	0.00015	0.00015	0.00014	0.00012	0.00011	0.00010	0.00010	0.00010	0.00009	0.00009	0.00009
	Sun																							
W	0.082	0.086	0.095	0.103	0.110	0.115	0.118	0.120	0.122	0.122	0.121	0.119	0.119	0.118	0.116	0.112	0.101	0.093	0.091	0.090	0.090	0.089	0.087	0.102
kW	0.00008	0.00009	0.00009	0.00010	0.00011	0.00011	0.00012	0.00012	0.00012	0.00012	0.00012	0.00012	0.00012	0.00012	0.00012	0.00011	0.00010	0.00009	0.00009	0.00009	0.00009	0.00009	0.00009	0.00010

Figure 32. Warehouse Prototype Load Profile

Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	M-F																							
W	0.300	0.276	0.268	0.285	0.346	0.433	0.517	0.587	0.638	0.672	0.693	0.701	0.705	0.710	0.716	0.729	0.750	0.774	0.787	0.776	0.710	0.578	0.445	0.356
kW	0.00030	0.00028	0.00027	0.00029	0.00035	0.00043	0.00052	0.00059	0.00064	0.00067	0.00069	0.00070	0.00070	0.00071	0.00072	0.00073	0.00075	0.00077	0.00079	0.00078	0.00071	0.00058	0.00044	0.00036
	Sat																							
W	0.310	0.282	0.271	0.284	0.329	0.408	0.499	0.576	0.632	0.666	0.685	0.694	0.699	0.704	0.712	0.726	0.751	0.776	0.791	0.784	0.728	0.607	0.475	0.362
kW	0.00031	0.00028	0.00027	0.00028	0.00033	0.00041	0.00050	0.00058	0.00063	0.00067	0.00069	0.00069	0.00070	0.00070	0.00071	0.00073	0.00075	0.00078	0.00079	0.00078	0.00073	0.00061	0.00047	0.00036
	Sun																							
W	0.297	0.277	0.269	0.281	0.324	0.401	0.487	0.559	0.609	0.637	0.649	0.656	0.662	0.668	0.674	0.687	0.708	0.731	0.743	0.731	0.669	0.553	0.430	0.346
kW	0.00030	0.00028	0.00027	0.00028	0.00032	0.00040	0.00049	0.00056	0.00061	0.00064	0.00065	0.00066	0.00066	0.00067	0.00067	0.00069	0.00071	0.00073	0.00074	0.00073	0.00067	0.00055	0.00043	0.00035

Figure 33. Hospitality Prototype Load Profile

Appendix E. Cost Analysis Calculations

Labor Rate	$75	Fully burdened
Super. Rate	20.0%	Industry Avg
Tax Rate	9.5%	State Sales Tax
Distr. Markup	15.0%	Industry Avg
EC Markup	20.0%	Industry Avg
GC Markup	10.0%	Industry Avg

	BASE											
Space	Component	Qty	Unit Material	Labor Units	Labor	Mat'l	Superv	EC Markup	Tax	GC Markup	TOTAL	Per SF
Office	Troffers	20	$60.00	0.5	$750	$1,200.00	$150.00	$240.00	$136.80	$248	$2,724	$1.09
	Home run	1	$50.00	5	$375	$50.00	$75.00	$10.00	$5.70	$52	$567	$0.23
	Fixture connect	5	$10.00	0.5	$188	$50.00	$37.50	$10.00	$5.70	$29	$320	$0.13
	Switch MS	1	$40.00	0.5	$38	$40.00	$7.50	$8.00	$4.56	$10	$107	$0.04
Open Office	Troffers	16	$60.00	0.5	$600	$960.00	$120.00	$192.00	$109.44	$198	$2,180	$0.87
	Home run	1	$50.00	5	$375	$50.00	$75.00	$10.00	$5.70	$52	$567	$0.23
	Fixture connect	16	$10.00	0.5	$600	$160.00	$120.00	$32.00	$18.24	$93	$1,023	$0.41
	Timer	1	$125.00	0.5	$38	$125.00	$7.50	$25.00	$14.25	$21	$230	$0.09
Corridor	Downlights	4	$90.00	0.5	$150	$360.00	$30.00	$72.00	$41.04	$65	$718	$0.29
	Home run	1	$50.00	5	$375	$50.00	$75.00	$10.00	$5.70	$52	$567	$0.23
	Fixture connect	4	$10.00	0.5	$150	$40.00	$30.00	$8.00	$4.56	$23	$256	$0.10
	Ceiling MS	1	$60.00	0.5	$38	$60.00	$7.50	$12.00	$6.84	$12	$136	$0.05
Conference	Pendants	2	$800.00	4	$600	$1,600.00	$120.00	$320.00	$182.40	$282	$3,105	$1.24
	Home run	1	$50.00	5	$375	$50.00	$75.00	$10.00	$5.70	$52	$567	$0.23
	Fixture connect	2	$3.00	1	$150	$6.00	$30.00	$1.20	$0.68	$19	$207	$0.08
	Ceiling MS	1	$60.00	0.5	$38	$60.00	$7.50	$12.00	$6.84	$12	$136	$0.05
	Switch connect	1	$10.00	0.5	$38	$10.00	$7.50	$2.00	$1.14	$6	$64	$0.03
Kitchenette	Troffers	1	$60.00	0.5	$38	$60.00	$7.50	$12.00	$6.84	$12	$136	$0.05
	Undercabinet	1	$40.00	0.5	$38	$40.00	$7.50	$8.00	$4.56	$10	$107	$0.04
	Home run	1	$50.00	5	$375	$50.00	$75.00	$10.00	$5.70	$52	$567	$0.23
	Fixture connect	2	$10.00	0.5	$75	$20.00	$15.00	$4.00	$2.28	$12	$128	$0.05
	Ceiling MS	1	$60.00	0.5	$38	$60.00	$7.50	$12.00	$6.84	$12	$136	$0.05
Reception	Downlights	4	$90.00	0.5	$150	$360.00	$30.00	$72.00	$41.04	$65	$718	$0.29
	Home run	1	$50.00	5	$375	$50.00	$75.00	$10.00	$5.70	$52	$567	$0.23
	Fixture connect	4	$10.00	0.5	$150	$40.00	$30.00	$8.00	$4.56	$23	$256	$0.10
	Sensor connect	1	$60.00	0.5	$38	$60.00	$7.50	$12.00	$6.84	$12	$136	$0.05
Subtotals					$6,150	$5,611	$1,230	$1,122	$640	$1,475	$16,228	**$6.49**
Ballasts										Fixtures	$9,689	**$3.88**
System										Wiring	$5,593	**$2.24**
Devices										Devices	$946	**$0.38**

		DALI					ANALOG					DAYLIGHTING				
Space	Component	Modification	Qty	Unit Cost	Subtotal	Per SF	Modification	Qty	Unit Cost	Subtotal	Per SF	Modification	Qty	Unit Cost	Subtotal	Per SF
Office	Troffers	DALI Ballast	20	$50.00	$1,000.00	$0.40	0-10V ballast	20	$30.00	$600.00	$0.24	Sensor	5	$50.00	$250.00	$0.10
	Home run	DALI wires	1	$20.00	$20.00	$0.01	Hub	1	$250.00	$250.00	$0.10	LV wiring	5	$10.00	$50.00	$0.02
	Fixture connect	DALI hub	1	$200.00	$200.00	$0.08	Zone unit	5	$75.00	$375.00	$0.15					
	Switch MS	DALI sensor				$0.00	LV wiring	5	$25.00	$125.00	$0.05					
Open Office	Troffers	DALI Ballast	16	$50.00	$800.00	$0.32	0-10V ballast	16	$30.00	$480.00	$0.19	Sensor	2	$50.00	$100.00	$0.04
	Home run	DALI wires	1	$20.00	$20.00	$0.01	Zone unit	2	$75.00	$150.00	$0.06	LV wiring	2	$10.00	$20.00	$0.01
	Fixture connect	DALI switch				$0.00	LV wiring	16	$25.00	$400.00	$0.16					
	Timer					$0.00	LV sensor	5	$25.00	$125.00	$0.05					
Corridor	Downlights	DALI Ballast	4	$35.00	$140.00	$0.06	0-10V ballast	4	$30.00	$120.00	$0.05					
	Home run	DALI wires	1	$20.00	$20.00	$0.01	Zone unit	2	$75.00	$150.00	$0.06					
	Fixture connect	DALI sensor				$0.00	LV wiring	4	$25.00	$100.00	$0.04					
	Ceiling MS					$0.00	LV sensor	3	$25.00	$75.00	$0.03					
Conference	Pendants	DALI Ballast	6	$50.00	$300.00	$0.12	0-10V ballast	6	$30.00	$180.00	$0.07					
	Home run	DALI wires	1	$20.00	$20.00	$0.01	Zone unit	2	$75.00	$150.00	$0.06					
	Fixture connect					$0.00	LV wiring	3	$25.00	$75.00	$0.03					
	Ceiling MS					$0.00	LV sensor	2	$25.00	$50.00	$0.02					
	Switch connect															
Kitchenette	Troffers	DALI Ballast	1	$50.00	$50.00	$0.02	0-10V ballast	1	$30.00	$30.00	$0.01					
	Undercabinet	DALI Ballast	1	$50.00	$50.00	$0.02	0-10V ballast	1	$30.00	$30.00	$0.01					
	Home run	DALI wires	1	$20.00	$20.00	$0.01	Zone unit	2	$75.00	$150.00	$0.06					
	Fixture connect					$0.00	LV wiring	2	$25.00	$50.00	$0.02					
	Ceiling MS					$0.00	LV sensor	1	$25.00	$25.00	$0.01					
Reception	Downlights	DALI Ballast	4	$35.00	$140.00	$0.06	0-10V ballast	4	$30.00	$120.00	$0.05	Sensor	1	$50.00	$50.00	$0.02
	Home run	DALI wires	1	$20.00	$20.00	$0.01	Zone unit	1	$100.00	$100.00	$0.04	LV wiring	1	$10.00	$10.00	
	Fixture connect					$0.00	LV wiring	4	$25.00	$100.00	$0.04					
	Sensor connect	DALi commission	1	$500.00	$500.00	$0.20	LV sensor	2	$25.00	$50.00	$0.02	Commission	1	$500.00	$500.00	$0.20
Subtotals		DALI Apportioned			$3,300.00	**$1.32**				$4,060.00	**$1.62**				$980.00	**$0.39**
Ballasts		to match		$0.51	$2,480.00	**$0.99**				$1,560.00	**$0.62**				0	**$0.00**
System		0-10 volt system		$0.71	$820.00	**$0.33**				$2,175.00	**$0.87**				0	**$0.00**
Devices				$0.11	0	**$0.00**				$325.00	**$0.13**				$980.00	**$0.39**

	Basis	Low	High	
Ballasts	Apportioned ballast cost+ digital devices cost	$0.61	$0.75	
System DR	50% of system cost	$0.35	$0.44	
System Day	25% of system plus 100% of daylight cost	$0.57	$0.61	
Other	25% of system plus cost of sensors or controls	$0.18	$0.22	Plus

Figure 34. Office Prototype Cost Analysis

Base case Description:		2008 Title 24 Required Controls			
	Installed cost:	$0.00			
Enter kW schedule for base case					

	Daytime base			Night time base		
Hour	M-F	Sat	Sun	M-F	Sat	Sun
1	0.00018	0.00018	0.00018	0.00018	0.00018	0.00018
2	0.00018	0.00018	0.00018	0.00018	0.00018	0.00018
3	0.00018	0.00018	0.00018	0.00018	0.00018	0.00018
4	0.00020	0.00018	0.00018	0.00020	0.00018	0.00018
5	0.00025	0.00019	0.00018	0.00025	0.00019	0.00018
6	0.00036	0.00021	0.00019	0.00036	0.00021	0.00019
7	0.00051	0.00025	0.00020	0.00051	0.00025	0.00020
8	0.00065	0.00030	0.00021	0.00065	0.00030	0.00021
9	0.00072	0.00034	0.00022	0.00072	0.00034	0.00022
10	0.00075	0.00035	0.00023	0.00075	0.00035	0.00023
11	0.00074	0.00035	0.00023	0.00074	0.00035	0.00023
12	0.00074	0.00033	0.00023	0.00074	0.00033	0.00023
13	0.00074	0.00031	0.00023	0.00074	0.00031	0.00023
14	0.00074	0.00028	0.00022	0.00074	0.00028	0.00022
15	0.00073	0.00025	0.00021	0.00073	0.00025	0.00021
16	0.00068	0.00023	0.00021	0.00068	0.00023	0.00021
17	0.00061	0.00022	0.00020	0.00061	0.00022	0.00020
18	0.00051	0.00020	0.00019	0.00051	0.00020	0.00019
19	0.00042	0.00019	0.00019	0.00042	0.00019	0.00019
20	0.00034	0.00019	0.00018	0.00034	0.00019	0.00018
21	0.00028	0.00018	0.00018	0.00028	0.00018	0.00018
22	0.00024	0.00018	0.00018	0.00024	0.00018	0.00018
23	0.00021	0.00018	0.00018	0.00021	0.00018	0.00018
24	0.00019	0.00018	0.00018	0.00019	0.00018	0.00018
	Only day time hours during this schedule are kWh or TDV calculated			Only night time hours during this schedule are kWh or TDV calculated		

Proposed case description:		Tuning - OFFICE			
	Installed cost:	$0.81			
Enter kW schedule for proposed case					

	Daytime proposed			Night time proposed		
Hour	M-F	Sat	Sun	M-F	Sat	Sun
1	0.00016	0.00015	0.00015	0.00016	0.00015	0.00015
2	0.00015	0.00015	0.00015	0.00015	0.00015	0.00015
3	0.00016	0.00015	0.00015	0.00016	0.00015	0.00015
4	0.00017	0.00015	0.00015	0.00017	0.00015	0.00015
5	0.00022	0.00016	0.00016	0.00022	0.00016	0.00016
6	0.00031	0.00018	0.00016	0.00031	0.00018	0.00016
7	0.00044	0.00021	0.00017	0.00044	0.00021	0.00017
8	0.00055	0.00025	0.00018	0.00055	0.00025	0.00018
9	0.00061	0.00029	0.00019	0.00061	0.00029	0.00019
10	0.00063	0.00030	0.00019	0.00063	0.00030	0.00019
11	0.00063	0.00030	0.00020	0.00063	0.00030	0.00020
12	0.00063	0.00028	0.00020	0.00063	0.00028	0.00020
13	0.00063	0.00026	0.00019	0.00063	0.00026	0.00019
14	0.00063	0.00023	0.00019	0.00063	0.00023	0.00019
15	0.00062	0.00021	0.00018	0.00062	0.00021	0.00018
16	0.00058	0.00020	0.00017	0.00058	0.00020	0.00017
17	0.00052	0.00018	0.00017	0.00052	0.00018	0.00017
18	0.00044	0.00017	0.00016	0.00044	0.00017	0.00016
19	0.00036	0.00016	0.00016	0.00036	0.00016	0.00016
20	0.00029	0.00016	0.00015	0.00029	0.00016	0.00015
21	0.00024	0.00015	0.00015	0.00024	0.00015	0.00015
22	0.00020	0.00015	0.00015	0.00020	0.00015	0.00015
23	0.00018	0.00015	0.00015	0.00018	0.00015	0.00015
24	0.00016	0.00015	0.00015	0.00016	0.00015	0.00015
	Only day time hours during this schedule are kWh or TDV calculated			Only night time hours during this schedule are kWh or TDV calculated		

Figure 35. Example Kilowatt Schedule for Cost-Effectiveness Analysis (Office Prototype)

Year	Maintenance Costs Base case	Proposed case	Maint Savings PV $	Future Value Multiplier
1			$0.00	97%
2			$0.00	94%
3			$0.00	92%
4			$0.00	89%
5		$ 0.05	-$0.04	86%
6			$0.00	84%
7			$0.00	81%
8			$0.00	79%
9			$0.00	77%
10		$ 0.05	-$0.04	74%
11			$0.00	72%
12			$0.00	70%
13			$0.00	68%
14			$0.00	66%
15		$ 0.28	-$0.18	64%
Total			-$0.26	

50000 hr ballast replacement

Energy and Cost Savings Summary: Tuning - OFFICE

Hour	Savings Total kWh	Savings TDV kBtu	Savings Energy Cost PV $	PV Savings Maint. PV $	Cost Savings Total PV $
1	0.01	0.16	$ 0.01		
2	0.01	0.15	$ 0.01		
3	0.01	0.15	$ 0.01		
4	0.01	0.16	$ 0.01		
5	0.01	0.20	$ 0.02		
6	0.02	0.29	$ 0.03		
7	0.02	0.41	$ 0.04		
8	0.03	0.53	$ 0.05		
9	0.03	0.61	$ 0.05		
10	0.03	0.65	$ 0.06		
11	0.03	0.69	$ 0.06		
12	0.03	0.76	$ 0.07		
13	0.03	0.85	$ 0.08		
14	0.03	0.96	$ 0.09		
15	0.03	1.02	$ 0.09		
16	0.03	0.98	$ 0.09		
17	0.03	0.89	$ 0.08		
18	0.02	0.71	$ 0.06		
19	0.02	0.52	$ 0.05		
20	0.02	0.38	$ 0.03		
21	0.01	0.29	$ 0.03		
22	0.01	0.23	$ 0.02		
23	0.01	0.20	$ 0.02	PV Savings	Cost Savings
24	0.01	0.18	$ 0.02	Maint. PV $	Total PV $
Total	0.52	11.96	1.06	-0.26	$1
				Incremental Cost	$0.81
				B/C ratio	1.00
		PV$/kWh	$ 2.057		
		$/kWh	$ 0.172		

Figure 36. Example Calculation of Energy and Cost Savings (Office Prototype)

Appendix F. LightFair Memorandum