



## PIER Lighting Research Program



California Energy Commission  
Contract # 500-01-041

### Prioritized R&D / Standards Connections

#### Deliverable 6.3.5b

*November 2, 2004*

Submitted To:  
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## Executive Summary

The purpose of this report is to facilitate a discussion of each project's potential to influence the future development of efficiency standards.

A technology must have a track record in the market before being considered as a basis for code development. The product must demonstrate adequate and consistent energy savings, be readily available in the market, and be non-proprietary in nature in order to be considered for a code revision. Since most of the LRP projects are in the final design stages, or in early marketing stages, they need more promotional efforts to establish market presence before any code revisions can be undertaken. Utility incentives are a good way to establish market presence.

This report therefore considers the prospects for the adoption of the LRP technologies into an incentive program run by California utilities. Four factors are analyzed:

- Opportunity for Code Improvement
- Total Resource Cost Ratio
- Peak Demand Reduction Cost
- Strategic Benefits

Most of the LRP projects were designed to cost-effectively reduce energy consumption, but the cost estimates show that several of them would be cost-effective in reducing peak electrical demand as well (in the case of demand reduction, cost-effectiveness can be judged relative to existing sources of demand reduction).

Technologies that reduce electrical load at times of peak demand, for instance daylight-linked lighting controls, are particularly valuable because they simultaneously reduce both energy consumption and peak demand.

It should be borne in mind that the results of the Total Resource Cost calculations (as discussed below) are based on the assumption that the electricity consumption of each technology follows the general shape of the electrical demand curve. This means that technologies that reduce peak demand are undervalued, and those that primarily reduce load at non-peak times may be overvalued by TRC.

**Figure 1 – Summary of the merits of each project for adoption into utility incentive schemes; an asterisk indicates a strong reason for inclusion in a utility incentive program**

Project #, Project Name		Opportunity for Code Improvement	Total Resource Cost Ratio	Peak Demand Reduction Cost	Strategic Benefits
2.1	LED Exterior Lighting	*	Not calculated	Not calculated	*
2.2	LED Task Lighting		Not calculated	Not calculated	
2.3	LED Low Profile Lighting		Not calculated	Not calculated	
3.1	Retrofit Fluorescent Dimming	*	Not calculated	Not calculated	*
3.2	Load shedding Ballast	*	Not calculated	*	
3.3	Classroom Photosensor	*		*	*
4.1	Hotel Bathroom Lighting	*			*
4.2	ENERGY STAR® Residential Fixtures	*	Not calculated	Not calculated	*
4.3	Retrofit Energy Efficient Downlights	*	*	*	
4.4	Portable Workstation Lighting		Not calculated	Not calculated	*
4.5	Integrated Classroom Lighting	*			*
5.1	Bi-level Stairwell Fixtures	*	*		
5.2	HID Electronic Ballast testing	*	Not calculated	Not calculated	
5.3	Low Glare Outdoor Lighting		Not calculated	Not calculated	*
5.4	DALI		Not calculated	Not calculated	

**Figure 2 - Rating system used in Figure 1**

Rating	Opportunity for Code Improvement	Total Resource Cost Ratio	Peak Demand Reduction	Strategic Benefits
*	Near-term, opportunity for code change (see Summary below)	TRC ratio > 1	Prospect for > 1 MW at a cost <\$200/kW	Significant strategic benefit
	Long-term opportunity, or no opportunity for code change	TRC ratio < 1	No significant prospect	No strategic benefit, or limited benefit

## Definition of Terms

### *Opportunity for Code Improvement*

Technologies and design approaches can form the basis for improvements in the mandatory and prescriptive efficiency standards demanded by Title 24 and other voluntary standards such as LEED, CHPS and Energy Star. To be considered as part of an argument in favor of a standards improvement, a technology must achieve a certain level of success in the open market, and must demonstrate verifiable and repeated energy savings at a reasonable cost.

Because the technologies in the LRP portfolio have, by their nature, not yet been successful in the open market, they cannot yet be considered ready to influence standards. A few of the projects seem set to achieve market success, but the lighting market is highly unpredictable due to the influence of factors such as aesthetics, ergonomics, multiple alternative uses for the same technology, and architectural co-ordination that do not affect other building technologies to the same degree.

In this report the projects have been divided up into those with “near-term” potential (i.e., they could be considered for the 2008/2011 edition(s) of Title 24, or for other voluntary standards that will be written during the next 2-5 years), and those with “long-term” potential. This distinction is subjective, but is based on market readiness and goodness-of-fit with the structure of existing codes and standards.

### *Total Resource Cost Ratio*

Net costs have been calculated using the California Public Utilities Commission (CPUC) Total Resource Cost (TRC) method. This method seeks to quantify the net energy cost (to society as a whole) of installing energy-saving measures. The outcome variable is the TRC Ratio, which is the total benefit divided by the total cost, irrespective of who receives the benefits and who pays the costs.

TRC has been used because the most immediate development path for the LRP technologies is to be adopted into an incentive program run by California utilities, and these incentive programs are overseen by the CPUC, which uses the TRC method to evaluate net cost. The TRC evaluates only the annual energy saving, and does not yet include a method for evaluating peak load reduction – this is planned for 2005.

It should be remembered that the “benefit” side of the TRC equation only takes into account the financial value of the energy saved, it does not attempt to quantify the value of other environmental and societal benefits that arise either from the technology itself or from the energy saved.

### *California Energy Commission Cost effectiveness criterion for Title 24*

If the LRP projects are to be used as support for future proposals for changes to the Title 24 energy efficiency standards, they will have to pass the California Energy Commission

(CEC) Net Cost tests. The CEC's tests are slightly different method to the CPUC's, yet sufficiently similar that the results under one test are highly indicative of results under the other. The CEC is required by law to develop and maintain energy efficiency standards that are "*cost effective, when taken in their entirety, and when amortized over the economic life of the structure when compared with historic practice*"<sup>1</sup>. More information on the principles of life-cycle costing used by the CEC can be found on their website<sup>2</sup>. The CEC currently uses a criterion called "Annual Life-Cycle Cost", in which the net present value (NPV) of the savings is calculated by multiplying the annual savings by the present value of a unit of saved energy. This method is very similar to the CPUC's Total Resource Cost.

### ***Peak Demand Reduction Cost***

Because the TRC method does not include peak demand reduction, we have quantified the demand reduction that is expected to result from each of the technologies, and have expressed it in \$/W, i.e. the cost of reducing summer peak demand by one Watt. The magnitude of these values is discussed later in this report.

#### *Peak Demand Reduction Requirements for Title 24*

The CEC uses Time-Dependent-Valuation (TDV) to estimate the costs avoided by technologies that include a significant element of peak demand reduction. This is a more advanced approach than annual LCC. Under this method it is necessary to estimate energy savings on an hourly basis. The energy savings for each hour are multiplied times the net present value of energy for that hour. The CPUC does not currently have an equivalent to this calculation method.

### ***Strategic Benefits***

The Commission's legal requirement for cost-effectiveness cited above applies to the standards as a whole, rather than to each individual measure. This gives the Commission some latitude to support technologies that may not be themselves cost-effective, but serve to support other technologies, or to advance the market, or to prepare the ground for future change. For this reason, this report sets out some of the strategic issues that surround each of the LRP projects.

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<sup>1</sup> Warren Alquist Act, Section 25402.

<sup>2</sup> California Energy Commission, *Life Cycle Cost Methodology, California 2005 Building Energy Efficiency Standards*. Submitted by Eley Associates under contract number 400-00-061, P400-02-009, March 2002

## Summary

### Opportunity for Code Improvement

The following table provides a snapshot of the code potential analysis conducted. Details on each of the projects and the nature of code opportunities and barriers are provided in the subsequent sections of this report.

**Figure 3 - Code Opportunity Summary**

Project #, Project Name		Term	Relevant Codes/ Standards	Market Readiness
2.1	LED Exterior Lighting	Near-term	Title 24	<b>Market Ready Soon</b>
2.2	LED Task Lighting	Long-term	Title 24	Under Development
2.3	LED Low Profile Lighting	Long-term	Title 24	Under Development
3.1	Retrofit Fluorescent Dimming	Long-term	Title 24, CHPS	Under Development
3.2	Load shedding Ballast	Long-term	Title 24, CHPS	Under Development
3.3	Classroom Photosensor	Near-term	Title 24, Title 20, NEMA, CHPS	<b>Market Ready Soon</b>
4.1	Hotel Bathroom Lighting	Near-term	Title 24	<b>Market Ready</b>
4.2	ENERGY STAR® Residential Fixtures	Near-term	Title 24, Energy Star	<b>Market Ready Soon</b>
4.3	Retrofit Energy Efficient Downlights	Near-term	Title 24, Title 20, Energy Star	<b>Market Ready</b>
4.4	Portable Workstation Lighting	Long-term	Title 24	Under Development
4.5	Integrated Classroom Lighting	Near-term	Title 24, Dept. of State Architect, LEED, CHPS	<b>Market Ready</b>
5.1	Bi-level Stairwell Fixtures	Near-term	Title 24, ANSI	<b>Market Ready</b>
5.2	HID Electronic Ballast testing	Near-term	Title 20	N/A
5.3	Low Glare Outdoor Lighting	Long-term	Title 24, IESNA	Under Development
5.4	DALI	Long-term	Title 20, NEMA	Under Development

## Total Resource Cost Ratio

For energy-efficiency measures, the Total Resource Cost (TRC) ratio provides an indication of whether the measure will result in a net financial expenditure or a net financial saving for society. TRC ratios less than one indicate a net expenditure, ratios greater than one indicate a net saving.

This section describes TRC calculations performed for five of the PIER LRP projects:

- 3.3 Classroom Photocell System
- 4.1: Hotel and Institutional Bathroom Lighting Project
  - The analysis is conducted for the wall switch nightlight only. The project team is also developing a fixture integrated nightlight that is expected to have greater savings due to reduction in installed wattage.
- 4.3: Energy-Efficient Retrofit/Remodel Alternative to Incandescent Downlights
- 4.5: Integrated Classroom Lighting System
- 5.1: Bi-Level Stairwell Fixture Performance

Figure 4 shows the TRC ratio for each project, along with a projection of what each project's incremental measure cost would have to be, to make the TRC ratio equal to one.

Project number	Project Title		TRC Ratio	Incremental Measure Cost	Incremental measure cost required to make TRC=1	
3.3	Classroom Photocell		0.78	\$719	\$553	
4.1	Hotel Bathroom Lighting ("business hotel")		0.32	\$65	\$21	
	Hotel Bathroom Lighting ("vacation hotel")		0.82	\$65	\$53	
4.3	CFL Downlights for Kitchens		4.22	\$10	N/A	
4.5	Classroom Lighting	Scenario A	2-row switching, estimate from case study	0.66	\$619	\$409
		Scenario B	2-row dimming, estimate from case study	0.48	\$994	\$477
		Scenario C	3-row switching, estimate from case study	0.30	\$1719	\$516
		Scenario D	3-row dimming, estimate from case study	0.23	\$2219	\$510
		Scenario E	2-row switching, energy saving estimate based on bi-level switching study	0.30	\$619	\$186
5.1	Bi-level fixture		1.06	\$277	N/A	

**Figure 4 – TRC ratios and cost reduction requirements**

The calculations of TRC ratio in this report do not include the administrative and overhead costs required to run the programs. These can typically be as high as 30% of the program cost. Thus a product would typically need a TRC ratio of at least 1.30 in order to cost effective in a utility program.

Figure 5 summarizes the process used to calculate TRC ratios. For each project, only one sample calculation is shown – the others follow the same format but with different values. The letters in parentheses describe how each value is calculated from previous values. More information about how each value was derived can be found in the following sections.

The only values used in the calculation of TRC ratio are:

- Gross annual energy savings (positive effect)
- Gross incremental measure cost (negative effect)
- Expected useful life (positive effect)
- Present value of annualized savings per kWh (calculated from expected useful life)

From the list above, it can be seen that the calculation of TRC ratio does not include a value for expected peak demand reduction, and that the ratio is based only on annual savings estimates. However, the value of annualized savings per kWh is based on an average of both on-peak and off-peak costs, so for technologies where the on-peak load is similar to the off-peak load, the effect of peak demand reduction is factored in correctly. Conversely, technologies that save more load at peak time than at other times will be undervalued in the TRC calculation, and technologies that save less load at peak time than at other times will be overvalued.

The CPUC is currently in the process of adopting a more detailed set of calculations to value programs based on their peak savings, but this won't be available until 2005.

<b>Project Number</b>	<b>3.3</b>	<b>4.1</b>	<b>4.3</b>	<b>4.5</b>	<b>5.1</b>
<b>Project Title</b>	Classroom Photocell	Hotel Bathroom Lighting††	CFL Downlight	Classroom Lighting†††	Bi-level fixture
<b>Unit Goal</b> (a)	800	770	20000	1600	3000
<b>Unit Definition</b>	one classroom	one fixture	one downlight head	one classroom	one fixture
<b>Installation, Service, and Repair Labor Costs</b>	0	0	0	0	0
<b>Gross Annual Energy Savings (kWh)</b> (b)	773	50	59	258	392
<b>Gross Incremental Measure Cost</b> (c)	\$719	\$35	\$10	\$619	\$264
<b>Expected Useful Life (years)</b> (d)	16	8	16	16	16
<b>Net-to-Gross Ratio</b> (e)	0.8	0.8	0.8	0.8	0.8
<b>Total Gross Incremental Measure Cost</b> (f=a*c)	\$575,200	\$26,950	\$200,000	\$990,400	\$792,000
<b>Total Net Incremental Measure Cost</b> (g=f*e)	\$460,160	\$21,560	\$160,000	\$792,320	\$633,600
<b>Projected Annual Net Energy Savings (MWh)</b> (h=a*b*e)	495	31	944	330	941
<b>Projected Lifecycle Net Energy Savings (MWh)</b> (i=h*d)	7916	246	15104	5284	15053
<b>Present Value of Annualized Savings per kWh</b> (j†)	0.72	0.42	0.72	0.72	0.72
<b>Net Electricity Benefits</b> (k=h*j)	\$354,209	\$12,959	\$675,885	\$236,445	\$673,593
<b>TRC ratio</b> (l=k/g)	<b>0.77</b>	<b>0.6</b>	<b>4.22</b>	<b>0.30</b>	<b>1.06</b>
† average present value of all kWh to be saved over the EUL of the measure. Assuming a discount rate of 8.15%					
†† Business hotels, new rooms					
††† 2 row switching system, energy savings estimated from bi-level study					

**Figure 5 – Sample TRC ratio calculations**

## Peak Demand Reduction Costs

Peak demand reduction is an increasingly important component of California's energy infrastructure, although it remains difficult to quantify the financial benefit of reducing peak demand, and the market for peak demand savings is not yet well established.

For this report, we have simply calculated the expected cost of achieving a Watt of peak demand reduction using each of the LRP technologies, amortizing the cost of each technology over its expected useful life. Only one of the technologies is specifically aimed at demand reduction, but several of them substantially reduce demand as a side-effect of reducing energy consumption; this is particularly true of technologies that reduce light levels in response to daylight.

### *Lighting – HVAC Interaction*

It should be noted that in these calculations the “raw” estimates for annual energy savings and peak demand reduction are both modified by a factor that takes into account the interaction between lighting and HVAC systems. When lights are switched off, cooling energy is usually saved because the heat generated by the lights does not have to be removed from the building by the air conditioning system. The amount of additional energy saved varies depending on the climate and on the efficiency of the air conditioning system. For California, the additional savings average around 18% of the lighting energy savings (assuming a “lighting-to-cooling fraction” of 0.5<sup>i</sup> and a coefficient of performance for the air conditioning system of 2.5. The figure for 2.5 COP is calculated from the Federal standard<sup>ii</sup> for 8.5 EER and a conversion factor of 0.293).

An 18% adjustment for “lighting-HVAC interaction” has therefore been made to the figures for both annual energy savings and the peak demand reduction for each of the LRP lighting technologies, except for the bi-level stairwell fixture and the hotel bathroom nightlight fixture, in which the energy savings are generally achieved overnight when there is no cooling load.

### *Cost of Peak Demand Reduction*

The estimates in Figure 6 can be compared with values for the cost of electrical load shedding given in a report from the Peak Load Management Association (Peak LMA)<sup>iii</sup>. The Peak LMA report found that the average cost of load shedding in dedicated load shedding programs was \$85/W, which is not dissimilar to some of the values shown below. This indicates that, in addition to project 3.2 (load shed ballast), projects 3.3 (classroom photosensor) and 4.3 (residential retrofit fixture) could be viewed by utilities as passive load-shedding programs, comparable in cost to managed load-shedding programs. These “passive” programs would reduce the “peak” of the demand curve, and would have lower overhead costs than managed programs, but could not be relied upon to shed a known amount of load at a specific time.

The maximum cost reported by the Peak LMA was \$878, which indicates that the LRP technologies may be a lot more cost-effective than the least cost-effective parts of existing utility load-shedding portfolios.

It should be noted that no interest rate has been applied to the capital cost of the measures shown in Figure 6.

**Figure 6 – Peak Demand Reduction Costs**

Project Number		3.2	3.3	4.1	4.3	4.5	5.1
Project Title		Load-shed ballast	Classroom Photocell	Hotel Bathroom Lighting†	CFL Downlight	Classroom Lighting††	Bi-level fixture
Gross Incremental Measure Cost	(a)	-	\$719	\$65	\$10	\$619	\$277
Projected Net Coincident Peak Demand Reduction (W)	(b)	-	295	12.8	7.6	18	Data not available
Expected Useful Life (years)	(c)	-	16	8	16	16	16
Peak Demand Reduction (\$/kW)	(d=a/b/c)	\$94 <sup>a</sup>	\$152	\$635	\$82	\$2,149	-
<sup>a</sup> See Deliverable 6.3.4: Complementary Research Review † Business hotels †† 2 row switching system, energy savings estimated from bi-level study							

## Detailed Report

Following is a brief discussion on each of the PIER LRP products for the following two criteria:

- **Opportunity for Code Improvement** – In this section we identify the barriers to compliance with existing codes and standards provisions, opportunities to use current code provisions for increasing market penetration of the products, as well as opportunities for improving current codes and standards based on the LRP product capabilities.
- **Strategic Benefits** - In this section we identify possible additional benefits that go beyond the energy savings achieved by each technology in its intended application. In some cases the definition of strategic is problematic; for instance the DALI Protocol is intended for a wide variety of applications and is therefore inherently strategic. The Portable Workstation Lighting fixture is intended for a market that does not yet exist and may not ever exist unless the initiative is taken to create it, and for that reason we have classified it as a strategic product. In other cases, such as the Retrofit Energy-Efficient Downlight, the product could create a widespread reduction in energy use in its target market, but since this is usually the expectation inherent in an incentive program, we have not classified this project as strategic.

### 2.1 LED Exterior Lighting

#### *Opportunity for Code Improvement*

Nonresidential, high-rise residential and hotel/motel exterior, porch, and perimeter lighting is covered by the 2005 California Title 24 energy standards. Permanently installed luminaires must either be high efficacy (i.e., lamp efficacy of at least 60 lumens per watt for luminaires 100W or more), or be controlled by motion control devices. In addition all permanently installed outdoor lighting is required to be controlled by photocontrol or astronomical time switch that automatically turns off the outdoor lighting when daylight is available.

Residential outdoor lighting must use high efficacy light sources (40 lumens per watt for lamps 15 Watts or less) or be controlled with a motion sensor with integral photosensor.

Since the efficacy of LEDs is currently less than 40 lm/W, LED light fixtures without occupancy sensors with integral photosensor currently do not qualify for the outdoor lighting requirements. Even with the integral occupancy and photosensor, the product faces one additional hurdle to compliance with Title 24 – the always ON feature of the LED amounts to an always-on standby load for the light fixture. Title 24 stipulates that all non-high efficacy fixtures must be completely shut OFF during times of non-occupancy. An exception for LED ‘stand-by’ lighting may be sought in the future code revision cycle.

However, the efficacy of LEDs is constantly improving, and they might qualify as high-efficacy sources in the years to come.

In order to control glare, light trespass and sky glow, nonresidential outdoor lighting must use luminaires that are designated as “cutoff” (i.e. they do not emit light above horizontal) when the installed wattage per lamp is above 175 watts. However, there is currently no requirement for residential outdoor lighting to meet this cutoff standard. Currently, cutoff would be difficult to achieve because most residential outdoor lighting uses CFLs, which are not photometrically suited to achieving cutoff designation without compromising efficiency and uniformity of illuminance. Conversely, LEDs are small point sources and can easily be controlled to meet cutoff requirements without significant loss of efficiency, and while preserving uniformity. Therefore, if a future revision of Title 24 were to require residential lighting to meet the same cutoff requirements as nonresidential lighting, an existing market for LED fixtures would be beneficial.

#### *Strategic Benefits*

No research has been conducted to find out what performance features homeowners want from outdoor luminaires, and how these luminaires are used in practice. A monitored field trial of installed systems might suggest ways in which outdoor luminaire designs could be improved, or ways in which they could more efficiently be regulated while preserving the essential performance features the homeowners value. This knowledge could lead to a significant reduction in residential outdoor lighting use, and so is strategically important.

## **2.2 LED Task Lighting**

#### *Opportunity for Code Improvement*

Task lighting is not currently covered by the California Title 24 standards for either residential or non-residential buildings. The 2001 California Title 20 Appliance Standards have wattage restrictions for torchiere fixtures, placing a lamp wattage limitation of no more than 190 watts on one fixture. Fixtures below 190W are currently not covered by either standard.

Based on the improving efficacy, color properties and safety features of LEDs, changes could be proposed to future round of changes to the Title 20 appliance standards to include efficiency requirements (lumens/watt or total wattage per lamp) for task light fixtures.

#### *Strategic Benefits*

Although the current rate of development of LEDs and LED fixtures is extremely rapid, at this stage we see no clear strategic benefits arising from this technology. LEDs do seem to offer two possible benefits over the CFL lamps currently used in high-efficacy task lights – small size, and controlled beam spread. However, the issue of heat dissipation is critical to making this technology work for task lighting, both for energy efficiency and safety in use.

## **2.3 LED Low Profile Lighting**

### *Opportunity for Code Improvement*

The low profile fixture developed within this project was intended for use in elevators. Elevator lighting is not currently given specific treatment in Title 24, but it is included in the “planned lighting” of the space, so it contributes toward the total lighting power density calculation. Since elevator lighting is such a small component of the lighting of a building (2% is the figure estimated by the project team) that it seems unlikely to be considered specifically in future revisions of the standard, so we don’t anticipate this project to have a significant impact in the context of future code development.

The low-profile fixture could be used in other applications, but these have not yet been identified.

### *Strategic Benefits*

As above, although the current rate of development of LEDs and LED fixtures is extremely rapid, at this stage we see no clear strategic benefits arising from this technology

## **3.1 Retrofit Fluorescent Dimming**

### *Opportunity for Code Improvement*

Title 24 currently provides Power Adjustment Factor credits for dimming ballasts that encourage the use of fluorescent dimming in various spaces. Since this product is designed for retrofit application, it is not currently governed by the Title 24 energy codes in California, which deal mostly with new construction. The only exception is when over 50% of the luminaries are replaced, the lighting needs to comply with the Title 24 code requirements. The nature of retrofit required for installing the retrofit fluorescent dimming system would not trigger this code requirement.

A code change proposal that includes comprehensive efficiency requirements for retrofits and existing buildings is currently being discussed, but will not be in place before 2008. Utility incentives to support the early adoption of this technology would advance the prospects for treatment of existing buildings in future revisions of Title 24.

### *Strategic Benefits*

This project is by its nature strategic, because it facilitates energy savings across a wide variety of applications, and enables better use of existing energy-saving resources.

## **3.2 Load shedding Ballast**

### *Opportunity for Code Improvement*

For new construction applications, the 2005 California Title 24 (Table 146-A) provides a power adjustment factor (control credit) of 0.25 for using *manual dimming with automatic load control of dimmable electronic ballasts*. These credits are not mandatory

in nature and only serve to provide an incentive to use a technology that does not have the desired market penetration for a mandatory standard. For retrofit applications, the same credit can be taken when retrofitting more than 50 percent of the lighting system (light fixtures), which would trigger a requirement for code compliance with the latest standards. This requirement for code compliance is only triggered if the whole fixture, rather than just the ballast, is being replaced.

However, the ballast defined in project 3.2 is not a dimming ballast but a switching ballast, and is not designed to be manually controlled by occupants (though, incidentally, this feature could easily be provided, and would make the ballast compliant with the multi-level switching requirements of Title 24 2005 §131(b)).

Within table 146-A, the power adjustment factor for “load control” could be expanded to cover non-dimming ballasts. It should be noted that load shedding may be redundant in spaces that have automatic daylight controls.

Alternatively, if pilot installations show that lighting load shedding is cheap and unobtrusive, it could be considered as a mandatory measure in, for instance, office and warehouse lighting in future revisions of Title 24.

### *Strategic Benefits*

Load shedding is a priority for the California utilities and the California Energy Commission, both of whom anticipate increasing peak loads over the coming years. Load shedding is critical to the health of the California electricity market, and as such this product is strategic. If this technology is proven to be cost-effective and shows consistent savings, it could be included in the suite of tools used by the utilities to achieve load shedding.

## **3.3 Classroom Photosensor**

### *Opportunity for Code Improvement*

The specifications of the photocell have the potential for inclusion in the “Acceptance Testing Requirements” for approved controls in future versions of Title 24, *if it is accepted by the controls industry as an industry wide standard*. This industry wide acceptance could come in the form of standards by national associations and standards-setting bodies, or through an industry group set up for this specific purpose that results in commitments from various manufacturers to implement the product specifications in their product lines.

The product itself already enjoys daylighting control credits in the existing code language and together with the bi-level control-enabled occupancy sensor benefits from the bi-level control credit in the 2005 Title 24 code (Table 146-A). In this case the code provision is in advance of verified energy savings, since no large field trials have yet been conducted to measure the effectiveness of daylighting control in sidelit spaces in California. Following the results of such a study, it may be justifiable to change the value of the control credit, or in certain spaces to mandate the use of daylighting control.

The most innovative features of the photosensor system are the “desktop commissioning tool” and the “sliding setpoint” control algorithm. Both these features are new to the US market and are potentially important developments. However, success of the system depends largely on the acceptance of the commissioning protocol by various manufacturers and in-turn designers and users of the spaces that this product is targeting. It would be worthwhile to incorporate the commissioning protocols in various commissioning standards that are taking shape in California and elsewhere in the US.

The product may also benefit if the CHPS program finds the system cost effective and beneficial for schools.

### *Strategic Benefits*

The Classroom Photosensor uses an innovative “sliding setpoint” control system designed to make the operation of the system less obvious and less visually intrusive, and thereby to improve occupant acceptance of daylight-linked systems. This is an important strategic goal because sliding setpoint systems could also be used in offices and other daylit spaces.

As part of this project, computer simulations of the visual conditions in classrooms have been run, and have shown that the photosensor maintains a fairly constant illuminance on the working plane. Another important strategic goal in the development of daylight-linked control systems is to find out whether maintaining a certain value of desktop illuminance is a good idea for a control system, or whether some other method would better suit the classroom environment, and further improve the acceptance of systems. Monitoring of installed systems would bring this strategic goal within reach.

The classroom photosensor system is designed to work with dimming ballasts. An increased market for dimming ballasts is desirable from a strategic point of view, since this will improve the understanding of dimming technologies among electrical contractors, lighting reps and specifiers, and may help to standardize products.

## **4.1 Hotel Bathroom Lighting**

### *Opportunity for Code Improvement*

Hotel and motel guestrooms are currently excepted from the nonresidential requirements of Title 24 (2005), and are treated the same as residential buildings. This means that they are required to have either high efficacy lamps, or occupancy-sensor controls, but not both. Most new-build hotel and motel bathrooms use high efficacy lamps already, and no control credit is available for owners who install this new product.

The other code related issue with the product is the always ON feature of the LED during periods of non-occupancy. Since, the code stipulates that the source be either high-efficacy or be OFF during time of non-occupancy, the motion sensor night-light would not qualify with the existing 2001 or the upcoming 2005 Title 24 standards. A definition of ‘stand-by’ lighting load may be introduced in future revisions of the standard to account for a low level always-on lighting for way finding or night-light.

To encourage the adoption of not only this product, but of other lighting controls more widely, the current exception for hotel and motel guestrooms in Title 24 could be removed in future revisions. Trials of the acceptance of lighting control system in guestrooms are an essential precursor to any revision.

#### *Strategic Benefits*

The occupancy sensor used in the wall switch version of this device is very similar to occupancy sensors sold in the residential market. Successful introduction of this device in hotels and motels would familiarize a lot of people with this technology, and might encourage them to use occupancy sensors in their own homes.

### **4.2 ENERGY STAR® Residential Fixtures**

#### *Opportunity for Code Improvement*

These light fixtures are considered to be task lighting or portable lighting, so they are not currently governed by Title 24 for residential applications. Section 1605.3(n) of the 2001 California Title 20 Appliance Standards has wattage restrictions for torchiere fixtures, limiting lamp wattages to a maximum of 190 watts on one fixture. Light fixtures of less than 190W are currently not covered by the standard.

However, if the products demonstrate considerable savings and acceptance by purchasers, there is a possibility of proposing new efficiency requirements for task lighting in residential applications in the Title 20 standards. Utility rebates might be the best way to ensure that enough fixtures are bought to form a basis for field verification.

Finally, these products are anticipated to have ENERGY STAR® certification.

Currently, there is one major difference in the Title 24 specifications and ENERGY STAR® in that ENERGY STAR® does not require electronic ballasts while Title 24 standards require electronic ballasts for all high-efficacy hard-wired fixtures. However, ENERGY STAR® is actively considering incorporating the electronic ballast in its specifications, which would make it easy for ENERGY STAR® products to qualify as Title 24 compliant fixtures for hardwired lighting. Any future recommendations for inclusion of task lighting in Title 24 or Title 20 is bound to include requirements for electronic ballasts, so this is an important criterion for the LRP product development.

#### *Strategic Benefits*

The residential light fixture market is dominated by fixtures with traditional styling that were originally designed for incandescent lamps and are not well suited to CFLs or linear fluorescent lamps. To support the increased use of high efficacy lamps in the residential market, it would be useful to encourage fixtures such as those developed in the LRP project, which either use modern styling, or use traditional styling that has been adapted for high-efficacy lamps.

The Complementary Research Review (deliverable 6.3.4) cites evidence that task lights are prevalent in US homes, and make up a significant amount of residential lighting

energy use, which makes the support of high efficacy task lighting an important strategic goal.

### **4.3 Retrofit Energy Efficient Downlights**

#### *Opportunity for Code Improvement*

Exception 150(k)2 to 2005 Title 24 allows up to 50% of the lighting in residential kitchens to be non-high efficacy. CFL-based kitchen downlight are becoming widespread in California, and this holds out the possibility that in future revisions of Title 24, this exception could be removed. Currently, fluorescent fixtures are the only viable way of achieving high efficacy lighting in residences; questions remain, however, over whether the color rendering of CFLs and linear fluorescent lamps is sufficiently good to mandate their use as the only light source in kitchens. The adoption of high efficiency lighting in kitchens is proceeding quickly, and the Retrofit Energy Efficient Downlight is one such product currently being marketed and ‘test-driven’ by builders. Along with similar efforts by DOE and other agencies, this has the potential of affecting future energy standards for residential lighting.

#### *Strategic Benefits*

The main feature of this product that differentiates it from other CFL downlight fixtures is its remote and multi-lamp ballast. The ballast along with the master-slave configuration of fixtures generates savings in installation costs and time, which in turn results in a greater benefit/cost ratio for this product compared to other CFL downlights.

### **4.4 Portable Workstation Lighting**

#### *Opportunity for Code Improvement*

Portable lighting is potentially a much more efficient way to light an office than the current practice of general lighting from ceiling-mounted fixtures. However, portable lighting is currently not governed by the Title 24 or Title 20 standards. However, Title 24 does acknowledge task lighting in the prescriptive requirements of the 2005 revision of Title 24, which state that if the wattage of task lighting is not known at design time, the lighting power density calculation should assume 0.2W of portable lighting power (section 146(b)). This would potentially give advantage to a task-ambient lighting system which would not be required to use the additional 0.2W for portable lighting in their installed LPD calculations. To get compliance for such a task-ambient system, the lighting designer needs to submit adequate supporting document to indicate the installed wattage for ambient and task lighting separately, and using their combined total LPD as the designed LPD for the space. This combined LPD is anticipated to be lower than the LPD from traditional ceiling mounted lighting.

An alternative approach might be to allow a Power Adjustment Factor (“control credit”) for lighting that can be controlled from the workstation. Many studies have found that people who are given more control over their lighting tend to use it less, so such an

addition to the control credits would be justified *prima facie* on the basis of research, but would require field verification before being adopted into code.

A more radical approach in the longer term would be to reduce allowable lighting power densities to the point where ceiling lighting would no longer be able to guarantee sufficient workstation illuminance at every point in the room.

### *Strategic Benefits*

The section above on “Opportunity for Code Improvement” describes the strategic advantage of encouraging task-based rather than general lighting.

## **4.5 Integrated Classroom Lighting**

### *Opportunity for Code Improvement*

One of the most important innovations of this project is the use of fixtures that are pre-wired for occupancy sensors; this greatly speeds up installation time on site, and reduces the possibility of wiring mistakes. If field trials show that this system is a significant benefit, a requirement or a credit for pre-wired lighting controls in continuous-row suspended light fixtures could be incorporated into the Collaborative for High Performance Schools guidelines.

Another aspect of this system relevant to code is the high percentage of uplight in the space. The view of the project team, and of many lighting researchers, is that uplight allows the same impression of “lightness” to be created with a lower lighting power density, since uplight reduces the impression of gloom, and provides better lighting of faces and walls. Pending successful field monitoring, future revisions of Title 24 could reduce the allowable lighting power density for schools, and encourage the use of a certain percentage of uplight.

A final innovative feature is the streamlined process for specification, ordering and delivery. To some degree, streamlined procedures are a standard feature in the lighting industry – for instance, when ordering a luminaire it’s not necessary to specify that it include a lampholder and a mounting kit, those things are “boxed” with the fixture. However, the Integrated Classroom Lighting System takes this idea to a further level by allowing specifiers to order the fixtures and the controls in the same package. This speeds up the design process since the designer knows for sure that the wires will be routed correctly inside the fixtures, and will physically fit inside the fixture housing without causing physical or electrical interference. There are benefits for the electrical contractor too, since the system arrives on site in one box rather than several, and the contractor has a single point of contact in case of questions, errors or complaints. It is possible that this streamlined process could be given credit within the CHPS or Acceptance Testing requirements.

The Technology Transfer Plan alludes to potential of getting the integrated lighting system approved and encouraged through the California Department of the State Architect. The DSA is currently looking into the code implications for lighting in classrooms (both traditional as well as re-locatable), and there could be greater market penetration of the lighting system if the DSA is on board in the marketing strategy.

The product specifications (including, for instance, the integrated wiring system and its connections) need to be non-proprietary in nature in order to make the specifications industry-accepted standards and for possible inclusion in the acceptance testing requirements. The approach, as mentioned in the TTP, of doing more long-term demonstration projects and some pilot installations would help in further identifying the system costs as well as performance issues.

### *Strategic Benefits*

The section above on “Opportunity for Code Improvement” lists several strategic benefits, all of which could be supported in future revisions to energy efficiency standards.

## **5.1 Bi-level Stairwell Fixtures**

### *Opportunity for Code Improvement*

The latest ANSI standard (ANSI 117.1 to be published in the next ANSI 101 life safety code) offers both a barrier to energy conservation goals as well as a new window of opportunity for the bi-level stairwell fixture product.

The new standards increase the minimum light levels in stairwells from one foot-candle to 10 foot-candles with the provision of having occupancy-based controls of the light fixtures that would enable 10 foot-candles during time of occupancy and, otherwise, allow lower light levels. This requirement could potentially increase lighting power consumption in stairwells above existing consumption levels if the lights are not turned off for sufficient amounts of time. However, this new requirement potentially opens a great opportunity for the bi-level fixture nationwide as local fire marshals start adopting and implementing the standards.

Since the energy savings would be much higher with the new standards than the existing standards, the product would enjoy a much improved cost-benefit ratio and the payback periods for the product should be improved considerably.

One drawback of the new fire standards is that they require a minimum 15 minute delay for motion sensors in stairwells, which might reduce the energy savings achieved by the bi-level fixtures. The results from the four initial field trials (not available at the time of writing) should determine whether this 15 minute delay should be seen as a major obstruction to energy savings. If so, it may be possible to propose an amendment to the forthcoming California Uniform Fire Code; notice of proposed changes must be received by August 2004.

In the 2005 revision of the California Title 24 energy standards, there are already bi-level lighting control credits for small private offices, classrooms, hallways in hotel/motel, library stacks, and warehouse aisles. Stairwells were also considered for a bi-level lighting control credit, but this was dropped due to lack of appropriate savings and usage data on staircases. If this project succeeds in generating this data, it is possible to propose the addition of stairwells to spaces eligible for bi-level control credits in the next code change cycle.

### *Strategic Benefits*

This project seems to be self-contained, and to offer no strategic benefits.

## **5.2 HID Electronic Ballast testing**

### *Opportunity for Code Improvement*

Preliminary results indicate large variances in performance between ballasts from different manufacturers, and the technology (for dimming HID ballasts) continues to develop on a monthly basis. Manufacturers' data shows that electronic HID ballasts consistently yield better efficacy and longer lamp life than magnetic HID ballasts, so if the third-party results from the LRP study replicate these figures, requirements for electronic ballasts could be included in the California Title 24 and Title 20 standards during the next round of changes.

The major lamp manufacturers are currently introducing miniature HID lamps and ballasts (20-39W) on to the US market, following their successful introduction in Europe. If the US versions of these ballasts prove to be reliable in operation, and save energy without causing other undesirable side-effects such as conducted interference, future revisions of Title 24 could encourage their adoption by increasing the required efficacy of lamps in retail, entertainment and hospitality spaces.

### *Strategic Benefits*

The technologies of HID lamps and especially HID dimming are advancing constantly, and the terminology is often confusing to specifiers and designers. Manufacturers' commercial need for product differentiation and branding seems to take precedence over the clarity of information provided to their customers, and this may have slowed the overall acceptance of new HID technology by the market. The market has been further confused by the introduction during the past five years of ceramic discharge tubes, which are often associated with electronic ballasts.

The market for HID lamps is changing rapidly. Competition from T8, T5 and now CFL lamps in warehouse applications is squeezing the HID market, but metal halide lamps are taking over from high pressure sodium lamps in streetlighting applications. HIDs remain unique because they are the only source that combines high efficacy with a small luminous area, making them very suited to applications such as floodlighting that require a lot of lumens and tight beam control. Strategically, therefore, better understanding of HID technologies among specifiers and designers remains an important goal, and the dissemination of objective third-party information from this LRP project could have a very positive impact on energy use in HID applications.

## **5.3 Low Glare Outdoor Lighting**

### *Opportunity for Code Improvement*

Glare is currently not defined or referred to in Title 24, and the absence of the term reflects the wider uncertainty of knowledge about exactly what glare is and how it can be

quantified. It is far from clear whether the performance specification for the Low Glare Outdoor fixture will result in a fixture that gives a low glare sensation to passers-by.

Title 24 uses the IES's definition of a "cutoff" luminaire in its requirement for outdoor lighting of nonresidential buildings (Section 130), but this does not equate with low glare; cutoff requirements serve only to limit light trespass and sky glow.

IES is considering new lighting standards for outdoor lighting that would include requirements for low glare luminaires, and is continuing to develop a methodology to assess outdoor lighting glare and sky glow. Luminaires with low sky glow tend to be more efficient because they use reflectors to concentrate light on the ground, thereby achieving the required illuminance levels with fewer lumens and fewer Watts. The IES recommendations for luminaire types for low glare and low light trespass are also being re-considered in light of findings that full-cutoff luminaires are not entirely effective as low glare luminaires; the definition of glare may turn out to be highly context-dependent. There seems to be no immediate prospect that an agreed criterion for glare (or for visibility) will be included in Title 24.

One of the performance specifications of the low-glare fixture is that it achieves a high uniformity of illumination from a low mounting height. If field trials show that a "wall pack" fixture can achieve levels of efficiency higher than are currently required by Title 24 without causing excessive glare, it might be possible to reduce the allowed lighting power densities of  $0.4\text{W}/\text{ft}^2$  in parking garages (Table 146-A) and  $0.04\text{-}0.15\text{W}/\text{ft}^2$  for general site illumination currently prescribed in Title 24.

Note that the California Title 24 requirements specifically exclude roadway lighting and traffic signage, but include other outdoor signage, facade lighting, and sales canopies amongst other spaces.

### *Strategic Benefits*

The 2005 Title 24 standards introduce a whole new set of regulations for outdoor lighting that aim to reduce the installed wattage of outdoor luminaires through the creation of lighting zones. There are four lighting zones, with Zone 1 corresponding to ecologically sensitive areas such as national and state parks, Zone 2 and 3 with semi-urban and urban areas, while Zone 4 is for areas with need for high illumination. In Zones 1, 2 and 3, the 2005 standards propose to lower installed LPDs and cutoff requirements in order to prevent sky glow and light trespass. However, glare is an important omission. The issue of glare and visibility potentially can have a significant impact on future legislation on outdoor lighting.

## **5.4 DALI**

### *Opportunity for Code Improvement*

The project team is working with NEMA on incorporating the additions to the DALI protocol into the NEMA Standards. After its adoption in the NEMA standards and when commitments from various manufacturers are secured, the DALI specifications could be adopted into other state and national standards such as California Title 20 standards and the Acceptance Testing Requirements.

*Strategic Benefits*

The DALI protocol project is by its nature strategic, because it facilitates energy savings across a wide variety of applications, and enables better use of existing energy-saving resources.

## Appendix A: Total Resource Cost Ratio and Peak Demand Reduction

For convenience, this section combines both TRC and peak demand reduction calculations.

### Definition of Terms

**Total Resource Cost (TRC) Ratio:** Total Resource Cost Ratio is the ratio of the monetary benefits of a measure to its monetary costs. The benefit and cost are defined from a societal perspective, i.e. irrespective of who pays for them, and who receives the benefits.

A TRC Ratio  $>1$  means that the measure should save society money rather than costing it money. There are of course some non-monetary costs and many non-monetary benefits that arise from each measure, but these are not quantified in the TRC calculations.

Formal definitions of the terms used in these calculations can be found in the CPUC's Energy Efficiency Policy Manual<sup>iv</sup>.

**Unit Goal:** Number of units (see "Unit Definition" below) expected to be installed under the incentive program, during the whole (multi-year) life of the program.

**Unit Definition:** The unit upon which the total resource calculations are based. For instance, this could be either a single luminaire or a room full of luminaires, depending on which is the most useful and convenient definition. The unit definition includes all associated hardware, e.g. control equipment, lamps.

**Installation, Service, and Repair Labor Costs:** This includes only the costs borne by the utility, not those borne by the customer

**Gross Coincident Peak Demand Reduction:** The number of kW by which each unit is expected to reduce electrical demand during the peak period, compared to the base case. The Energy Efficiency Policy Manual defines the peak period as noon to 7 p.m. Monday through Friday, June, July, August and September. Whenever possible we have used data for the height of the peak period, 4:00-6:00 pm.:00p.m.),

**Gross Annual Energy Savings:** The number of kWh by which each unit is expected to reduce annual energy consumption, compared to the base case

**Gross Incremental Measure Cost:** The difference in installed cost (per unit) between the measure and the base case. This cost must include all additional installation and commissioning costs, and the net present value of any additional maintenance costs.

**Expected Useful Life:** The average equivalent period for which the measure is expected to continue to produce the savings described above.

**Net-to-Gross Ratio:** "Net" savings are those that are due only to the program, i.e. all those customers for whom the incentive payment made the difference between buying

and not buying the system. “Freeridership” describes savings achieved by customers who would have bought the system even in the absence of the incentive program, but are taking advantage of the incentive payment. Net savings plus freeridership equals gross savings, so the net-to-gross ratio describes the proportion of customers that would not have bought the improved system if they hadn't been given an incentive. For example, 0.8 NTG means that 20% of customers would have bought the improved system even if they hadn't been offered an incentive, whereas 80% have “truly” been incentivized.

## Sample TRC Ratios and Peak Demand Reduction Calculations

This section explains in detail how the sample TRC ratios and peak demand reduction values were derived for the LRP products. The purpose of this section is to serve as a template for future reference.

### 3.3 Classroom Photocell and Control System

#### *Unit Goal*

The unit goal for this measure is the same as for the Integrated Classroom Lighting System (see section 4.5 below), except that only those classrooms that are suitable for daylighting (i.e. those with high average daylight factors) would be suitable for this measure. The number of suitable classrooms is not known, but are assumed to be around 50%, making the unit goal for this measure 800 classrooms.

#### *Unit Definition and Baseline*

One classroom, 30' x 32' (=960 sq ft) with three rows of recessed fixtures dimmed by row. Lighting power density 0.9W/sq ft. The classroom has manual override of the dimming settings, and no occupancy sensors.

The baseline is a classroom with manual bi-level switching in which occupancy sensors switch the lights off after a 15-minute time delay.

#### *Installation, Service, and Repair Labor Costs*

These costs are not expected to be borne by the utility.

#### *Gross Annual Energy Savings*

The photocell system would save energy whenever the lights are switched on during daylight hours, regardless of whether the room is occupied or not. Conversely, the energy that would be saved by an occupancy sensor during the day and overnight would be lost.

HMG's bi-level switching study<sup>xv</sup> shows that lights are usually either full-on or off during occupied daylight hours. The flat-topped shape of the daily load profiles in the bi-level study (which suggest that teachers do not switch lights on or off during the day to compensate for daylight) indicate that the likelihood of lights being either on or off remains constant during the day. This means that the estimated percentage lighting

energy use (45%) can simply be multiplied by the average duration for which lights are switched on, to derive a figure for energy savings (see Figure 7).

Modifying factor	Effect	Subtotal	Unit	Source
Energy savings from photocell system				
Lights are switched on while the room is unoccupied for 3.6% of the time	(a) = $0.036 * 24 * 7 * 52$	314	hours per year	endnote <sup>xv</sup>
Lights are switched on while the room is occupied for 12.9% of the time	(b) = (a) + $(0.129 * 24 * 7 * 52)$	1441	hours per year	endnote <sup>xv</sup>
New-build classroom measures 30' by 32' and has a lighting power density of 1.2 W/sq ft	(c) = (b) x 30 x 32 x 1.2	1660	kWh per year potential saving	deliverable 3.3.2b, and lighting calcs
Photocell system saves 55% of load	(d) = (c) x 0.55	913	kWh per year	deliverable 3.3.4b
Energy savings lost by not using an occupancy sensor				
Loss of occupancy sensor savings	(e) = (d) - 258	655	kWh per year	energy consumption calcs for 4.5
Lighting-HVAC interaction	(f) = (e) x 1.18	773	kWh per year	endnote <sup>i</sup>
<b>GROSS ANNUAL ENERGY SAVINGS</b>		<b>773</b>	<b>kWh per year</b>	

**Figure 7 - Calculation of annual energy savings for the classroom photocell**

*Gross Incremental Measure Cost*

Modifying factor	Effect	Subtotal	Source
Cost of the classroom photocell	(a) = \$150	\$150	The Watt Stopper
Cost of replacing the photocell after 8 years	(b) = (a) + \$150	\$300	The Watt Stopper
Avoided cost of occupancy sensor	(c) = (b) - \$75	\$225	RS Means, p.268
Incremental cost of dimming ballasts over electronic ballasts	(d) = (c) + 12 x \$67 - 12 x \$30	\$669	RS Means, p.263
Dimming wall switch	(e) = (d) + \$50	\$719	The Watt Stopper
<b>GROSS INCREMENTAL MEASURE COST</b>		<b>\$719</b>	

**Figure 8 – Calculation of gross incremental measure cost for classroom photocell**

*Expected Useful Life*

16 years; the system relies on both a photocell (standard EUL of 8 years) and fluorescent dimmable fixtures (standard EUL of 16 years). The photocell can be expected to fail

before the fixtures, so the gross IMC includes the cost of replacing the photocell once. The calculations are therefore based on a 16-year expected useful life.

#### *Net-to-Gross Ratio*

0.8; this is the standard NTG value for “all other nonresidential programs” from the Energy Efficiency Policy Manual.

#### *Gross Coincident Peak Demand Reduction*

Figures from HMG’s bi-level switching study<sup>xv</sup> show that classroom lighting loads during peak time average 47%. Load profiles show that almost all of this load is constituted by classrooms in which the lighting is switched fully on.

The Simulation Report (deliverable 3.3.4b) shows that in classrooms that are suitable for daylighting, energy use during the period 8:15am to 3:45pm averages around 45%. This is broadly in line with a variety of research findings in the Complementary Research Review (deliverable 6.3.4). This figure of 45% assumes average sky conditions and 12-month operation, so energy use during peak times can be assumed to be much lower than this; without stretching credulity, energy use could be assumed to be 35% during peak times.

<b>Modifying factor</b>	<b>Effect</b>	<b>Subtotal</b>	<b>Unit</b>	<b>Source</b>
Initial value: average peak lighting load in classrooms	(a)	47%	% load reduction	endnote <sup>xv</sup>
Photocell system reduces peak load by 65% in those classrooms in which the lights are switched on.	(b) = (a)* 0.65	31%	% load reduction	modified from deliverable 3.3.4b
Standard classroom measures 30’ by 32’ and has a lighting power density of 1.2 W/sq ft	(c) = (b) x 30 x 32 x 1.2	357	W per classroom	deliverable 3.3.2b, and Title 24 2005
Loss of peak load reduction due to occupancy sensors	(d) = (c) - 18	339	W per classroom	peak demand reduction calcs for 4.5
Lighting-HVAC interaction	(e) = (d) x 1.18	400	W per classroom	endnote <sup>i</sup>
<b>COINCIDENT PEAK DEMAND REDUCTION</b>		<b>400</b>	<b>W per classroom</b>	

**Figure 9 - Coincident Peak Demand Reduction Calculation for Classroom Photocell**

### ***4.1 Hotel and Institutional Bathroom Lighting Project***

It should be noted that two different versions of the nightlight sensor have been developed: the first version has an LED nightlight and an occupancy sensor built in to a wall switch; the second version has an LED nightlight and an occupancy sensor factory-fitted into a “vanity unit” light fixture. The first version is designed to be retrofitted into guestrooms whereas the second is designed to be installed in guestrooms that are being newly constructed or remodeled. The analysis is conducted for the wall switch nightlight only. The project team is also developing a fixture integrated nightlight that is expected

to have greater savings due to reduction in installed wattage, and is expected to have a higher TRC ratio.

### *Unit Goals – New Construction and Remodeling*

The Energy Information Administration’s Commercial Buildings Energy Consumption Survey (CBECS)<sup>v</sup> table B9 shows that approximately 80 million square feet of lodging was built in the US per year, during the period 1990-2000. We have used this figure as a starting point to calculate the unit goal, as shown in Figure 10.

Modifying factor	Effect	Subtotal (new rooms)	Subtotal (retrofits)	Unit	Source
Initial value	(a)	80,000,000	sq ft per year	CBECS database, table B9 <sup>v</sup>	
Assumption that the rate of construction of lodging over the next few years will be the same as for 1990-2000.	None	80,000,000		sq ft per year	n/a
Assumption that California’s share of this new construction is proportional to its population	$(b) = (a) \times 34/294$	9,252,000		sq ft per year	n/a
Assumption that 75% of this floorspace is guest rooms	$(c) = (b) \times 0.75$	6,939,000		sq ft per year	n/a
Assumption that the average room measures 15'x30'	$(d) = (c) \div 450$	15,420		rooms per year	n/a
Assumption that the number of hotel rooms retrofitted with light fixtures is double the number of new hotel rooms	$(e) = (d) \times 3$	15,420	30,839	rooms per year	n/a
Assumption that program goal is 5% market share	$(f) = (e) \times 0.05$	771	1542	rooms per year	n/a
Incentive program will last for two years	$(g) = (f) \times 2$	1542	3084	rooms	n/a
<b>UNIT GOAL</b> , assuming that half the rooms are in “vacation” hotels, and half are in “business” hotels		771	1542	rooms in “vacation” hotels	
		771	1542	rooms in “business” hotels	

**Figure 10 – Calculation of unit goal for bathroom lighting project**

Data from the 2002 NRNC Market Characterization for Southern California Edison shows 4,342,000 sq ft of hotels built in CA. Using the method described above, this would lead to a unit Goal of 3600 rooms (rather than 4600 as estimated above). Since the data used in Figure 10 above is based on a 10-year average, while the SCE data is based on one year -- which could have been a slow year for hotel construction in California due to the energy crisis, lower economic growth and several other factors -- the unit goal numbers for the project are based upon CBECS.

### *Retrofits*

Data from the 1997 US Economic Census cited on the Technology Transfer Plan (deliverable 4.1.5a) shows that there are 365,800 hotel guestrooms in California. All of these are potentially suitable for the wall switch version of the LED nightlight.

Incidentally, comparing the above estimate of 365,800 guestrooms with our estimate that 46,260 guestrooms are either built from scratch or refurbished each year, puts the average life of a hotel room at 7.9 years. This seems intuitively reasonable and seems to support the unit goal for the light fixture version of the LED nightlight.

### *Unit Definition*

The first version of the LED nightlight comprises a standard wall switch fitted with an LED nightlight and an infra-red occupancy sensor. The second version comprises a standard commercially available fluorescent light fixture, factory-fitted with an LED nightlight and an infra-red occupancy sensor. In this section we concentrate on the wall switch version only.

### *Installation, Service, and Repair Labor Costs*

These costs are not expected to be borne by the utility.

### *Gross Annual Energy Savings*

The project team monitored the use of a number of prototype units at a Doubletree hotel (see deliverable 4.1.2). The average bathroom vanity light at the Doubletree hotel had a load of 180W; we have used this figure as a starting point to calculate annual energy savings, as shown in Figure 11. We have not taken into account energy savings that would accrue from replacing the existing fixtures with lower-wattage fluorescent fixtures, so these results are valid only for the retrofit wall switch unit:

Modifying factor	Effect	Subtotal (business hotel)	Subtotal (vacation hotel)	Unit	Source
Initial value	(a)	0.180	0.180	kW per fixture	deliverable 4.1.2
Fixtures were switched on for an average of 4.42 hours per day without the nightlight, and 2.37 hours per day after the nightlight was installed	(b) = (a) x (4.42 – 2.37)	0.369	0.720	kWh per day	deliverable 4.1.2b
Nightlight consumes 4W and is switched on for 21.63 hours per day (on days room occupied)	(c) = (b) - 21.63 x 0.004	0.282	0.633	kWh per day	deliverable 4.1.2b
The average hotel room is occupied 61% of the days in the year	(d) = (c) x 0.61 x 365	63	141	kWh per year	Selwitz, R, <i>PWC: business should improve during 2004</i> , Hotel & Motel Management, Jan 12, 2004
Nightlight consumes 4W during unoccupied days (39% of the year)	(e) = (d) - 0.39 x 24 x 365 x 0.004	50	127	kWh per year	deliverable 4.1.2b
<b>GROSS ANNUAL ENERGY SAVINGS</b>		<b>50</b>	<b>127</b>	<b>kWh per year</b>	
* <a href="http://articles.findarticles.com/p/articles/mi_m3072/is_1_219/ai_112654945">http://articles.findarticles.com/p/articles/mi_m3072/is_1_219/ai_112654945</a> )					

**Figure 11 – Calculation of gross annual energy savings for bathroom lighting project**

#### *Gross Incremental Measure Cost*

For the first, wall switch version, the estimated cost of the unit (from the Technology Transfer Plan (deliverable 4.1.5a) is \$35. The estimated cost of retrofitting this into a wall switch is \$30 (30 minutes work at \$60 per hour). The gross IMC for the first version is therefore \$65.

For the fixture-mounted version, the nightlight and occupancy sensor are factory-fitted as part of a new luminaire. The Technology Transfer plan (deliverable 4.1.5a) quotes the cost of the motion sensor and LED nightlight at \$35, and the estimated cost of modifying the fixture and fitting the unit at \$30 (30 minutes work at \$60 per hour). The gross IMC is therefore the same as for the first version - \$65.

#### *Expected Useful Life*

8 years; this is the standard EUL for lighting occupancy sensors, from the Energy Efficiency Policy Manual.

### *Net-to-Gross Ratio*

0.8; this is the standard NTG value for “all other nonresidential programs” from the Energy Efficiency Policy Manual.

### *Gross Coincident Peak Demand Reduction*

The Performance Analysis (deliverable 4.1.2b) gives a graph of electrical demand before and after installation of the unit. Averaging values from the peak period (12:00-6:00 p.m.) shows that the unit saves 7.1% of the installed load (roughly 40% of the actual load before installation).

Applying this 7.1% to the average installed load of 180W gives a peak demand reduction of 12.8W per unit.

### **4.3 Energy-Efficient Retrofit/Remodel Alternative to Incandescent Downlights**

In analyzing this project, we have compared the fixture with a 65W R-30 incandescent, rather than with another high-efficacy fixture such as a 26W CFL downlight. The rationale for this is that the reduced cost of the LRP fixture makes it competitive with R-30 fixtures, and so builders might use the LRP fixture in place of an incandescent, for instance in kitchens where 50% of the lighting watts can still be made up of low-efficacy fixtures under the requirements of Title 24 2005. Compared with a standard 26W CFL fixture the LRP fixture offers little to no energy savings, but does offer a reduction in cost.

### *Unit Goal*

Data from the California Department of Finance<sup>vi</sup> shows that, if present trends continue, around 250,000 new homes will be built per year in California over the next few years. This figure includes both multi-family (around 70,000) and single-family (around 180,000) homes.

The Market Assessment Report (deliverable 4.3.1a) shows that new single-family homes have approximately 6 kitchen downlights. This puts the potential market for the product at 1.5 million downlights per year. Given this huge potential market, a unit Goal for an incentive program seems arbitrary, so we have used a figure of 20,000 over a two-year incentive program.

### *Unit Definition*

Despite the fact that the fixture has a single ballast supplying two lamps in two separate reflectors, in order to avoid confusion when figures from this project are compared with figures from other projects, we will define the unit as being one single downlight head.

Each head comprises a low-glare specular reflector in an IC-AT housing and a 26W compact fluorescent lamp. A gasket is used to achieve airtightness between the housing and the ceiling sheetrock, as required by Title 24 2005.

### *Installation, Service, and Repair Labor Costs*

These costs are not expected to be borne by the utility.

#### *Gross Annual Energy Savings*

A study by Jennings et al.<sup>vii</sup> for Tacoma Public Utilities, later cited by Mills et al.<sup>viii</sup> showed that the average residential light fixture was switched on for 1.8 hours per day, although kitchen fixtures were cited as an example of high-use fixtures that are likely to be switched on for longer periods.

HMG's Residential Lighting Baseline<sup>x</sup> found that kitchen fixtures were switched on for an average of 3.4 hours per day. HMG showed that, across all room types fluorescents were likely to be switched on for longer than other lamp types, but the reason for this was not determined (for instance, it could be that users want to extend lamp life, because the fixtures' low energy consumption leads them not to care about energy use so much, or because CFLs are more likely to be installed in high use fixtures). The usage figures were 3.1 hours per day for CFL, 2.2 for incandescent.

For these calculations we have used the HMG figure of 3.4 hours per day, which when multiplied by the 40W difference between the high efficiency fixture and a 65W R-30 incandescent, gives an annual energy saving of 50 kWh/year. Adding an additional 18% for lighting-HVAC interaction gives a figure of 59 kWh/year.

#### *Gross Incremental Measure Cost*

The Technology Transfer plan (deliverable 4.3.2a) gives an expected "distribution house cost" for the luminaire of \$73.65 (\$36.83 per unit, since each head is one unit). Assuming a 40% retail markup, the cost of the fixture is projected at \$51.50. From RS Means<sup>ix</sup>, the cost (excluding installation) of a regular downlight fixture is \$36.60, the difference in cost is therefore around \$15.

There is likely to be a slight reduction in installation time due to the use of one ballast rather than two (estimated at \$5) means that the incremental measure cost is estimated at \$10 per head.

#### *Expected Useful Life*

16 years; this is the standard EUL for a compact fluorescent fixture, from the Energy Efficiency Policy Manual.

#### *Net-to-Gross Ratio*

0.8; this is the standard NTG value for "all other residential programs" from the Energy Efficiency Policy Manual.

#### *Gross Coincident Peak Demand Reduction*

A 1996 report from HMG<sup>x</sup> showed that kitchen and dining room lights, like most residential fixtures, have a 5% likelihood of being switched on during most of the morning and afternoon, but that this percentage increases rapidly after 16:00. Since the

statewide afternoon load peak reaches its maximum between 16:00 and 18:00, we have used the average value over this period (20%).

For the purpose of this calculation we have assumed that the energy-efficient downlight will act as a direct replacement for a 65W R-30 incandescent spotlight. This is corroborated by a finding in the HMG baseline study that, within the 40-100W incandescent range (the lamps typically used in kitchen downlights), the average lamp wattage used was 57W.

The power consumption of the ballast used in the energy-efficient fixture is around 50W<sup>3</sup>, 25W per head, so the saving would be  $0.2 \times (65-25) = 8W$ . This should be increased by a further 18% to allow for lighting-HVAC interaction. This gives an estimated peak demand reduction of 9.4W.

#### ***4.5 Integrated Classroom Lighting System***

##### *Unit Goal*

There are several different sources of information that allow complementary estimates of the unit goal for the ICLS to be made. These estimates (A-C) are shown below in Figure 12, Figure 13, and Figure 14. They lead to very similar estimates, of around 1600 classrooms as the unit goal for project 4.5.

Firstly, statistics from the California Office of Public School Construction<sup>xi</sup> show that there are 1,031,000 pupils in the state for whom new schools are required during the next five years. There are also 1,104,000 pupils for whom classroom modernizations are required. These estimates are based on the state's classroom loading standard (25 pupils per classroom for K-6 and 27 per classroom for 7-12). This allows an estimate of new construction and modernization to be, as shown in Figure 12.

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<sup>3</sup> Source: discussion with project team. The ballast is under-running the lamps.

Modifying factor	Effect	Subtotal		Unit
		K-6	7-12	
New construction over the next five years				
Number of eligible pupils	(a)	429725	601216	pupils
Target number of pupils per classroom	(b)	25	27	pupils per classroom
Number of classrooms required	(c=a/b)	17189	22267	classrooms
Modernizations over the next five years:				
Number of eligible pupils	(d)	499289	604312	pupils
Target number of pupils per classroom	(e)	25	27	pupils per classroom
Number of classrooms required	(f=d/e)	19972	22382	classrooms
Total number of new classrooms	(g=c+f)	37161	44649	classrooms
Combined total of K-6 and 7-12 classrooms	(h)	81810		new classrooms required in the next five years
Assumption that the incentive program will last for two years	(i) = (h) x 2/5	32724		new classrooms required during the program
Assumption that program goal is 5% market share	(j) = (i) x 0.05	1636		units
<b>UNIT GOAL</b>		<b>1636</b>		<b>units</b>

**Figure 12 – Calculation A of the unit goal for the classroom lighting system**

The unit goal from calculation A is corroborated by Southern California Edison's Nonresidential New Construction Database<sup>xii</sup>, which gives a figure of 15,143,000 sq ft of new school construction in California for 2002. This leads to a second estimate (calculation B) for the unit goal, as shown in Figure 13.

<b>Modifying factor</b>	<b>Effect</b>	<b>Subtotal</b>	<b>Unit</b>	<b>Source</b>
Initial value	(a)	15,143,000	sq ft of new school buildings per year	endnote <sup>xii</sup>
Assumption that classrooms make up 50% of new school building floorspace	(b) = (a) x 0.5	7,572,000	sq ft of new classrooms per year	n/a
California classrooms typically measure 32'x30'	(c) = (b) ÷ 960	7,887	new classrooms per year	deliverable 3.3.2b
Assumption that the number of classrooms remodeled per year is the same as the number of new classrooms	(d) = (c) x 2	15,774	units per year	n/a
Assumption that program goal is 5% market share	(e) = (d) x 0.05	787	units per year	n/a
Assumption that the incentive program will last for two years	(f) = (e) x 2	1577	units per year	n/a
<b>UNIT GOAL</b>		<b>1577</b>	<b>units</b>	

**Figure 13 – Calculation B of the unit goal for the classroom lighting system**

The unit goal from calculation B is further corroborated by Commercial Buildings Energy Consumption Survey (CBECS) data<sup>xiii</sup> that shows that during the period 1990-1999, 1,239M square feet of new educational floorspace was constructed nationally. This figure leads to a third estimate (calculation C) for the unit goal, as shown in Figure 14.

<b>Modifying factor</b>	<b>Effect</b>	<b>Subtotal</b>	<b>Unit</b>	<b>Source</b>
Initial value	(a)	1,239	M sq ft of new educational buildings nationally, 1990-1999	endnote <sup>xiii</sup>
Assumption that California's share of educational construction is proportional on a per-capita basis	$(b) = (a) \times 34 \div 290$	145	M sq ft of educational buildings	n/a
Assumption that educational building construction is continuing at the same rate, and assuming a two-year incentive program	$(c) = (b) \div 10 \times 2$	29	M sq ft of educational buildings	n/a
Assumption that classrooms make up 50% of new school building floorspace	$(d) = (c) \times 0.5$	15	M sq ft of new classrooms	n/a
California classrooms typically measure 32'x30'	$(e) = (d) \div 960$	15131	new classrooms	deliverable 3.3.2b
Assumption that the number of classrooms remodeled per year is the same as the number of new classrooms	$(f) = (e) \times 2$	30263	units	n/a
Assumption that program goal is 5% market share	$(g) = (f) \times 0.05$	1513	units	n/a
<b>UNIT GOAL</b>		<b>1513</b>	<b>units</b>	

**Figure 14 – Calculation C of the unit goal for the classroom lighting system**

#### *Unit Definition*

One classroom, 30' x 32' (=960 sq ft) with two rows of suspended fixtures, one occupant sensor, teacher control center including an "A/V mode" switch, fixtures switched by row. Lighting power density 0.9W/sq ft.

#### *Installation, Service, and Repair Labor Costs*

These costs are not expected to be borne by the utility.

#### *Gross Coincident Peak Demand Reduction*

Any reduction in peak demand needs to be judged relative to an established baseline level of energy consumption when only manual switching is installed in the classroom. During occupied periods, if the Integrated Classroom Lighting System uses manual on-switching, the energy consumption can be assumed to be the same as for the manual switching baseline. During unoccupied periods, the ICLS is designed to achieve lighting energy savings by switching off lights that might have been left switched on by occupants (although whether energy savings are typically achieved in practice is far from clear<sup>xiv</sup>).

The calculations shown in Figure 15 are based on a study on bi-level manual switching patterns in classrooms<sup>xv</sup>. The study provides data for unoccupied periods, but does not differentiate peak from non-peak times, so the data includes all times of day including night time. During unoccupied periods on weekdays, classrooms average 9% lighting energy consumption. This 9% consumption is the basis for calculation of the peak demand reduction achieved by the ICLS, as described in Figure 15:

Modifying factor	Effect	Subtotal	Unit	Source
Initial value	(a)	9%	peak lighting load reduction	endnote <sup>xv</sup>
Standard classroom measures 30' by 32' and the ICLS has a lighting power density of 0.9 W/sq ft	(b) = (a) x 30 x 32 x 0.9	78	W per unoccupied classroom	deliverable 3.3.2b, communications with project team
Assumption that classrooms are unoccupied for 75% of the time during peak periods	(c) = (b) x 0.25	20	W per classroom	n/a. Note that peak period extends beyond typical school hours
Assumption that the occupant sensor time delay is set to 15 minutes, and that unoccupied daytime periods last for an average of one hour	(d) = (c) x 0.75	15	W per classroom	n/a
Lighting-HVAC interaction	(e) = (d) x 1.18	18		endnote <sup>i</sup>
<b>COINCIDENT PEAK DEMAND REDUCTION</b>		<b>18</b>	<b>W per classroom</b>	

**Figure 15 – Calculation of coincident peak demand reduction for classroom lighting system**

### *Gross Annual Energy Savings*

We have used two sources of information to estimate gross annual energy savings for the Integrated Classroom Lighting System; the first is the case study of Heritage Oaks School conducted by the ICLS project team as part of the LRP, and the second is HMG's study on bi-level switching in classrooms<sup>xv</sup>.

In the case study, the school had a particular type of recessed lighting system before the ICLS was retrofitted – this lighting system provides the baseline for the estimates derived from the case study (scenarios A-D). To make these estimates more representative of typical classrooms we have adjusted the savings from the case study in line with typical classroom conditions as found in the bi-level study, and as dictated by Title 24.

For the estimate based on the bi-level study (scenario E), the baseline was taken to be the technology that offers the cheapest route to compliance with Title 24 2005. In practice, we expect that the cheapest route will be the use of recessed lensed fixtures controlled by a time clock with a manual override switch.

### *Scenarios A-D*

Data from the Heritage Oaks School case study are reproduced below in Figure 16. The energy saving figures from the case study were much higher than we had expected, and this is explained in part by the very high lighting energy consumption of Heritage Oaks School before the retrofit. The annual consumption of 5983 kWh per classroom means that the lights were switched on for 37.9% of the time during the year (including nights, weekends, holidays, etc). In the bi-level switching study, the lights in the average classroom were switched on for only 17.8% of the time. The energy savings reported in the Heritage Oaks case study have been scaled down by the ratio of these percentages, to bring them in line with more typical usage. This scaling down is appropriate as long as the difference in hours of lighting use is due to longer hours of occupancy of the building (i.e., if Heritage Oaks School is used after-hours), but would not be appropriate if the long hours of lighting use at Heritage Oaks are due to staff leaving the lights on overnight.

Even after this scaling down, the energy savings from the case study are still more than double those predicted by the bi-level study (scenario E). This may be due to a number of factors such as the particular daylighting strategies of the case study classrooms, the training of the teachers, or the hours of use.

### *Scenario E*

The bi-level study cited above showed that classrooms were unoccupied with the lights on for 4.1% of the time (over a 24 hour, 7 day per week baseline). This 4.1% breaks down as 3.6% of the time at full output, 0.2% at high-only, and 0.3% at low-only.

These percentages can be used to calculate a good approximation to the amount of energy saved, because the high-only circuits averaged 0.797 W/sq ft while the low-only circuits averaged 0.703 W/sq ft. Full output required both the low and high circuits to be switched on. Hence the total estimated energy saving can be calculated, as shown in Figure 17.

The values for TRC given at the beginning of this report represent the widest range of values given in Figure 17 and Figure 16.

<b>Modifying factor</b>	<b>Effect</b>	<b>Subtotal</b>				<b>Unit</b>
Initial value( pre-retrofit lighting energy consumption)	(a)	5983				kWh per year per classroom
		Scenario A: 2 rows, switching	Scenario B: 2 rows, dimming*	Scenario C: 3 rows, switching	Scenario D: 3 rows, dimming*	
Control, modified from 1.8W/sq ft to 1.2W/sq ft typical new construction	(b = a * 1.2 / 1.8)	3989	3989	3989	3989	kWh per year per classroom
Recorded energy consumption of ICLS	(c)	2778	2569	2464	2458	kWh per year per classroom
Difference due to ICLS	(d = b - c)	1211	1420	1525	1531	kWh per year per classroom
Scaling factor to bring hours of use in line with typical figures from the bi-level study	(e = d * 17.9 / 37.9)	572	670	720	723	kWh per year per classroom
<b>GROSS ANNUAL ENERGY SAVING</b>		<b>572</b>	<b>670</b>	<b>720</b>	<b>723</b>	<b>kWh per year per classroom</b>
*In the case study, some of the classrooms had an additional level of functionality that allowed the teacher to dim the downlight portion of the light fixture using a wall-mounted dimming control. This was known as the "AV mode"						

Figure 16 – Scenarios A-D: Calculation of annual energy savings for classroom lighting system (based on Heritage Oaks School case study, project deliverable)

Modifying factor	Effect	Subtotal	Unit	Source
3.6% of the time spent at full output during non-occupied periods	$(a) = 0.036 \times (0.797 + 0.703)$	0.0540	W/ sq ft	endnote <sup>xv</sup>
0.2% of the time spend at high-only during non-occupied periods	$(b) = (a) + 0.002 \times 0.797$	0.0556	W/ sq ft	endnote <sup>xv</sup>
0.3% of the time spend at low-only during non-occupied periods	$(c) = (b) + 0.003 \times 0.703$	0.0577	W/ sq ft	endnote <sup>xv</sup>
Classroom measures 30' by 32'	$(d) = (c) \times 30 \times 32$	55.4	W per classroom	deliverable 3.3.2b
Savings sustained for an entire year	$(e) = (d) \times 24 \times 365 / 1000$	485	kWh per year per classroom	n/a
Scaling these savings down for a new-build 0.9W/sq ft classroom, rather than the average 1.5W/sq ft classrooms in the bi-level study	$(f) = (e) \times 0.9 / 1.5$	291	kWh per year per classroom	lighting calcs
Assumption that the occupant sensor time delay is set to 15 minutes, and that unoccupied daytime periods last for an average of one hour	$(g) = (f) \times 0.75$	218	kWh per year per classroom	n/a
Lighting-HVAC interaction	$(h) = (g) \times 1.18$	258	kWh per year per classroom	endnote <sup>i</sup>
<b>GROSS ANNUAL ENERGY SAVINGS</b>		<b>258</b>	<b>kWh per year per classroom</b>	

**Figure 17 – Scenario E: Calculation of annual energy savings for classroom lighting system (switching only)**

#### *Gross Incremental Measure Cost*

As noted in “Unit Goal” above, we have assumed that the base case for comparison is the cheapest system that allows compliance with Title 24 2005. This would be a system of recessed lensed fixtures controlled by a time clock system with manual override as described in Title 24 section 131. To achieve the Title 24 requirement of 1.2 W/sq ft, 12 fixtures would typically be used. The base case does not include occupancy sensors, since then there would be (on paper) no difference in energy consumption between the base case and the ICLS. Gross IMC has been calculated as shown in Figure 18: Note that the IMC for Scenario E is the same as for Scenario A.

Modifying factor	Effect	Subtotal				Source
		Scenario A/E: 2 rows, switching	Scenario B: 2 rows, dimming*	Scenario C: 3 rows, switching	Scenario D: 3 rows, dimming*	
Installed cost of the ICLS	(a)	\$2600	\$3100	\$3700	\$4200	Finelite
Installed cost of one replacement occupancy sensor (see "Expected Useful Life" below)	(b) = (a) + \$125	\$2725	\$3225	\$3825	\$4325	RS Means, p.268, modified to require 0.5 hours' labor
12 recessed lensed fixtures (2' x 4', 3 lamp, consumes around 1.2Wsq ft, typical new classroom)	(c) = (b) - 12 x \$158	\$829	\$1204	\$1929	\$2429	RS Means, p.260
Clock dial time switch with enclosure	(d) = (c) - \$90	\$739	\$1114	\$1839	\$2339	RS Means, p.183
Interval timer wall switch to override clock	(e) = (d) - \$58	\$781	\$1056	\$1781	\$2281	RS Means, p.180
Regular bi-pole wall switch	(f) = (e) - \$62	\$619	\$994	\$1719	\$2219	RS Means, p.181
<b>GROSS INCREMENTAL MEASURE COST</b>		<b>\$619</b>	<b>\$994</b>	<b>\$1719</b>	<b>\$2219</b>	

**Figure 18 – Calculation of gross incremental measure cost for classroom lighting system**

#### *Expected Useful Life*

16 years; the system relies on both an occupancy sensor (standard EUL of 8 years) and fluorescent fixtures (standard EUL of 8 years). The occupancy sensor can be expected to fail before the fixtures, so the gross IMC includes the cost of replacing the occupancy sensor once. The calculations are therefore based on a 16-year expected useful life.

#### *Net-to-Gross Ratio*

0.8; this is the standard NTG value for "all other nonresidential programs" from the Energy Efficiency Policy Manual.

### **5.1 Bi-Level Stairwell Fixture Performance**

Francis Rubinstein, Lawrence Berkeley National Laboratory

### *Unit Goal*

Data on the number of stairwell, number of landings and their square footage is not readily available, but the Technology Transfer Plan (deliverable 5.1.3) contains an extensive analysis of available data that leads to an estimate of 30,000 fixtures per year in California. We have assumed 5% market penetration during the incentive program, and that the incentive program would last for two years; these assumptions lead to a goal of 3000 fixtures during the life of the program.

Since the initial data from LBNL's monitoring of high-rise buildings on the Berkeley Campus shows that the greatest savings are achieved on landings above the second story, we recommend that an incentive program should concentrate on high-rise rather than low-rise buildings.

### *Unit Definition*

One landing lit by a single 2x32W T8 bi-level fixture with integral ultrasonic occupancy sensor. Fixture consumes 62W at full output, 7W at minimum output (3% light output).

### *Installation, Service, and Repair Labor Costs*

These costs are not expected to be borne by the utility.

### *Gross Annual Energy Savings*

As part of this project, LBNL monitored the staircases of four multi-storey buildings on the Berkeley campus. They found that, on average, the stairwell light fixtures would be at full output for 269 minutes per day, and at low output for 1171 minutes per day. The time spent at low output represents a saving over the base case in which the fixture would be constantly at full output. The expected annual energy saving is shown in Figure 19.

<b>Modifying factor</b>	<b>Effect</b>	<b>Subtotal</b>	<b>Unit</b>	<b>Source</b>
Initial value	(a)	1171	minutes per day in low output state	initial results from LBNL, personal communication with Francis Rubinstein
60 minutes per hour, 365 days per year	(b) = (a) / 60 x 365	7124	hours per year in low output state	n/a
Difference in electrical load between high output and low output states	(c) = (b) x (62-7)	392	kWh per year	n/a.
<b>GROSS ANNUAL ENERGY SAVINGS</b>		<b>392</b>	<b>kWh per year</b>	

**Figure 19 - Calculation of annual energy savings for bi-level stairwell fixture**

This represents an energy saving of around 72%, which is very similar to the 60% savings reported by the Lighting Research Center in a study of a multi-storey commercial building in Manhattan.

### *Gross Incremental Measure Cost*

Gross IMC has been calculated as shown in Figure 20. It should be noted that dimming fluorescent lamps to low levels can reduce the life of the lamp. This effect varies considerably from one lamp to another because fluorescent lamps employ different types of circuit to regulate current at low levels. The effect on lamp life in this case is not known.

<b>Modifying factor</b>	<b>Effect</b>	<b>Subtotal</b>	<b>Source</b>
Retail cost of the stairwell fixture	(a)	\$187	Technology Transfer Plan
Installed cost of one replacement occupancy sensor (see "Expected Useful Life" below)	(b) = (a) + \$125	\$312	RS Means, p.268, modified to require 0.5 hours' labor
Retail price of a conventional staircase lighting fixture (surface mounted 4' x 2', 2x32W T8)	(c) = (b) - \$78	\$234	RS Means, p.260
Difference in fixture installation time	(d) = (c) - \$0	\$234	
Assume that the time required to commission each occupancy sensor is 30 minutes at \$60/hr, = \$30	(e) = (d) + \$30	\$264	
<b>GROSS INCREMENTAL MEASURE COST</b>		<b>\$264</b>	

**Figure 20 – Calculation of gross incremental measure cost for bi-level stairwell fixture**

The ultrasonic presence detectors will have to be carefully commissioned to ensure that each sensor is triggered by movement on adjacent landings. It is not known how long this will take, and how often re-commissioning may be required. The estimate of 30 minutes per landing is not based on research data or RS Means time estimates.

#### *Expected Useful Life*

16 years; the system relies on both an occupancy sensor (standard EUL of 8 years) and fluorescent fixtures (standard EUL of 16 years). The occupancy sensor can be expected to fail before the fixtures, so the gross IMC includes the cost of replacing the occupancy sensor once. The calculations are therefore based on a 16-year expected useful life.

#### *Net-to-Gross Ratio*

0.8; this is the standard NTG value for "all other nonresidential programs" from the Energy Efficiency Policy Manual.

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