Wireless Lighting Control

A Life Cycle Cost Evaluation of Multiple Lighting Control Strategies

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Who should read this study?

- *Office Property Managers*
- *Facility Managers*
- *Office Tenants*
- *Utility Companies*
- *Lighting Designers*
- *Electrical Engineers*
- *Electrical Contractors*

These questions will be answered *about lighting control systems in office retrofit and tenant finish projects:*

- *How* ***cost effective*** *are lighting control systems?*
- *Will* ***emerging wireless lighting controls*** *save more money and energy than other lighting controls?*
- *Which* ***lighting control strategies*** *best suit the specific priorities of different clients?*
- *Do* ***advanced, programmable lighting controls*** *save more energy than conventional lighting controls?*
- *How much energy can be saved* ***compared to a code-compliant office****?*
- *How does* ***space planning*** *affect lighting control energy savings?*

Introduction

Lighting controls present a key opportunity for designers and engineers to tune the lighting system to the needs of the occupants in a dynamic manner while potentially saving significant energy. As the need to reduce lighting energy consumption continues to increase, the ability to dynamically modify the energy use profile within a space is of great value, both to building owners and operators, and to the major utilities whose grid must respond.

With the current availability of energy-efficiency incentives and rebates, utilities are strongly encouraging the use of advanced lighting controls. Combined with the annual energy savings, these incentives and rebates can often reduce the initial cost burden on the building owner, providing further reason to expand on the flexibility of the lighting system.

This study evaluates the cost effectiveness and potential energy savings of a lighting control retrofit project in a typical 1970's office building in two different geographical locations, Boston and Los Angeles. Multiple commercially-available lighting control systems as detailed in the Methodology section are compared to study the return on investing in lighting controls to capitalize on reducing lighting energy costs.

Intent of the Study

- **Energy and Cost**: Compare lighting control technologies that reduce energy use below code requirements, and understand the cost-effectiveness of those technologies.
- **Wireless & Advanced Lighting Controls Advantage**: Evaluate the advantages of emerging advanced and wireless lighting controls, and the cost impact of reduced wiring in retrofit and tenant finish office building projects through the use of wireless and reconfigurable control devices.
- **Evidence Basis for Design**: Provide a reference source for lighting designers and electrical design engineers to communicate the potential savings of lighting control systems to their clients.
- **Encourage Utility Rebates**: Contribute lighting control energy analysis research to utility companies to encourage expansion of utility rebate programs for lighting controls.

Key Findings of the Study

<u>Quantitative Findings</u>

- Space planning effects access to daylight, therefore lighting energy.
- Advanced lighting controls can achieve nearly 50% less energy than code-compliant lighting controls.
- Wireless lighting controls have lower capital costs than the other lighting control systems studied in office retrofit applications.
- Using dimmable ballasts everywhere can be cost effective.
- Addressable, networked lighting control systems (wired and wireless) significantly reduce labor costs.
- Reduced labor and energy costs of advanced, networked lighting control systems can out-weigh increased equipment and commissioning costs.
- Addressable, networked lighting control systems (wired & wireless) offer more features for the same or less life cycle cost as the other lighting control systems evaluated.

<u>Qualitative Findings</u>

- Employee satisfaction is likely to increase with their ability to control their lighting to provide the optimal luminous environment.
- Addressable, networked lighting systems allow for easy system reconfiguration, allowing the system to be adapted for future uses with minimal time and cost.
- Addressable, networked lighting systems are adaptable to changing room conditions, allowing sensor locations to be adjusted based on interior configurations.

- Real-time energy monitoring is possible through addressable, networked lighting systems (wired & wireless), allowing the operator of a building to understand the interaction of the users with the lighting system, provide education about the capabilities of the lighting system and personal energy use, and encourage education and awareness of lighting energy use.

<u>Other Issues</u>

- When designing and specifying an advanced lighting control system, it is important to understand the knowledge and experience of the contractor, and to determine if pre-bid training on the control system architecture should be provided.
- Specific to retrofit scenarios, the use of connectorized cabling and its impact on additional wiring should be understood. Quantifying the existing power structure and determining the optimal method to reconfigure the space can lead to a reduced capital cost investment.
- The coordination of emergency lighting systems and advanced control systems should be understood to verify system compatibility and take full advantage of features of the advanced control systems.
- The cost of dimming ballasts is widely varied, both between manufacturers and between suppliers.
- There are significant challenges associated with design-phase pricing of control scenarios, since shop-drawing level component lists are rarely available until the project has been bid, leaving a level of uncertainty in the pricing that is often compensated by an elevated bid price.
- The configuration of partitions in the open office is likely to have significant impacts on the potential energy savings, including such issues as partition size, orientation, placement and material.

Control Strategies

As the market for lighting controls broaden, the number of different types of control systems available to designers and engineers broaden as well. For this study, six various control system types were examined. It is assumed, for all control scenarios, that the luminaires themselves remain unchanged, except for field ballast replacements.

Standard Manual Switch

Digital Time-switch

0 – Energy Baseline

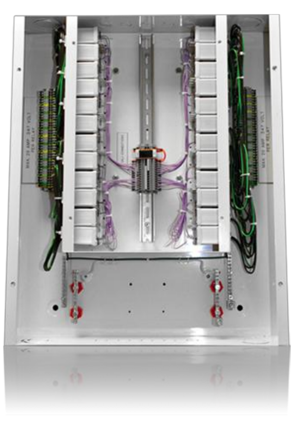
This control strategy provides the bare minimum of devices necessary to meet the mandatory control provisions of ASHRAE 90.1-2007 and is used to establish an energy baseline to which the potential savings of advanced control strategies can be evaluated. For the office space considered, the mandatory requirements included automated control for all enclosed spaces and automatic shut-off for open office areas up to 2,500 square feet. Either vacancy sensors or time-switch control can be used to meet these requirements. This scenario was used to establish the energy baseline for this office lighting retrofit study.

Photocell

Occupancy Sensor

1 – Localized Control

This control strategy upgrade provides the bare minimum of devices necessary to meet the mandatory control provisions of California's Title 24 2008, which can be considered a codified example of an advanced lighting control strategy. For this space, the mandatory requirements include occupancy-based automatic control for all enclosed areas. The mandatory requirements also include photocell control of perimeter open office spaces with access to daylight. In order to meet the mandatory requirements of multi-level operation, it was assumed that the ballasts are changed out, to provide inboard/outboard switching with bi-level capabilities.



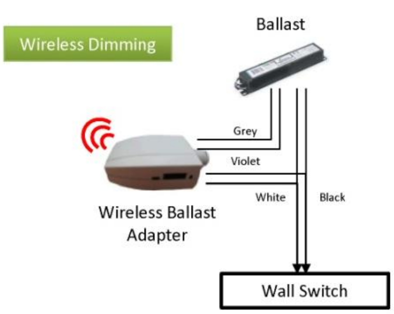
Relay Panel

2 – Relay Panel Switching

The relay panel control scenario adds an additional layer of flexibility and control via a central lighting relay panel. This scenario also enhances the occupant-based control by adding vacancy sensors to all spaces. Photocells are also included in the open office spaces that have access to daylight. In combination, the vacancy sensors and photocells automatically control the lighting to reduce energy use. During periods of inactivity, the vacancy sensors will automatically turn off the lighting, and require a manual-on operation when the user determines that the electric lighting is necessary. The photocells are provided to detect the availability of daylight, and respond with a signal to the relay panel, providing bi-level switching capability to maintain a consistent minimum interior workplane light level. Ballasts are changed out, in areas with available daylight, to allow for inboard/outboard switching to provide bi-level switching capabilities.

Dimming Panel

Addressable ballasts are interconnected with data cables to provide control signals



Wireless Sensor Adapters

3 – Dimming Panel

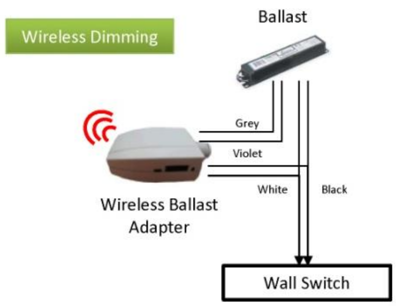
The dimming panel control scenario expands on the hard-wired capabilities of the relay panel control scenario. It is assumed for this scenario that the existing ballasts are replaced with dimming ballasts in all areas except non-daylit open offices and support spaces. Photocells are added to all private offices and conference rooms to allow daylight dimming and high-end trim dimming to reduce energy use. This scenario also includes vacancy sensors in all locations with manual overrides. In the non-dimmed areas, including the non-daylit open offices, the luminaires are fed through a relay panel, which receives signals from the occupancy sensors via the processor to trigger on/off action. The luminaires in the daylit spaces, including open offices, conference rooms and private offices, are fed through a dimming panel, which receives input from occupancy and daylight sensors via the processor to automatically control the lighting level.

4 – Addressable Ballasts

The addressable ballast control scenario further expands on the capabilities of hard-wired systems by providing digital addresses for all ballasts, and connecting them as a system through network cabling. The digital addresses allow control over each ballast individually, and also allow for re-zoning and flexibility over the life of the system. Photocells are provided in all spaces, with the exception of the support spaces, to allow for daylight dimming, high-end trim dimming, and lumen maintenance dimming. This scenario includes dual-technology occupancy sensors as well in all spaces. The entire lighting system is controlled via a software application provided on the server, which allows for control and re-zoning of the luminaires, as well as feedback for maintenance personnel regarding lamp outages and energy usage. In this scenario, all ballasts are changed out with addressable dimming ballasts.

5 – Wireless Partial Dimming

The wireless partial dimming control scenario provides dimming in the private offices, conference rooms and open offices that have access to daylight, while using wireless switching control throughout the non-daylit and support spaces. The integration of wireless photocells allows for dimming both to provide high-end trim and to respond to the presence of daylight. The battery-powered wireless photocells integrate simply into the scenario by communicating directly back to the area controller, which then responds with a signal to the dimming ballast adapters to dim the luminaires. Wired dual-technology occupancy sensors are also used in the open office areas, and use a wireless sensor adaptor to connect the sensors to the wireless system. Dimming ballasts are installed in luminaires in areas with daylight access.



Wireless Dimming

6 – Wireless Full Dimming

The wireless full dimming control scenario provides the most robust control system, with full daylight dimming, high-end trim dimming, lumen maintenance dimming, and occupancy sensing in all major spaces. This scenario again uses both wired and wireless occupancy sensors, and wireless photocells, all of which communicate via the wireless area controller to provide control over the luminaires. All ballasts in this scenario are changed out with dimming ballasts.

Methodology

Baseline Building Selection

The building selected for this study is based on a 1970's office building with a typical 2'x4' acoustical grid ceiling.

Floor Area: 25,000 sqft (typical per story)

Ceiling Height: 9'-0"

Windows:

- Sill Height: 2'-6"
- Top of Window: 8'-0"
- Glazing/Façade Area Ratio: 40%
- Glazing Type: Double Low-e T_{vis} = 0.65

Interior Space Planning

The floor used for this study used two different strategies for space planning to compare the energy effects of:

1. **A traditional space plan** with perimeter private offices located near the windows and interior open offices.
2. **An inverted space plan** that maximizes daylight availability by having perimeter open offices located near the windows, and interior private offices.

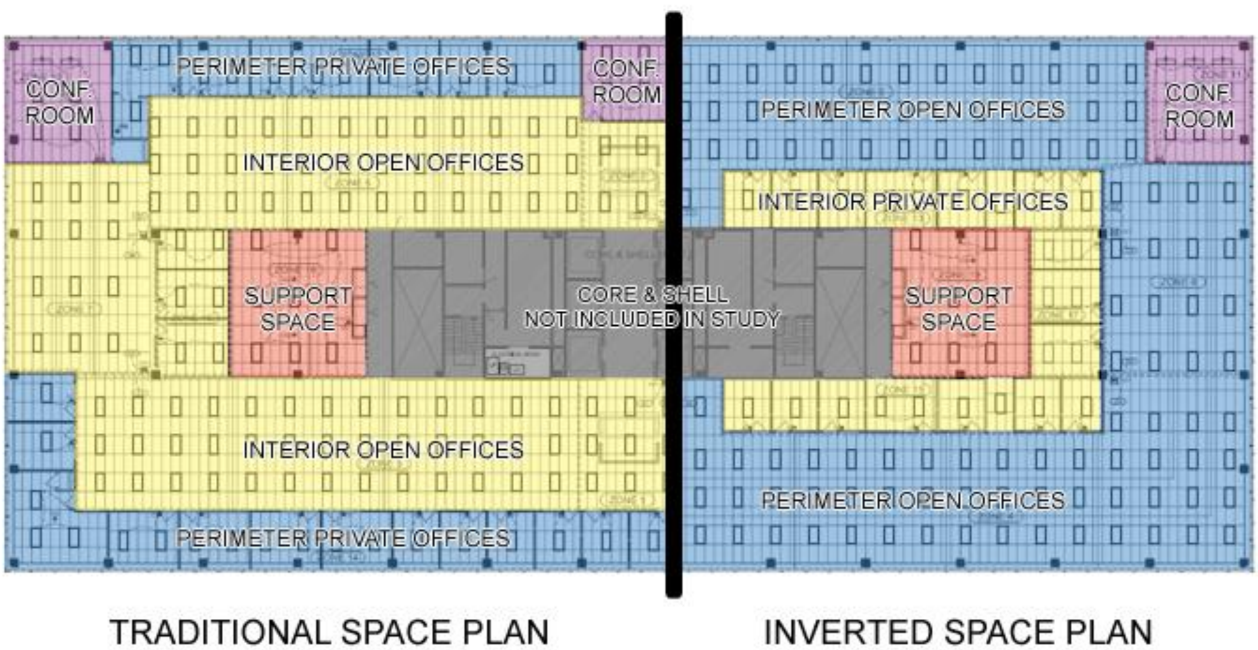


Figure 1 - Space Planning Diagram

Lighting and Control System Design

Existing Luminaire: 2'x4', 3-lamp T8, recessed parabolic troffer

Existing Layout: 8' x 8'

Resulting Task-plane Illuminance: 55 footcandles average

Target Task-plane Illuminance: 35 footcandles average

ASHRAE minimum control zone: 2,500 sqft.

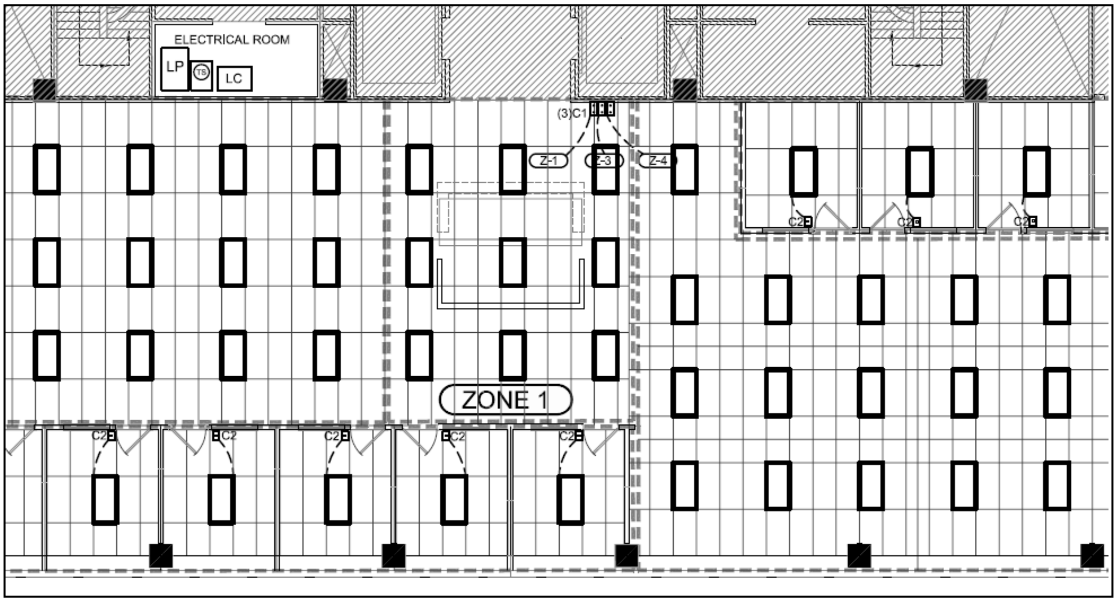


Figure 2 - Typical Luminaire Configuration

Contractor Equipment Pricing

An independent contractor provided material and installation costs for each of the lighting and control systems.

An independent contractor estimated the capital and installation cost for each of these scenarios. The contractor estimated component, wiring, and installation costs. Using RSMeans regional cost data, all of the capital costs were adjusted for the appropriate region of the country.

Commissioning Costs

A commissioning agent provided programming and commissioning costs for each of the control systems.

Programming and commissioning costs were estimated for each control strategy. This included programming of the various occupancy and daylight sensors, as well as the programming of all addressable and wireless components. The cost of commissioning included verification that the system performs as intended. The hourly rate of the commissioning agent was assumed to be the same for both locations, but the hourly rate of the electrician needed for many commissioning tasks was adjusted using RSMeans regional cost data.

LIGHTING POWER DENSITIES

Control Scenario	*Connected LPD*
• *0 – Energy Baseline*	*1.10 W/SF*
• *1 – Localized Control*	*1.11 W/SF*
• *2 – Relay Panel*	*1.12 W/SF*
• *3 – Diming Panel*	*1.13 W/SF*
• *4 – Addressable Ballasts*	*1.15 W/SF*
• *5 – Wireless Partial Dimming*	*1.09 W/SF*
• *6 – Wireless Full Dimming*	*1.09 W/SF*

Energy Modeling

- *Daylight Calculations:* The energy modeling began through daylight simulations, to account for the impact of daylight harvesting under certain control scenarios. Daylight simulations were performed for both locations for five key times per day (6am, 9am, 12pm, 3pm and 6pm) under both clear and overcast sky conditions. Linear interpolation of the daylight illuminance levels was performed to estimate the daylight level during non-simulated hours. Simulations were performed to study the daylight availability on the two solstices and on the 21st of each month in between, taking advantage of the symmetry of the solar year. To spread the data across a full calendar year, the monthly distribution of clear and overcast days for each location was determined based on data from the National Oceanic and Atmospheric Association (NOAA)[1], and the monthly values were weighted accordingly. Electric lighting workplane illuminance was calculated and used to determine the dimming levels for high-end trim dimming and daylight dimming under certain control scenarios. The resultant energy use when accounting for dimming, high-end trim and ballast performance was then determined.

- *Occupancy Profiles:* In order to determine the impact of occupant-based controls, such as occupancy sensors, vacancy sensors and manual control, an estimate of the hourly distribution of occupancy was obtained from the National Renewable Energy Laboratory (NREL). The weekday, Saturday and Sunday hourly occupancy profiles were weighted to create a single profile that accounted for variations throughout the week. These four occupancy profiles are shown in Figure 3.

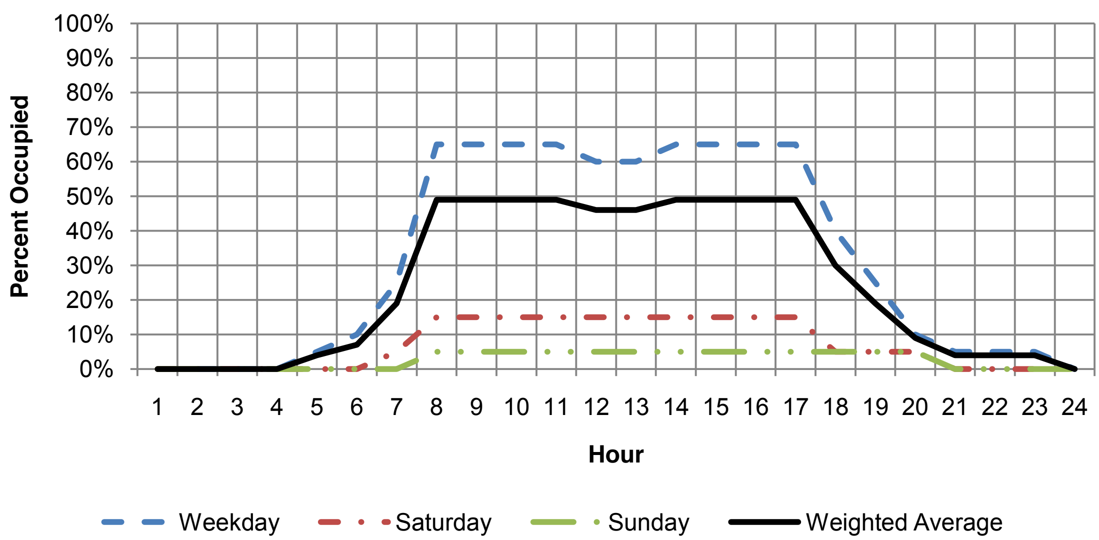


Figure 3 - Occupancy Profiles based on NREL Guidelines[2]

[1] http://lwf.ncdc.noaa.gov/oa/climate/online/ccd/cldy.html

[2] National Renewable Energy Laboratory. "Energy Savings Modeling and Inspection Guidelines for Commercial Building Federal Tax Deductions, Second Ed." May 2007, Table N2-5, "% People."

- *Occupant Switching Behavior:* It was assumed that, in a space without access to daylight or in a space with access on an overcast day, the occupants would turn on 100% of the lights if given control. It was also assumed that, in spaces with access to daylight on clear days, the occupants would turn on only 70% of the lights.
- *Occupancy Sensor Time Delay:* To account for the energy savings of occupancy sensors, previous research was found that provided an overall estimate of the anticipated energy savings based on space type and sensor delay time. The mean anticipated savings are shown in Table 1.

Table 1 – Estimated Energy Savings due to Occupancy Sensors, Vacancy Sensors and Time-Sweep

	Estimated Energy Savings				
Strategy	**Open Office-No Daylight**	**Open Office-With Daylight**	**Private Office**	**Conference Room**	**Support Spaces**
None	0%	0%	0%	0%	0%
Auto-Off with 10-Minute Delay	21.8%[3]	21.8%[3]	34%[4]	46%[4]	57.5%[5]
Auto-Off with 20-Minute Delay	21.8%[3]	21.8%[3]	28%[4]	39%[4]	57.5%[5]
Auto On/Off	29%[6]	29%[6]	27%[7]	39%[8]	57.5%[5]
Sweep Auto-Off[9]	21.8%	21.8%	31%	42%	57.5%

- *Hourly Occupancy Energy Savings:* As this simulation was performed hourly, the hourly impact of the occupancy sensors on reducing energy use was of interest. A series of curves were created that show energy savings due to occupancy as a function of the percentage occupied, as shown in Figure 4. When the space is at very low occupancy, it was assumed that the occupancy sensors would provide the most savings. For the private offices, conference rooms, and support spaces, it was assumed that the energy savings is nearly linear in its relationship to occupancy. For the open offices, it was assumed that the energy savings would reach zero before the space became fully occupied. The mean savings, for each of the curves across the full occupancy range, was controlled to match the resultant energy savings determined by the previous studies. The hourly anticipated savings, as a function of the occupancy level and type of occupant-based control, was then determined.

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[3] VonNeida, B., Maniccia, D. and Tweed, A. "An analysis of the energy and cost savings potential of occupancy sensors for commercial lighting systems." August 2000, Table 1, Mean value of mid-point of ranges for open office.

[4] VonNeida, B., Maniccia, D. and Tweed, A. "An analysis of the energy and cost savings potential of occupancy sensors for commercial lighting systems." August 2000, Table 4.

[5] VonNeida, B., Maniccia, D. and Tweed, A. "An analysis of the energy and cost savings potential of occupancy sensors for commercial lighting systems." August 2000, Table 1, Mean value of mid-point of ranges for storage areas.

[6] Galasiu, A.D. and Newsham, G.R. "Energy savings due to occupancy sensors and personal controls: a pilot field study." National Research Council Canada, September 2009.

[7] EERE Website. http://www1.eere.energy.gov/femp/procurement/eep_light_controls.html

[8] VonNeida, B., Maniccia, D. and Tweed, A. "An analysis of the energy and cost savings potential of occupancy sensors for commercial lighting systems." August 2000, Table 4, Assumed savings equal to minimum anticipated auto-off savings for conference room.

[9] Estimated as the mean savings from Auto-Off results.

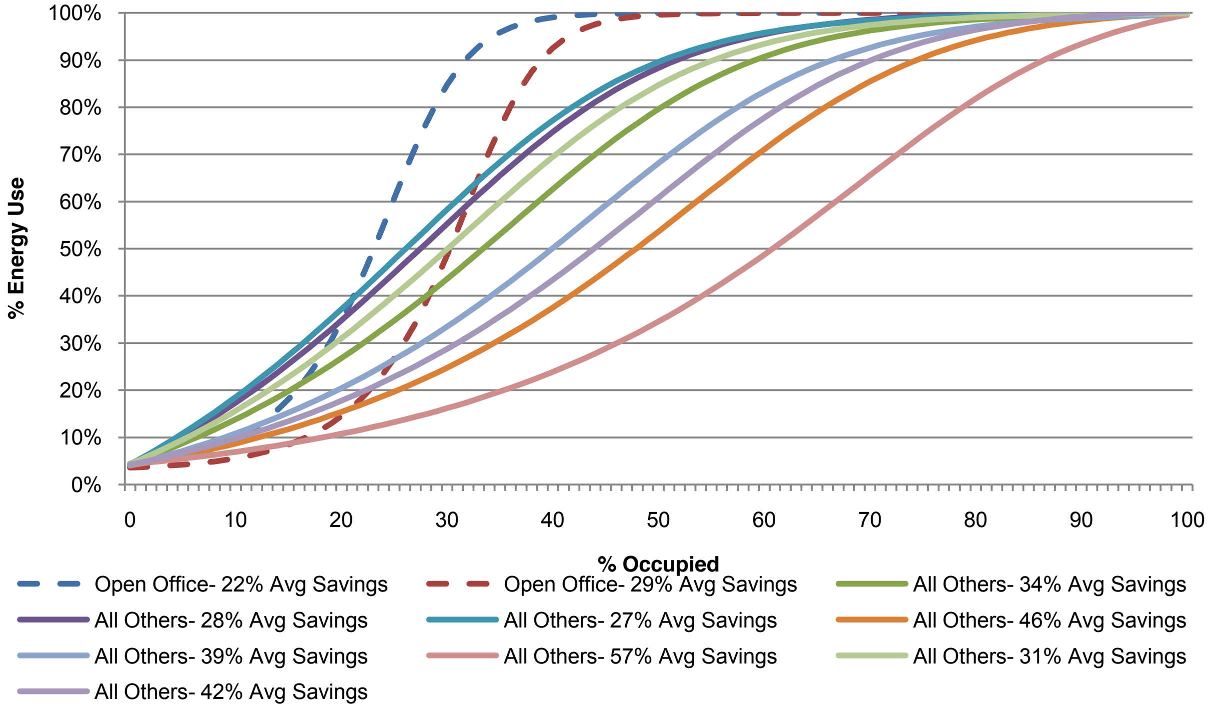

Figure 4 – Anticipated Energy Use as a Function of Occupancy and Type of Occupancy/Vacancy Sensor

- *Combined Energy Savings:* For each hour, the resultant energy use was determined as a percentage of the installed lighting power density. That calculation was based on the effects of daylight dimming, high-end trim dimming, and occupant-based controls. Finally, the total annual energy use in each zone under each control scenario was determined, as well as the peak monthly power demand.

Life Cycle Cost Evaluation

A life cycle cost evaluation effectively compares the total cost performance of the different control strategies over a range of project conditions. The analysis combined the capital and commissioning cost with the annual energy costs of each system. Assuming a real discount rate of 5%, these annualized energy costs were discounted to a present value over a 10-year analysis period. Adding the capital cost to the present value of the energy costs resulted in a total life cycle cost for each scenario.

Key Assumptions and Limitations

1. Lighting Design: The existing luminaire configuration was not adjusted from the current spacing of 8'x8', and the luminaires were not de-lamped for any scenarios. This results in tuned illuminance levels for all scenarios and zones that use photocells to dim or switch down to the target illuminance. However, scenarios and zones without photocells do not provide the same tuned illuminance level.
2. Design Phase Analysis: The scenarios described are fictional and were never actually built. This allowed a thorough analysis of

estimated capital, energy, installation, and commissioning costs. However, actual operating costs and equipment maintenance issues were not analyzed.

3. All capabilities of each control technology were applied to the entire scenario to provide for maximum flexibility.
4. Annual energy costs include the impacts of the utility rate structures from NSTAR (Boston) and Southern California Edison (Los Angeles).
5. Capital costs include currently available rebates for dimming ballasts, sensors and control systems from the respective utilities.

Results

Annual Energy Use

Figure 5 summarizes the anticipated annual energy density for both Los Angeles and Boston under all six control scenarios, along with the anticipated energy density of the energy baseline scenario. As is shown in the figure, the Wireless Full Dimming scenario is anticipated to have the lowest annual energy consumption, due to the integration of occupancy-based control, daylight harvesting and high-end trim dimming.

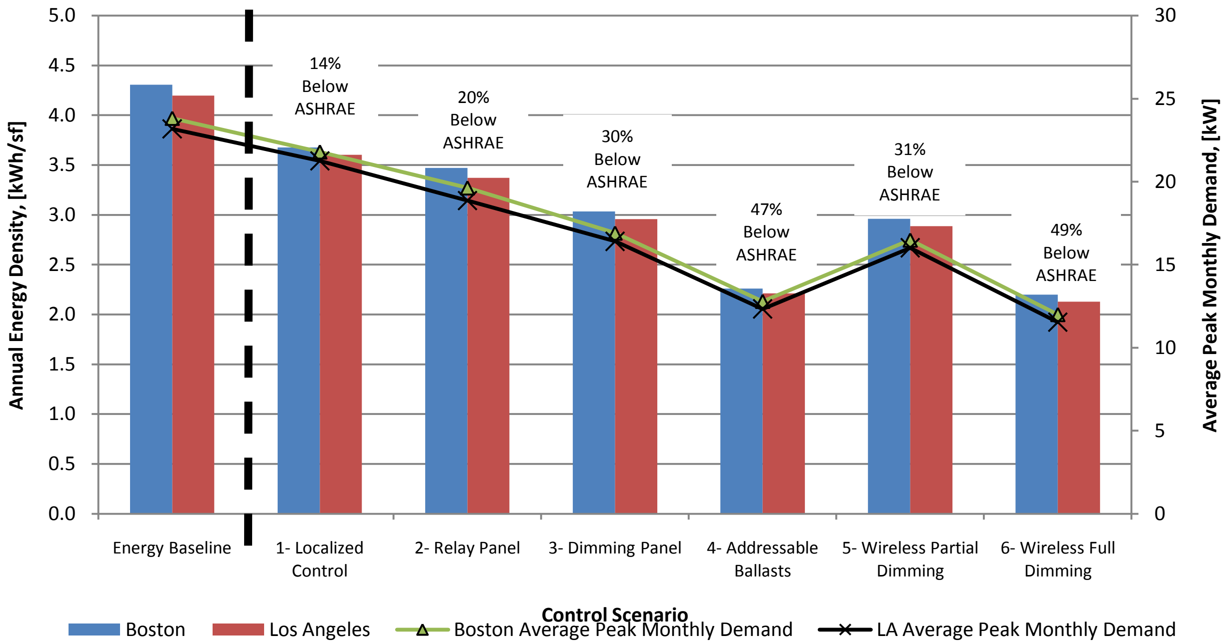

Figure 5 –Annual Energy Density and Associated Peak Monthly Demand

When considering both locations, the results show that the Wireless Full Dimming and Addressable Ballasts scenarios result in very similar annual energy densities due to the similar distribution of daylighting and occupancy controls. The Wireless Partial Dimming and Dimming Panel scenarios result in similar energy densities as both use daylight-responsive dimming in perimeter spaces, but do not take advantage of daylight sensors to provide tuned high-end trim dimming. The Relay Panel and Localized Control scenarios provide similar energy use, with the Relay Panel energy density slightly lower due the inclusion of inboard/outboard switching capabilities on all luminaires in spaces with access to daylight. In general, though, all of the studied advanced control strategies were able to provide significant energy savings below the ASHRAE 90.1-2007 energy baseline.

Generally, the lighting energy density in Los Angeles is lower than in Boston. The climate in Los Angeles shows more clear days per month then in Boston, which is the source of the difference in energy use. For control scenarios that include automated daylight-responsive dimming or switching, the lower energy density in Los Angeles is based on the increased daylight availability. For the ASHRAE energy baseline, which does not include daylight-responsive control, the difference in energy consumption per location is based on the assumed manual-on behavior.

Impact of Space Planning

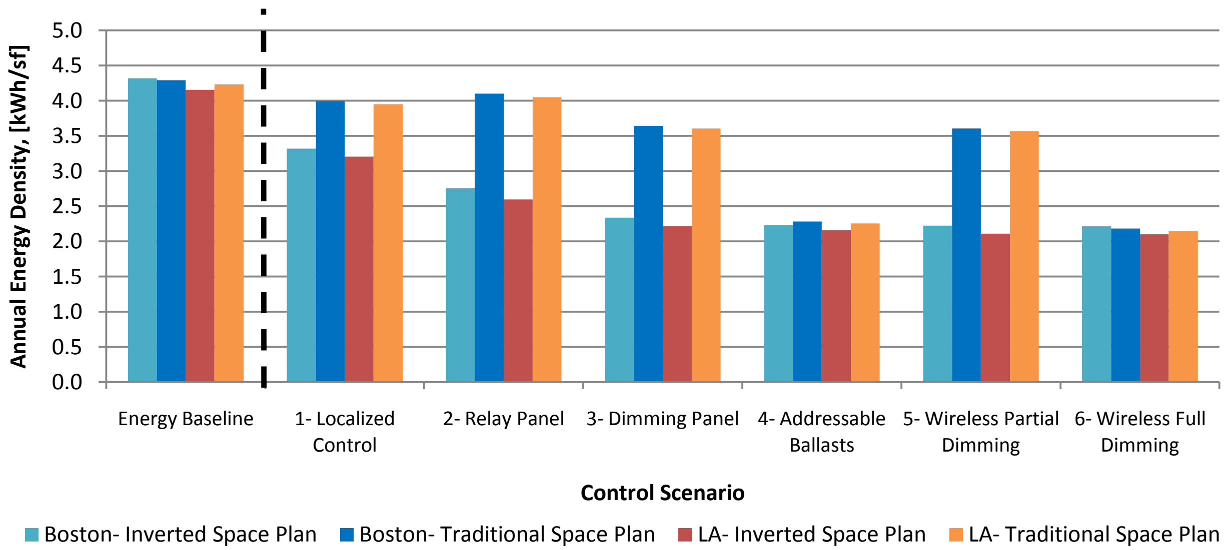

Figure 6 – Annual Energy Density, Split by Location and Space Planning

Figure 6 illustrates the resulting annual energy density for each location, split according to the type of space planning. It is clear that, for daylight-responsive control scenarios, the "Inverted Space Plan" side of the model resulted in a significantly lower energy density for both locations. For the energy baseline, which does not include the impact of daylight-responsive switching, the resulting variation in energy densities is mostly due to the distribution of interior spaces, as shown in Figure 7, and their associated access to daylight and assumed manual-on behavior. For Control Scenarios 4 and 6, which do include daylight-responsive dimming but also include high-end trim dimming, the impact of space planning is minimal since the majority of the dimming energy savings is primarily due to high-end trim dimming.

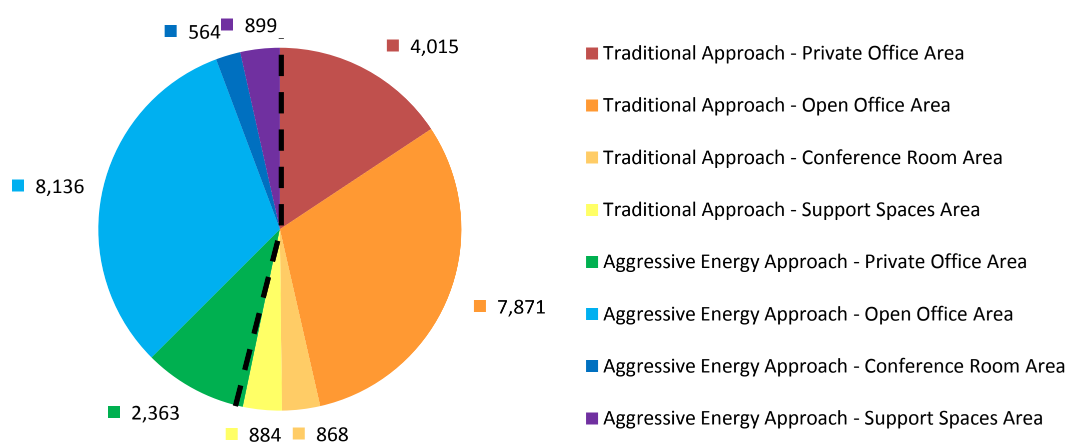

Figure 7 - Distribution of Spaces Types

Life Cycle Cost

The results for both Boston and Los Angeles show that the advanced lighting control strategies result in a lower life-cycle cost then the traditional control strategies.

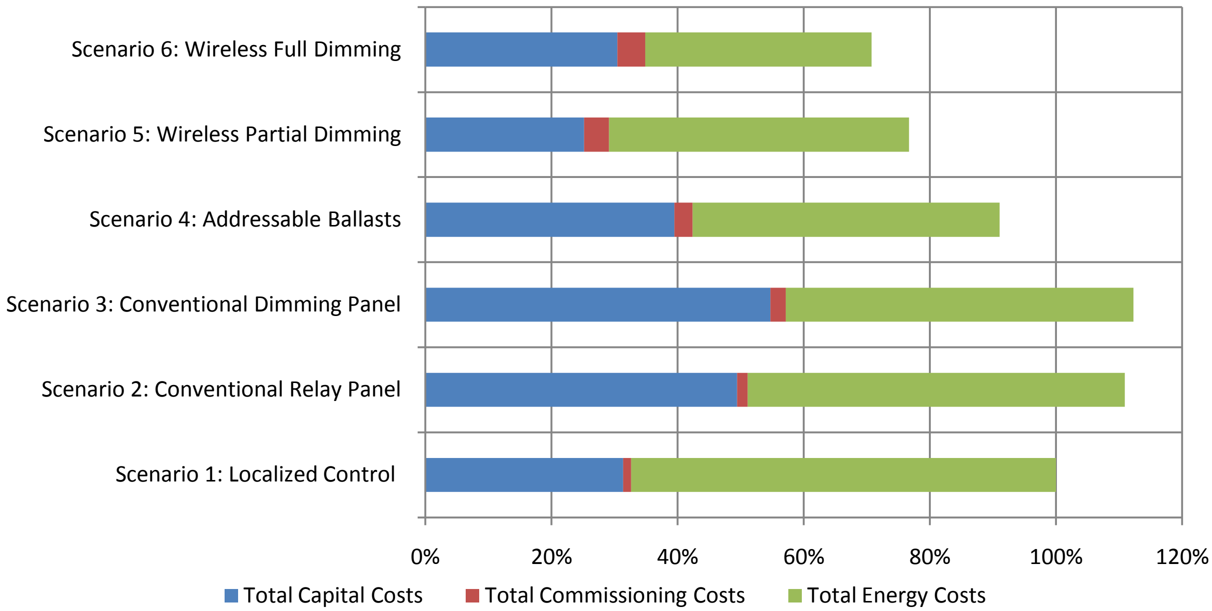

Figure 8 - Los Angeles: Life Cycle Cost Relative to Scenario 1

Table 2 - Los Angeles: Life Cycle Cost Summary, with Line Items showing Cost Relative to Scenario 1

	Energy Baseline	Scenario 1: Localized Control BASELINE	Scenario 2: Conventional Relay Panel	Scenario 3: Conventional Dimming Panel	Scenario 4: Addressable Ballasts	Scenario 5: Wireless Partial Dimming	Scenario 6: Wireless Full Dimming
Total Equipment & Installation Cost	-	100%	158%	174%	126%	80%	97%
Total Commissioning Cost	-	100%	145%	171%	310%	234%	258%
Total Annual Energy Cost	113%	100%	92%	81%	63%	80%	60%
Net Present Cost (LCC at 10 Years)	-	100%	115%	114%	89%	83%	76%

In Los Angeles, the Wireless Full Dimming scenario has the lowest life-cycle cost when considering an analysis period of 10 years, with the Wireless Partial Dimming and Addressable Ballast scenarios following closely behind. The two conventional panel-based systems require the highest initial investment, and do not save sufficient energy to offset that high cost.

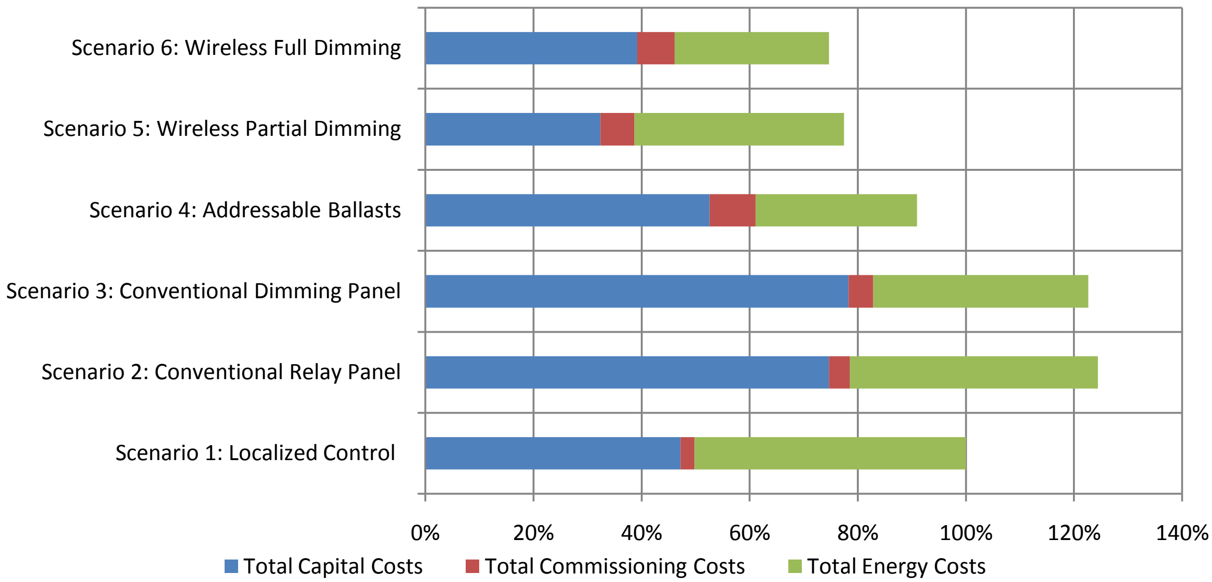

Figure 9 - Boston: Life Cycle Cost Relative to Scenario 1

Table 3 - Boston: Life Cycle Cost Density Summary

	Energy Baseline	Scenario 1: Localized Control BASELINE	Scenario 2: Conventional Relay Panel	Scenario 3: Conventional Dimming Panel	Scenario 4: Addressable Ballasts	Scenario 5: Wireless Partial Dimming	Scenario 6: Wireless Full Dimming
Total Equipment & Installation Cost	-	100%	158%	166%	111%	69%	83%
Total Commissioning Cost	-	100%	149%	176%	327%	243%	268%
Total Annual Energy Cost	112%	100%	91%	79%	59%	77%	57%
Net Present Cost (LCC at 10 Years)	-	100%	124%	123%	91%	77%	75%

In Boston, the Wireless Full Dimming scenario was shown to have the lowest life-cycle cost when considering a 10-year analysis period, due to improved energy savings at a marginally higher capital cost. That scenario, though, is closely followed by both the Wireless Partial Dimming scenario and the Addressable Ballast scenario, which provide high energy savings leading to the lowest operating cost.

Again, the traditional panel-based scenarios result in the highest life-cycle cost, mostly due to the high capital cost and lack of significant energy savings. Upgrading to a Title-24 compliant scenario, which can be used as a benchmark for codified efficient lighting controls, is less costly then providing a full panel-based system, requires the lowest commissioning investment, does reduce energy use to around 15% below the ASHRAE energy baseline.

Discussion of Results

Capital Costs

Capital Cost Category Descriptions

- *Control Equipment:* The cost of lighting control equipment supplied to the project via the Distributor and Contractor includes: switches, control stations, occupancy and vacancy sensors, photocells, power packs, and commissioning tools.
- *Devices:* Includes the Contractor's cost of labor, overhead and electrical commodities required to install switches, wall box dimmers, wall box occupancy sensors, control stations and photocells.
- *Branch Circuit Wiring:* Includes the Contractor's cost of materials, labor and electrical commodities required to provide both power and control signals, where used, from the panel to the lighting load. Also includes cost of routing control signal wiring between sensors and control components.
- *Demolition:* Includes the Contractor's cost of labor and overhead required to remove existing control devices, including switches, and branch-circuit wiring.
- *Lighting System:* Includes the Contractor's cost of materials, labor and electrical commodities required to install new ballasts in luminaire and make electrical connection from junction box to luminaire.
- *Control System:* Includes the Contractor's cost for materials, labor, overhead and electrical commodities required to install relay panels, dimming panels, contact interfaces, time switches, busway controllers, servers, and processors.
- *Lighting System Demolition:* Includes the Contractor's cost of labor, overhead, and electrical commodities required to remove existing ballasts and their associated wiring.
- *Commissioning:* Includes the Commissioning Agent's cost for commissioning, programming and calibrating the lighting control system. Commissioning includes:
    - Coordinating and developing the Owner's Project Requirements.
    - Reviewing the lighting controls design and specifications.
    - Developing commissioning specifications.
    - Reviewing Contractor submittals.
    - Preparing a Commissioning Plan.
    - Verifying that the installation meets the Owner's Project Requirements.
    - Verification of system performance.

Programming and Calibrating varies depending on the type of lighting control system. Programming for Addressable Ballast and Wireless control systems require a few more steps to locate individual ballast addresses and define control groups. Calibration of sensors is similar for all control systems. Programming and Calibration includes:

- Identifying, addressing, and establishing communication between panels, ballasts, sensors, and devices. (Addressable Ballasts and Wireless only)
- Programming ballast control groups. (Addressable Ballasts and Wireless only)
- Programming dimming scenes, time schedules, utility demand response strategies, and daylight dimming response.
- Calibrating occupancy sensor sensitivity and time delay, photo-sensor set points, dead-band adjustment, and time delay and fade rates.

Capital Cost Breakdown

The breakdown of the total capital cost for both locations is shown in Figure 10 for Los Angeles and Figure 11 for Boston, for the six analyzed control scenarios. The Conventional Panel Dimming scenario resulted in the highest capital cost due to the extensive rewiring work needed.

Though the control equipment cost is highest for the Wireless Partial and Full Dimming scenarios, the total capital cost is lower than the conventional upgrades due to a reduced need to restructure current wiring or run additional conductors to carry control signals. This reinforces the need to have an experienced contractor who is familiar with advanced control strategies, and can help to realize the potential for significantly reduced installed costs.

The capital costs for the two locations are not identical because of regional variations in the appropriate hourly rates for certified electricians, which are involved both in the actual installation, but also in the commissioning, of the system. The cost information provided by the independent contractor and commissioning agent was based on Los Angeles rates and prices, and then an adjustment was made to Boston rates using the Location Factors from RSMeans[10].

[10] RSMeans. "Electrical Cost Data 2009"

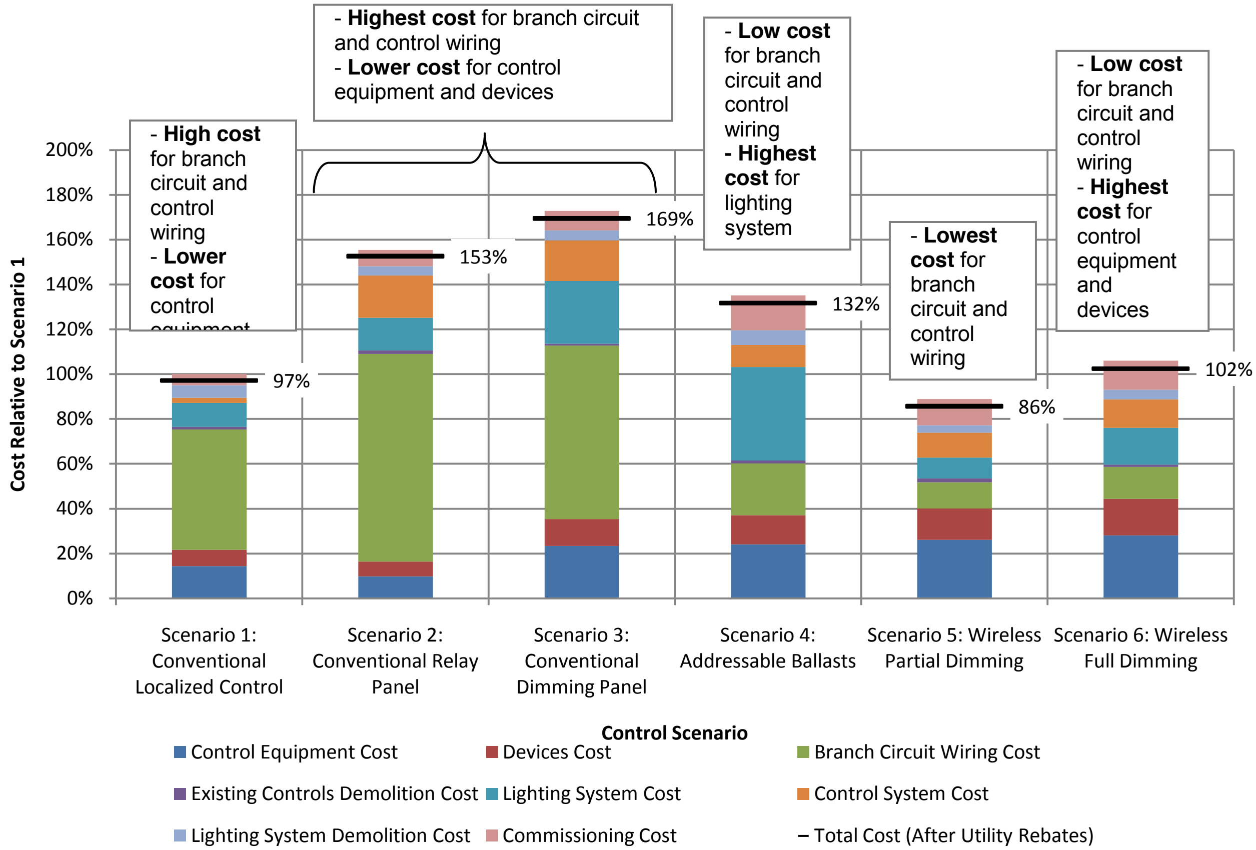

Figure 10 - Capital Cost Breakdown for Los Angeles

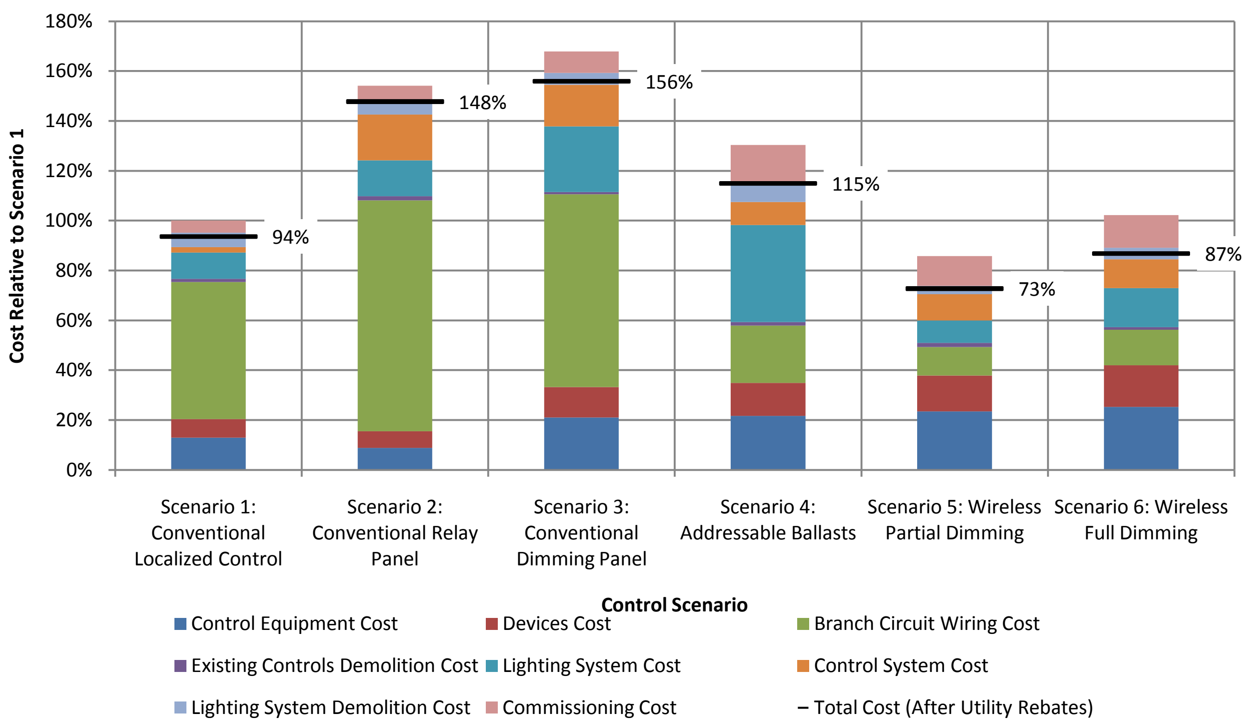

Figure 11 – Capital Cost Breakdown for Boston

Utility Equipment Rebates

The total capital costs for both locations also include the available equipment rebates from the two electrical utilities, which vary based on the type of control system, as shown in Figure 12. In Los Angeles, rebates are provided based on the quantity of controlling equipment, such as occupancy sensors and photocells, resulting in fairly uniform rebates across control scenarios. In Boston, rebates are provided based on the quantity of controlled lighting equipment, resulting in larger rebates when a more significant quantity of the lighting is controlled.

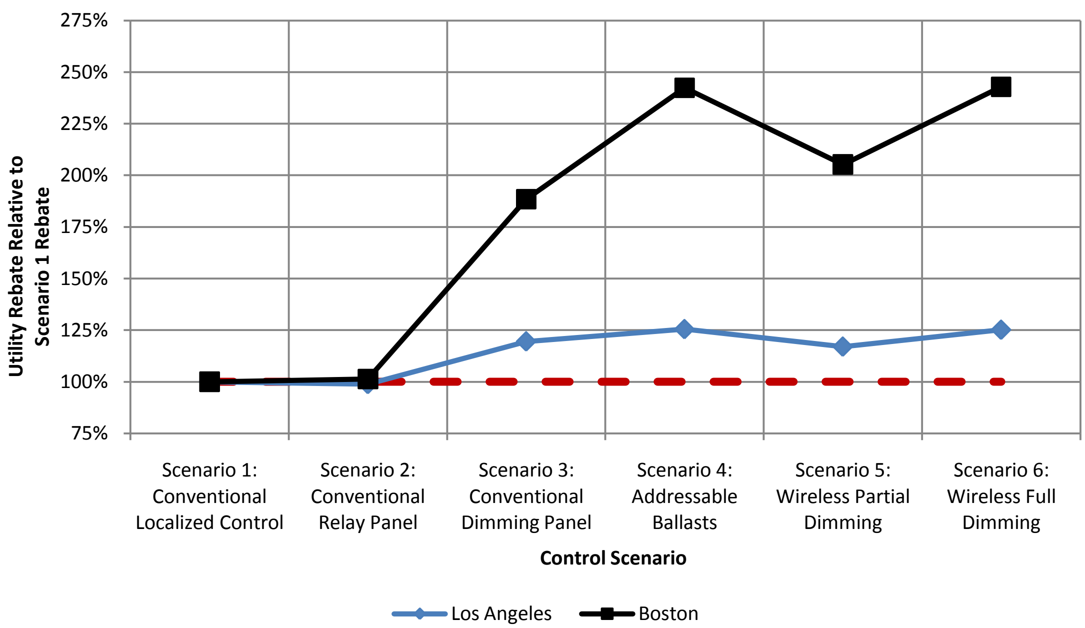

Figure 12 – Utility Rebates Relative to Control Scenario 1

Energy Costs

Utility Rate Structure

For the analysis in Boston, Rate Schedule B1 from NSTAR[11] was used, which incorporates a tiered energy use billing system and a demand system, and provides a different rate for peak summer conditions.

For Los Angeles, Schedule GS-2 from Southern California Edison[12] was used. This rate schedule uses a time-of-use schedule that is split for summer and winter, and also considers On-Peak, Mid-Peak and Off-Peak conditions.

The differences in the utility rate structures are apparent through the potential energy cost savings seen through daylight-responsive dimming, which serves to reduce energy costs during the most expensive time. In Boston, where no time-of-use schedule is used, the cost-savings from reducing peak energy use during the daytime is less significant than in Los Angeles, where energy rates peak at that same time.

Energy & Demand Charges

For both locations and under each of the eight control scenarios, the Annual Energy Cost Density was determined, considering both energy and demand charges.

In general, the demand charges in Boston are higher than in Los Angeles. In Los Angeles, a single demand charge rating is applied throughout the year, but in Boston, the demand charged is significantly increased during the summer months. Combined with lower daylight availability in Boston, the peak demand reached at mid-day results in a significantly higher annual cost.

The energy cost density is much higher in Los Angeles, due to the impact of the time-of-use rate structure. In particular, the scenarios that do not employ daylight-responsive controls result in a much higher energy cost density in Los Angeles then in Boston, since the peak pricing occurs during the peak of daylight availability.

[11] NSTAR Business Rate Data <http://www.nstar.com/ss3/business/rates_tariffs/rates/rates.asp>

[12] SCE Tariff Books <http://www.sce.com/NR/sc3/tm2/pdf/ce30-12.pdf>

Life Cycle Cost Evaluation

Because the lifecycle cost evaluation adds the present worth of annual energy over 10 years, it can capture economic benefits well after an initial cost has been paid back.

Figure 13 illustrates the life-cycle cost of the six control scenarios in Los Angeles as a function of the analysis period length.

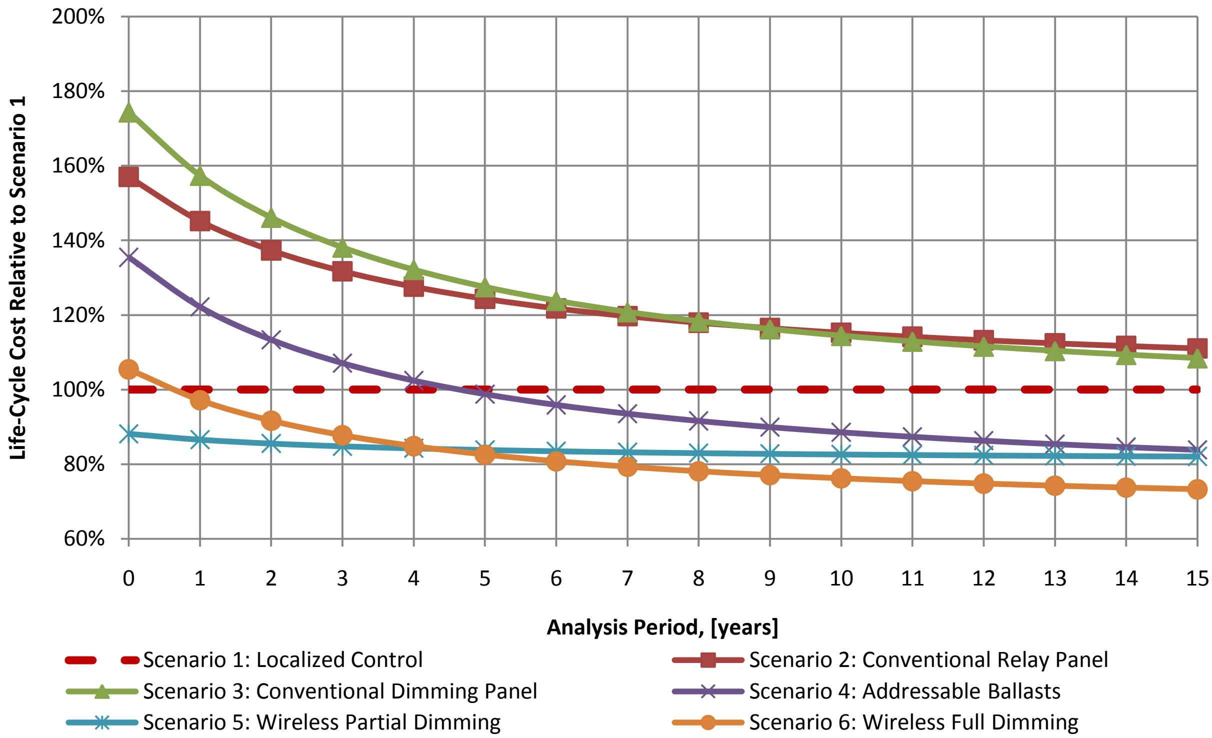

Figure 13 - Los Angeles: Life-Cycle Cost as a Function of Analysis Period Length, Relative to Control Scenario 1

As shown, the Wireless Full Dimming scenario has the lowest life-cycle cost at a 10-year period. This is due to additional energy savings beyond the Localized Control scenario through dimming in all spaces, combined with a capital cost that is not significantly more than a code-compliant Localized Control system.

The Wireless Partial Dimming scenario has a lower initial cost than the Localized Control scenario, and uses less energy, resulting in a lower life-cycle cost immediately after installation is complete. However, the additional energy savings seen in the Wireless Full Dimming scenario are greater than with Partial Dimming, with a break-even point between the two wireless scenarios between four and five years.

As is shown, the Addressable Ballast scenario has a break-even point in lifetime cost of ownership with the Localized Control scenario when the analysis period is around four years, which indicates that the initial investment into the advanced control system is essentially paid back within the first four years of ownership.

Both of the wired system upgrades, the Relay and Dimming Panel scenarios, result in the highest life-cycle cost due to the very high initial investment required to reconfigure the lighting control. The energy savings achieved by these two scenarios over the baseline does not offset the very high capital cost investment required.

Figure 14 shows the life-cycle cost of the various control scenarios in Boston.

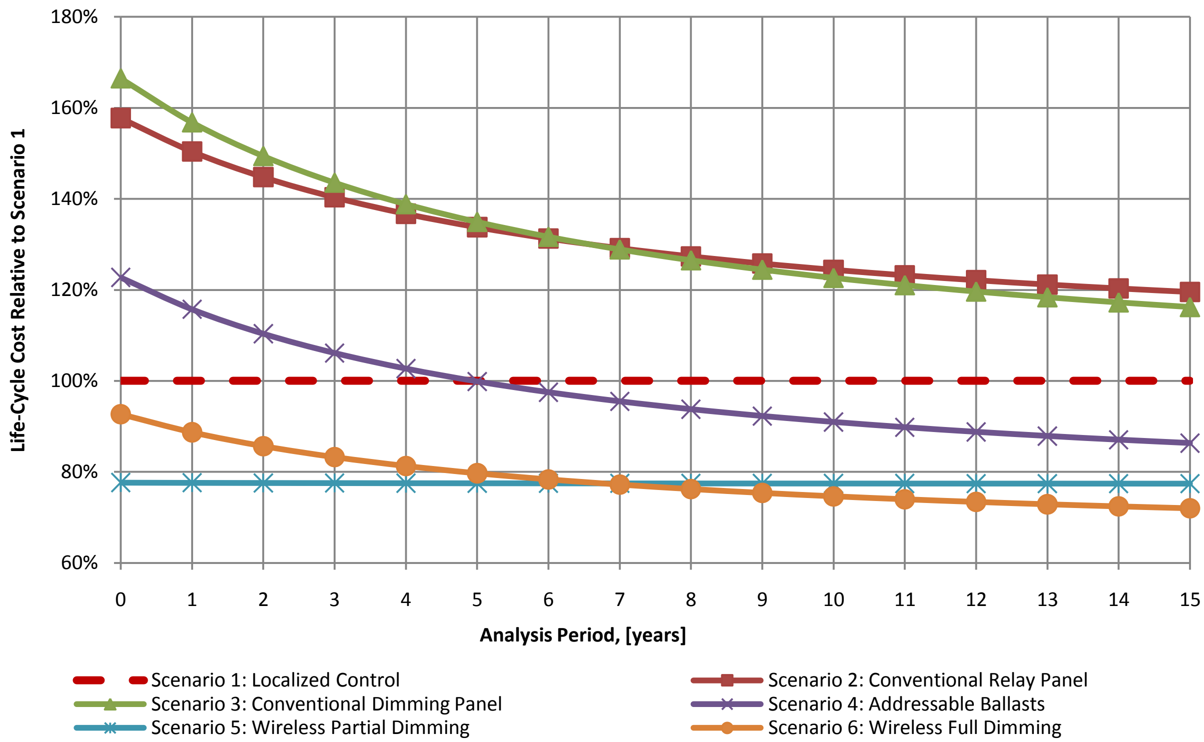

Figure 14 - Boston: Life-Cycle Cost as a Function of Analysis Period Length, Relative to Control Scenario 1

The Wireless Partial Dimming and Wireless Full Dimming scenarios have lower capital cost than the Localized Control scenario and maintain a lower cost-of-ownership across the analysis periods.

Additional energy savings with the Wireless Full Dimming results in the lowest 10-year life cycle cost, with a break-even point between the two wireless scenarios at about seven years.

The Addressable Ballast scenario requires a higher initial investment compared to the Localized Control scenario, but due to significant energy savings, it has a break-even point around five years with the Localized Control system.

The very high initial cost of the Relay Panel and Dimming Panel scenarios result in a very high life-cycle cost, and those systems do not pay back within the timeframes analyzed.

Conclusions

Based on the compiled results, some specific recommendations can be made, given the assumptions of this study.

- *How **cost effective** are lighting control systems?*
  - *Wireless and Addressable Ballast lighting controls can be cost effective, especially when the utility rate is based on time-of-use.*
  - *Relay Panel and Panel Dimming lighting controls are not cost effective for an aggressive energy retrofit strategy that incorporates daylight and occupancy responsive control. The cost of rewiring branch circuits is too high for the energy reductions to pay back in a reasonable time period.*
- *Do **intelligent wireless and addressable lighting controls** save more money and energy than other lighting controls?*
  - *Intelligent wireless and addressable lighting control systems can save more money and energy than conventional localized and centralized lighting control systems.*
- *Which lighting control strategies best suit the specific **priorities of different clients**?*

  If your client's priority is…
  - ***Fastest Payback**, then use… **Wireless Partial Dimming***
  - ***Best 10-year Investment**, then use…*
    - ***Wireless Full Dimming**, or*
    - ***Wireless Partial Dimming**, or*
    - ***Addressable Ballasts***
  - ***Lowest First Cost**, then use… **Wireless Partial Dimming***
  - ***Lowest Energy Use / Cost**, then use…*
    - ***Wireless Full Dimming**, or*
    - ***Addressable Ballasts***
  - ***Best for Reconfiguration**, then use…*
    - ***Addressable Ballasts**, or*
    - ***Wireless Full Dimming***
- *Do **advanced, programmable lighting controls** save more energy than conventional lighting controls?*
  - *Yes, the Wireless Full Dimming and Addressable Ballasts scenarios can save 15% - 35% more energy than conventional localized and centralized lighting controls.*
- *How much energy can be saved **compared to a code-compliant office**?*
  - *Using the Wireless Full Dimming or Addressable Ballasts control systems can save **35% below Title 2-2008**, and **49% below ASHRAE 90.1 2007**.*
- *How does **space planning** affect lighting control energy savings?*
  - *Space planning affects access to daylight. Locating open office areas near the perimeter windows provides more daylight for more floor area, increasing potential for energy savings with daylight dimming.*

Future Study

- **IECC Baseline**: Many cities have adopted the International Energy Conservation Code (IECC) for their energy code, and will be of interest to those cities.
- **Additional Locations**: To address more markets with differing climates and utility rate structures, a larger distribution of locations could be studied. Some suggested locations may include New York, Seattle, San Francisco, Miami, Houston, Austin, Denver, or others.
- **New Installations**: Understanding the costs associated with new construction installations.
- **Additional Market Sectors**: Some market sectors may have greater potential for energy savings from advanced and wireless lighting controls. Some suggested markets may include Big Box Retail, Warehouses, Data Centers, and Educational Facilities.
- **Workstation Occupancy Sensors & Plug Load Control**: How much energy can be saved by using occupancy sensors at each open office workstation to turn off task lights and non-essential plug loads? Is this fine granularity of control cost effective?
- **Demand Response Events:** Provide one or more demand events throughout the year, and include the energy cost impacts of meeting or not meeting the load-shedding requirements.
- **Post-Occupancy Cost Evaluation:** The costs included in this report are estimates based on best-practice and adjusted based on the assumed relative cost in each location. Evaluating the costs post-occupancy will provide a higher level of accuracy.

More Information

For more in-depth information related to this study, please refer to the following websites:

Daintree Networks www.daintree.net

Zigbee Alliance www.zigbee.org

DALI (Digital Addressable Lighting Interface) www.dali-ag.org

Lighting Controls Association www.aboutlightingcontrols.org

Southern California Edison www.sce.com

California Energy Commission www.energy.ca.gov

California Title 24 www.energy.ca.gov/title24/

NSTAR www.nstaronline.com

NREL (National Renewable Energy Laboratory) www.nrel.gov

DOE Commercial Lighting Solutions www.lightingsolutions.energy.gov

Advanced Lighting Guidelines
www.advancedbuildings.net/tools-guidance/advanced-lighting-guidelines

Lighting Research Center www.lrc.rpi.edu

National Research Council Canada www.nrc-cnrc.gc.ca

EREE (Energy Efficiency & Renewable Energy) www.eere.energy.gov

NOAA (National Oceanic and Atmospheric Administration) www.noaa.gov

GSA (U.S. General Services Administration) Smart Buildings Program
http://www.gsa.gov/portal/content/103965

Federal Green Construction Guide for Specifiers

http://www.wbdg.org/design/greenspec.php