CALIFORNIA ENERGY COMMISSION

PIER Lighting Research Program

Project 6.3 Codes and Standards Connections

FINAL REPORT

CONSULTANT REPORT

OCTOBER 2004

500-01-041-A-28

Arnold Schwarzenegger, *Governor*

CALIFORNIA ENERGY COMMISSION

Prepared By:
Heschong Mahone Group, Inc.
Abhijeet Pande, Lead Author
Douglas Mahone, Project Director
Fair Oaks, CA

Managed By:
Architectural Energy Corporation
Judie Porter
Program Director
Boulder, CO
CEC Contract # 500-01-041

Prepared For:
Don Aumann
Contract Manager

Nancy Jenkins
PIER Buildings Program Manager

ACKNOWLEDGEMENTS

The products and outcomes presented in this report are a result of funding provided by the California Energy Commission's Public Interest Energy Research (PIER) program on behalf of the citizens of California. Heschong Mahone Group, Inc. would like to acknowledge the support and contributions of the individuals below:

Project Director: Douglas Mahone, Heschong Mahone Group, Inc.

Project Manager: Abhijeet Pande, Heschong Mahone Group, Inc.

Technical Assistance: Lisa Heschong, Jonathan McHugh, Owen Howlett and Mudit Saxena, Heschong Mahone Group, Inc.

Review and Advisory Committee: Robert Knight and Bret Logue, BKi; William Pennington, Maziar Shirakh and Gary Flamm, California Energy Commission; Jonathan Livingston and Jeannine Komonosky, PG&E; Gregg Ander, SCE; Connie Buchan and Dave Bisbee, SMUD.

Element 6 Lead: Robert Knight, BKi

Element 6 Technical Advisory Group: Amy Cortese, Northwest Energy Efficiency Alliance; Kit Tuveson, Tuveson & Associates; James Bryan, Arden Realty; Peter Ngai, Peerless; David Malman, Architectural Lighting Design; Ron Lewis, DOE; Dave Komonosky, 16500; Peter Lai, CPUC; Terry McGowan, ALA; Adriana Valencia (CPUC alternate)

Program Advisory Committee: Ron Lewis, Department of Energy; Jerry Mills, Easy Lite; Gregg Ander, SCE; Bill Daiber, WFD Associates; James Bryan, Arden Realty; Neall Digert, Solatube; Jim Benya, Benya Lighting; Dennis Tiede, Sempra Utilities; Noah Horowitz, NRDC; Amy Cortese, Northwest Energy Efficiency Alliance; Pekka Hakkarainen, Lutron; Peter Turnbull, PG&E; Michael Waxer, Carmel Development Co; Kit Tuveson, Tuveson & Associates; David Kaneda, Integrated Design Associates, Inc; Connie Buchan, SMUD.

Program and Contract Management: Don Aumann and Nancy Jenkins, California Energy Commission. Karl Johnson, CIEE. Judie Porter, Architectural Energy Corporation

PREFACE

The *Codes and Standards Connections Final Report* is a part of the *Lighting Research Program (LRP)*, a Public Interest Energy Research (PIER) program. It was funded by California ratepayers through California's System Benefit Charges administered by the California Energy Commission (Commission) under PIER contract No. 500-01-041, and managed by the Architectural Energy Corporation. The PIER program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Commission), annually awards up to $62 million to conduct the most promising public interest energy research by partnering with Research, Development, and Demonstration (RD&D) organizations, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following six RD&D program areas:

- Buildings End-Use Energy Efficiency
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy
- Environmentally-Preferred Advanced Generation
- Energy-Related Environmental Research
- Strategic Energy Research.

The PIER LRP consisted of 6 elements; elements 2 through 5 each had 3-5 projects that developed an energy efficient lighting system, fixture, protocol, or controls product. The Codes and Standards Connections Final Report is the result of a two year effort of project 6.3 under Element 6 – Market Connections. Project 6.3 of the LRP identified existing codes and standards for lighting energy efficiency around the country with a focus on California state codes, linkages of the LRP products to existing codes and standards, opportunities to improve codes and standards through future PIER research and opportunities to further understanding of lighting fundamentals through PIER research.

For more information about the PIER program, or to obtain the Final Report and other publications produced by this project, please visit www.energy.ca.gov/pier or contact the Commission's Publications Unit at 916-654-5200. All research products are also available through the PIER LRP website at www.archenergy.com/lrp/products/codes.htm.

ABSTRACT

The *Codes and Standards Connections Final Report* is the result of a two year effort that identified existing codes and standards for lighting energy efficiency around the country with a focus on California state codes, linkages of the Public Interest Energy Research (PIER) programs' Lighting Research Program (LRP) products to existing codes and standards, opportunities to improve codes and standards through future PIER research and opportunities to further understanding of lighting fundamentals through PIER research.

The report identifies successes of the PIER LRP in the development of devices for the purpose of short-term energy efficiency improvements, but also identifies the minimal codes and standards connections of the LRP products due to the nature of the technologies used, features included in the products, and the developmental stage of the LRP products. It provides recommendations for future PIER lighting energy efficiency programs to include greater coordination of codes and standards development needs, utility emerging technologies programs and fundamental lighting research.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

The *Codes and Standards Connections Final Report* is a part of the *Lighting Research Program (LRP)*, a Public Interest Energy Research (PIER) program. The PIER LRP consisted of 6 elements; elements 2 through 5 each had 3-5 projects that developed an energy efficient lighting system, fixture, protocol, or controls product.

The *Codes and Standards Connections Final Report* is the result of a two year effort of project 6.3 under Element 6 – Market Connections. Project 6.3 of the LRP identified existing codes and standards for lighting energy efficiency around the country with a focus on California state codes, linkages of the LRP products to existing codes and standards, opportunities to improve codes and standards through future PIER research and opportunities to further understanding of lighting fundamentals through PIER research.

This report summarizes work performed for five separate tasks under this project. The Introduction to this report gives background information about the goals of this project, brief descriptions of the five tasks, and an overview of the codes and standards process.

Following the Introduction, the Project Approach section explains the process used to identify and prioritize the codes and standards connections for the LRP projects, and to identify future lighting research recommendations for PIER.

The Project Outcomes section summarizes the key findings from the five tasks that provide key inputs to the LRP product development process and future lighting research recommendations.

The final section, Conclusions and Recommendations, ties together the outcomes from each of the task reports. It provides recommendations for improving PIER research program connections to codes and standards, and also recommends future directions in lighting research for PIER.

The appendices are an important part of this report, as they include detailed task reports which form the basis for the Project Outcomes and Conclusions and Recommendations sections.

INTRODUCTION

The goal of the California Energy Commission's PIER Lighting Research Program (LRP) is to create new lighting technology and products that can: save energy, reduce peak demand, and reduce pollution for the citizens of California.

The Lighting Research Program (LRP) is a two-year $5.2 million R&D program focused on developing and introducing new energy efficient lighting technologies into the marketplace. This unique program is funded by the California Energy Commission and is managed by Architectural Energy Corporation. The LRP includes fifteen research projects and spans both the residential and commercial sectors, as well as outdoor lighting associated with buildings. The current report is part of the efforts to identify Codes and Standards connections for the LRP products, as well as identify future research opportunities for PIER in the area of residential and nonresidential lighting.

Project Goals

The primary goal of this project was to determine how the PIER Lighting Research Program can best translate its successes into workable code and standards proposals. The emphasis is to identify efforts that are likely to have the largest energy savings and/or demand reduction potential. A secondary goal was to identify additional lighting research needs that could be addressed by future PIER work.

This project meets the PIER Goal of Improving the Reliability/Quality of California's electricity by improving energy efficiency standards for lighting systems, which will reduce demand on the system. The objectives of the project are:

- Evaluate all Program lighting research efforts, and map the path from each research outcome into the codes and standards arena.
- Identify the most code-ready research outcomes and recommend steps to adoption, and identify those that may require additional R&D before they can enter the code process.
- Identify lighting codes and standards problems which require additional R&D, such as outdated lighting industry metrics which are referenced by codes.

Overview of the Tasks

This final report provides an overview of five companion reports that were prepared under the following project tasks:

Existing Lighting Codes and Standards Review

The goal of this task was to review the various lighting efficiency standards enacted across the nation, and to compare them to California's lighting standards. This work encompassed residential, nonresidential, and outdoor lighting standards. This review set the stage for understanding and improving technical and regulatory mechanisms which are used for encouraging energy efficiency in lighting. A companion task report for this task (Deliverable

6.3.1b) is available on the PIER LRP website at www.archenergy.com/lrp/products/codes.htm.

PIER LRP Project Review

The goal of this task was to review all of the projects in the Lighting Research Program (LRP) for their potential as code improvements under California's building and appliance efficiency standards. The companion task report (Deliverable 6.3.2b) is available on the PIER LRP website at www.archenergy.com/lrp/products/codes.htm lists all of the potential code change linkages including opportunities for code improvement, as well as features of the LRP products that do not meet the existing or pending code requirements.

Complementary Lighting Research Needs

The goal of this task was to identify research activities which can complement the R&D work done under the LRP, and which can help the R&D results to be more readily adopted into California's efficiency standards. A companion report for this task (Deliverable 6.3.4b) is available on the PIER LRP website at www.archenergy.com/lrp/products/codes.htm identifies linkages with outside activities which could make the LRP products work more effective in the standards arena.

Prioritized Lighting R&D/Standards Connections

The goal of this task was to identify the most promising LRP project results that could be adopted into the efficiency standards. A companion report for this task (Deliverable 6.3.5b) referenced in Appendix A identifies the highest priority projects and explains their connections to the standards.

Lighting Standards and Fundamental Lighting Research Needs Assessment

The goal of this task was to identify problem areas in the California lighting efficiency standards that require additional R&D. The goal was also to identify future lighting R&D that should be done in the public interest to improve appropriate California codes and standards. A companion report for this task (Deliverable 6.3.3b-6.3.6b) referenced in Appendix B assesses the needs of lighting efficiency standards which can be met with R&D which may not otherwise be recognized or anticipated by the R&D community. It also points to future R&D which could make the PIER Program work more effective in contributing to enhanced efficiency standards.

Codes and Standards Process Overview

In order to describe the Codes and Standards connections of the LRP products, as well as identify areas of research where the PIER (Public Interest Energy Research) program could help improve the California energy codes and assist the state in its goals of reducing per capital energy consumption and electrical demand it is first essential to understand the requirements of the codes and standards process and the PIER mandate.

PIER Goals to Impact Markets

The Public Interest Energy Research (PIER) program has a stated goal of decreasing "building energy use through research that will develop or improve energy efficient technologies, strategies, tools, and building performance evaluation methods." Though the primary thrust of this goal is to support research that improves the energy efficiency of buildings, implicit in this statement is that the research will actually make it into the market where it will decrease building energy use. One strategy to insure widespread market penetration is to have code adoption as an ultimate goal for a PIER project. If a product or finding resulting from PIER were adopted into the state energy codes, then the market effect will be fairly certain, since the codes would then require that type of technology, process, or some strategy of equal efficiency to be implemented in all new buildings. Thus, identifying code adoption as an ultimate goal for PIER project insures that it will have a large and permanent market impact. This report presents code adoption driven research activities that have been identified through consultations with the California Energy Commission Staff, California Investor Owned Utility staff and code consultants in the state of California.

Energy Codes Based on Established Technologies

It is important to recognize that the code adoption goal involves a different strategy than research and development of new innovative energy efficiency technologies. This is because code adoption happens at the tail end of a very long market development process, whereas innovative technologies enter the market at the front end. Figure 1 illustrates this concept, where the market for energy efficiency can be segmented in terms of a willingness to embrace new technology, from "Innovators" to "Laggards."

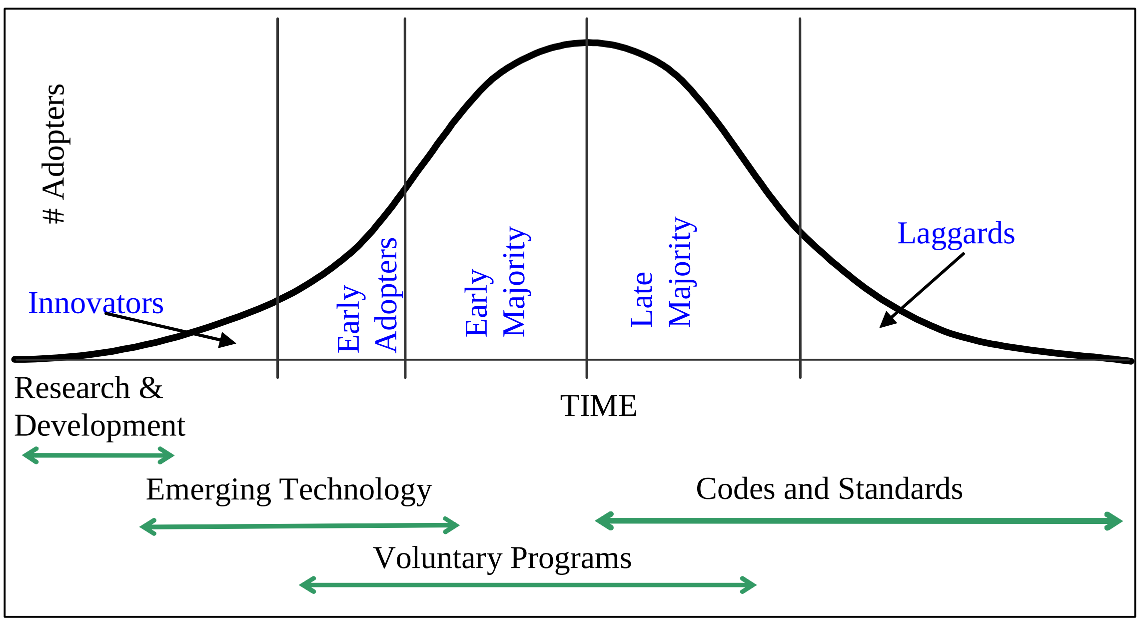

Figure 1 – Market segments and diffusion of energy efficiency innovations[1]

It is the innovators, at front end of the market, who have been the focus of PIER research directed at developing new energy efficient products. At the end such a research project, there may be the nucleus or idea for a new product, but also an expectation that investors and/or industry will take on the responsibility of the next steps to commercialize the product. However, this is often a very difficult and uncertain task. Many new products are introduced, but few survive the initial demands of the marketplace. Getting a new research idea to

[1] Illustration based upon 'Diffusion of Innovations' by Everett M. Rogers.

market—past regulatory compliance, manufacturing constraints, and consumer acceptance —is sometimes called the "valley of death" because there is so little public funding to help this process and it is hard to sustain a company on the small market share afforded to new products.

Once a product is commercially available, there tends to be greater level of support for each step of introduction into the market. The first small step is typically with emerging technology (ET) programs run by the California investor owned utilities. These ET programs identify and support technologies or practices that are promising but have yet to make a significant dent into the market. Often times these programs target early adopters who will provide a case study site where the technology can be tested under field conditions. These case studies help work out the last production and application problems; provide objective data for marketing materials and a small initial market for the product while production ramps up.

Once the initial problems have been worked out and feasibility of a new energy efficiency product has been demonstrated, the market is larger. However, there a number of factors that determine how well the product is received in the market. These include among other things the cost, aesthetics, competing products, sales avenues and market demand for such a product based on existing market needs. For those products that use promising energy efficiency technologies, public funds can be used to support expansion of the market. At this point large incentive-based programs are often targeted towards the market as a whole to purchase energy efficiency resources, increasing demand for the product and helping to increase production. If the product is seen as cost effective by the market, it may become standard practice without further support. If there are split incentives or other structural market barriers, it may require continued program support or a targeted market transformation program to help it become standard practice.

Only once the technology has moved through all these stages, and has been shown to save energy reliably and cost-effectively and does not cause any significant disruptions to the other uses of buildings (visibility, acoustics, indoor air quality, aesthetics etc.), then it may become a candidate for inclusion into the energy codes. In general the purpose of the energy codes is simply to eliminate the worst building design practices of the "Laggards" in favor of the standard practices of the majority, rather than to encourage the best practices of the "Innovators".

For a measure to be incorporated into the building efficiency standards it must pass a number of tests. It should be noted that mandatory measures have the most stringent eligibility tests, while compliance options and allowances may have a less stringent threshold for inclusion in codes. In general, not only must the energy savings be well characterized and substantial, but each measure must be shown to be:

- cost-effective based on current installed costs
- commercially available from more than one manufacturer
- feasible and compatible with current building practice
- have no net negative environmental or health impacts

Thus, many of the code-readiness questions related to market acceptance, pricing and feasibility render the newest, most innovative technologies unlikely candidates for inclusion into the building energy efficiency standards. In general, technologies that are considered for inclusion into energy codes already have a significant market position and a track record of reliable energy savings and known interactions with other building components.

Energy Codes Need Applied Research

The purpose of the energy codes is to save energy not create problems. Thus the standards have to consider whether there are consumer or user acceptance problems, and reliability or other concerns with requirements for a given technology. Since long term savings is desired there has to be some evaluation of the persistence of the savings.

Energy codes are predicated on the assumption that all of the requirements in the standards are "good practice;" they are cost-effective, do not violate the safety or structural requirements and are compatible with typical uses of buildings. In addition, when new technologies or design practices are adopted into the standards, it is expected that the life cycle savings of the new requirement *as compared to minimally compliant buildings as they are currently operated* is less than the incremental cost of the measure.

However, in general we do not know how people use their lighting. We do not know how long lights are operating for every occupancy type, we do not know with any great precision what lighting technologies are being installed in new buildings and we do not know how well designers are complying with the existing standards. Thus it is hard to estimate what the base case is for installed lighting wattage and even harder to estimate base case energy consumption. If we have a hard time estimating base case energy consumption it makes it almost impossible to estimate savings.

Some of these questions cannot be answered in the short time period immediately preceding the code adoption hearings. Some of these research questions require medium term data collection periods. This type of applied research fits well with the PIER program's skill set of independent and technically competent third part y research. Outside of the codes and standards sections of the utility efficiency programs the only other source of funding for this research is by manufacturers of affected technologies – not a recipe for objective analysis.

In general the thrust of utility programs including codes and standards is for short term acquisition of "resources" to reduce peak demand. There is need for longer term projects to support the fundamental basis of the standards such as

- how well are standards enforced
- how do people really design buildings
- how do people really operate buildings etc

These projects need an "owner" like PIER. Indeed PIER research projects helped develop the knowledge base that was the basis of several changes to the 2005 building efficiency standards including skylighting, duct sealing, acceptance testing, and insulation position measures. PIER research can complement the technical support that is currently being provided by the codes and standards divisions of the investor owned utilities as part of their public goods programs. Such research will ensure that the codes and standards process accurately reflects societal needs for energy conservation and evolve in ways that are both energy efficient and add to the safety and comfort of the people.

PROJECT APPROACH

HMG's role in the PIER LRP was twofold – a) provide internal review to the LRP projects on their codes and standards connections, research gaps, and their market and code readiness; and b) research the future codes and standards research needs, fundamental lighting research needs in consultation with codes and standards staff at the California Energy Commission, California utilities and energy consultants.

Project Review Plan

Existing Lighting Codes and Standards Review

For this task, efforts were based upon literature review of existing codes and standards around the country. The starting point was the California Title 24 Building Energy Efficiency Standards. These have been in force since their first adoption in 1978, with subsequent updates. The current version of Title 24 was adopted in 2001. The next update is scheduled to take effect in 2005. Requirements in both the 2001 and 2005 were included in the review.

HMG then summarized the lighting efficiency requirements in other states and in the national model energy codes and guidelines such as the ASHRAE standards, International Energy Conservation Code (IECC), LEED (Leadership in Energy and Environmental Design), EPA Energy Star program, Advanced Building Guidelines, and Collaborative for High Performance Schools (CHPS).

HMG also reviewed standards that regulate products available in the marketplace for use in construction. For lighting, these include national and state appliance efficiency standards such as the California Title 20 appliance standards.

The full task report found on the PIER LRP website, and summarized in the next chapter, Project Outcomes, explains the scope of each of the codes and standards mandatory provisions and prescriptive compliance options. The review was differentiated between residential, nonresidential and outdoor lighting standards. The review also highlighted the key differences in the intent and details of the various standards.

PIER LRP Project Review

HMG reviewed the published literature on all the PIER LRP research programs through the LRP team website, monthly progress reports, and PAC meeting notes to identify the nature of the projects, project deliverables, and the anticipated market penetration. Also, HMG had detailed conversations with the Element 6 Lead and other LRP project leads to discuss the status of various projects and to coordinate the marketing efforts with the codes and standards potential review. The Technology Transfer Plans (TTPs) submitted by the individual Project Leads also served as a basis for analyzing the anticipated codes and standards connections as proposed by the Project Leads.

Not all of the LRP projects have codes and standards connections, and not all of the projects that do have code potential have similar market potential and cost effectiveness. HMG therefore categorized the projects into the following three categories based on their code readiness:

1. CODE READY – these projects have demonstrated required performance and have met the cost effectiveness criterion for adoption into the code. Adoption in the code can be achieved by a number of ways including:

    a. Prescriptive Lighting Power Densities (LPD) - LPD's are defined for each space type, and are updated as lighting equipment efficiency increases, putting pressure on designers to use more efficient light sources.

    b. Power Adjustment Factors – Control credits are allowed for occupancy sensors, daylighting sensors, and other types of control not commonly installed. These credits are given in the form of Power Adjustment Factors. This PAF allows the designer more connected lighting load than the code minimum because the control will provide equivalence in energy savings. Typically, these credits are given to innovative controls and technologies that have not yet established a solid market base.

    c. Tailored Method of Compliance – This compliance path provides many "use it or lose it" opportunities to build additional lighting allowance into a project. Designed mainly for retail applications, it provides for as much as six watts per square foot in areas where display lighting or lighting for special needs is installed.

    d. Mandatory Code Measures – This compliance path simply mandates the use of certain technologies and products in various spaces. Products that have extensive market reach are extremely cost effective, or serve an important function critical to proper operation of the space are typically included in these measures.

    e. Appliance Standards Requirements – These standards regulate the manufacturing of equipment, and a technology can be included in the appliance standards if it has the potential to raise the energy efficiency levels over the existing technologies. California is preempted from regulating efficiency of equipment that is regulated by the federal government.

2. MARKET READY – These projects would include products that may have received the necessary certifications (such as UL) to make the product available in the market, but where the product is currently not cost effective or has not demonstrated its energy savings potential sufficiently to merit incorporating into codes and standards. HMG recommended additional testing to demonstrate product compliance to various regulations, or additional market studies including site data collection to demonstrate reliability and savings potential.

3. UNDER DEVELOPMENT – These projects clearly do not have a product that is either market ready or approved by the relevant standards approving body. HMG recommended additional features that these products should incorporate in order to better incorporate them in the codes and standards process.

a. Projects under Development with Near-term Code Potential: These projects have good connections with existing energy efficiency standards in California; however they will not be fully commercialized by the end of the Lighting Research Program. The project development is expected to be completed by the end of the current LRP time line. Some of these products have components that have been previously researched and approved by the standards process and well received in the market.

b. Projects under Development with Possible Long-term Code Potential: These projects currently do not have a market ready product and are in the early stages of product development. It may be too early to predict the code impacts. However, HMG lays out a set of criterion that should assist the Project Leads in developing their product plans and specifications. While these projects may be completed during the LRP time line, there might be further work needed to transform the results into a market ready product that can have code implications.

Each of the LRP research project was categorized per the criterion explained above, and detailed descriptions of the code connections as well as research needed to satisfy code requirements were included for each project.

The process was collaborative in nature and included consultations with the individual project leads and the Element 6 lead.

Complementary Lighting Research Needs

This task provided a discussion of the research context around each of the PIER Lighting Research Program (LRP) projects. This context includes prior and ongoing research that compares the general approach taken by each project with other possible approaches, research that suggests specific improvements that could be made to prototype products, and research that suggests future directions for a specific project either within or beyond the LRP. Awareness of parallel efforts and applications creates opportunities to contact other researchers and manufacturers that are involved with these same technologies to leverage each other's efforts.

The review was based upon a combination of literature review through trade journals, publications from industry research groups, market studies for various technologies and consultations with the project leads, industry professionals and other researchers.

For each project, the discussion was broken up into two main sections: "general research issues" and "issues specific to the LRP project". The former sections contained discussions of the major ongoing research issues relevant to each project, and of what further research may be needed to better understand the issues; the latter sections contained details of specific research findings or research needs that should influence the development of that project.

Typically, the analysis of each LRP project contained some or all of these elements:

- Accurately characterizing the base case conditions of the technology that the LRP products would replace. This characterization includes:
    - The current and projected quantity or market share of products installed in California buildings.

- Key features of the base case technologies including visibility cost, energy consumption, longevity, maintenance and ease of integrating into current building construction practices.
- Market research on what people like about the product and what they would like improved.
- Human behavior. This includes frequency of use of areas and lighting, need for wayfinding and security and the biological impacts of lighting.
- Adequately describing the key features of the proposed technology in terms of visibility, cost, energy consumption, cost-effectiveness, longevity, maintenance and ease of integrating into current building construction practices.
- Accounting for human factors: frequency of use, user acceptance, and biological impacts.
- Market research on user acceptance of unique features of the product and what they would pay for the product.
- Awareness of pros and cons of competing technologies: although since manufacturers' development work is confidential, it is often not possible to find information on products that are under development.
- Specifically for codes and standards, pertinent issues include: likely energy savings, cost-effectiveness, current favorability of codes toward the product, the level of market maturity and competition.

Prioritized Lighting R&D/Standards Connections

The purpose of this task was to facilitate a discussion of each project's potential to influence the future development of energy 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 considered the prospects for the adoption of the LRP technologies into an incentive program run by California utilities. Four factors were analyzed:

- Opportunity for Code Improvement: This section identified 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.
- Total Resource Cost Ratio: The California Public Utilities Commissions' Total Resource Cost (TRC) 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. The TRC ratio was calculated in support of the efforts to market the LRP products to the utilities, which have to report savings from their energy efficiency programs as a whole in terms of their TRC ratio. While individual products are not required to meet the TRC test, this task provided an estimate of the savings potential from the LRP products using a standard metric. Having said that, the researchers were aware of the limitations of the TRC methodology:

- The TRC currently evaluates only the annual energy saving, and does not yet include a method for evaluating peak load reduction – this is planned for 2005. Thus the results of the TRC calculations (reported on in later sections of this report) 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.
- Also 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.

- Peak Demand Reduction Cost: Because the TRC method does not include peak demand reduction, we quantified the demand reduction that is expected to result from each of the technologies in $/W, i.e. the cost of reducing summer peak demand by one Watt. 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.

- Strategic Benefits: While the TRC ratio and the peak demand savings calculations provide an estimate of the savings potential from the LRP products, these do not account for the other environmental and societal benefits of the products. They also do not account for the pivotal role a product might play in future development of energy efficient technologies. We therefore analyzed the key benefits of the LRP products that may not be accurately described by the savings numbers alone as strategic benefits.

Lighting Standards and Fundamental Lighting Research Needs Assessment

This task summarized findings on research needs for further improvements to the California Energy Efficiency Standards, and research needed to improve understanding of fundamental lighting issues. The criterion for the research needs was whether such a research would be appropriate for public interest research through PIER funding.

The research recommendations were developed through a series of meetings with the California Energy Commission codes and standards staff, utility codes and standards staff, utility emerging technologies staff, energy efficiency researchers and lighting experts.

The process involved discussion with the above mentioned stakeholders in the codes and standards development process about:

- 2005 Code Change Review and Remaining Issues – this described the major code revision in the building efficiency standards that take effect in 2005. It also described which measures were dropped due to industry opposition or lack of reliable information. This helped identify holes in current knowledge that have to be addressed if some measures are going to be considered for inclusion in the standards.
- 2008 Standards Prognosis – this summarized the thinking of key stakeholders on which measures are most likely to be considered for the 2008 revision of the building efficiency standards. This prognosis provides guidance of research topics that would have near term code impact.
- Research Needed to Improve California Title 24 Lighting Standards – this details the specific research topics that can support the development of the 2008 and 2011 building energy efficiency standards. The topics of this research can be characterized in the following categories–
    - Better understanding of how people design and use lighting (design and usage baselines)
    - Better characterization of pre-existing technologies (LED's, skylight louvers, digital lighting controls, fluorescent lamp cathodes, etc.)
- Fundamental lighting research needs – Basic research of human wants and needs for light and the impact of light on humans

Stakeholder Meetings

In order to conduct the research outlined above, HMG initiated and attended a number of meetings with various stakeholders such as:

- California Energy Commission codes and standards staff
- California utilities codes and standards staff
- California utilities emerging technologies staff
- Energy efficiency consultants
- Lighting experts
- PIER LRP project and element leads
- PIER LRP management

Advisory Group Inputs

The PIER LRP had two separate advisory groups –

- The Program Advisory Committee (PAC) – the PAC members' role was to provide guidance to the overall development of the LRP products and facilitate generation of market connections
- Technical Advisory Groups (TAG) – there was a separate TAG for each of the 6 elements within the LRP, and the TAG role was to provide detailed technical input on the products and recommendations

HMG attended all three PAC meetings, and presented its interim findings to the PAC for review. Interim reports were also submitted to the PAC members when needed. Inputs from the PAC members were incorporated into the final task reports.

HMG participated in the TAG telephone calls and provided progress reports on its tasks throughout the duration of the LRP. Interim findings were discussed with the TAG members, and comments incorporated into the final task reports.

PROJECT OUTCOMES

This chapter provides detailed summaries of the findings from each of the project tasks. Each subsection below summarizes one of the full task reports available on the PIER LRP website at www.archenergy.com/lrp/products/codes.htm.

Existing Lighting Codes and Standards Review

This section provides a concise summary of the task findings. The complete task report is available on the PIER LRP website.

Types of Lighting Standards

The Title 24 lighting standards, and most all other lighting standards as well, include both mandatory measures and prescriptive/performance measures. The mandatory measures are just that; they must be installed wherever they are applicable in a building design. An example of a mandatory measure would be the requirement to provide separate light switches in each separate room of a building. The prescriptive/performance measures govern overall system performance. They usually entail optional trade-offs to assist designers in handling special design situations. An example of a prescriptive/performance lighting requirement would be a whole building limit on installed lighting power density, which can be met in a variety of ways, and which may entail special control credits and exceptions for special cases.

Lighting efficiency standards tend to have the greatest impact and reach in the nonresidential buildings sector. Residential lighting standards are more limited in scope, due to the simpler lighting systems and equipment in residences, and the lower lighting energy requirements. Many, but not all, building codes also have requirements for outdoor lighting and lighting in unconditioned buildings such as parking garages or storage warehouses.

In addition to the Title 24 Energy Efficiency Standards, California also has the Title 20 Appliance Efficiency Standards. There are also federal appliance efficiency standards, and some other states also have appliance standards. While the building standards govern what designers may do when specifying the building systems, the appliance standards govern what manufacturers and distributors may sell. In the lighting arena, lighting appliance standards govern such things as ballast efficiency, or the minimum allowable operational characteristics of occupancy sensor controls.

Purpose and Benefits of Codes

Historically, codes were developed to insure safety in buildings. Since the 1970s, the code development community began to recognize other purposes for codes, particularly in the energy efficiency arena. One purpose of codes is to lock in the energy efficiency obtained through advances in the marketplace. Many times these advances are driven either by raw research or by utility sponsored programs that foster acceptance of an emerging technology or design practice. As technology improves and becomes commercially available, the code can recognize the technological advancement and capture the energy savings through a code update.

Codes Compared

States are typically the adoption agencies for codes. In most cases, local jurisdictions can supersede code if a local code is shown to be stricter than the code adopted at the state level. For this work, we looked at state codes by three different groups:

- those that follow the IECC[2], incorporating the ASHRAE[3] Standards by reference, and
- those that have developed state codes based on these national models, and
- those that have a uniquely designed code or significant variation from one of the other three models.

For details on the scope and intent of the various standards refer to the detailed task report on the PIER LRP website.

Code Adoption Status by State

The following two maps illustrate the energy code version for each state, for both residential and commercial construction. The Building Codes Assistance Project produced the first map (Figure 2). Jeff Johnson at the New Buildings Institute Inc., produced the second map, as shown in Figure 3.

[2] IECC – International Energy Conservation Code

[3] ASHRAE – American Society of Heating, Refrigerating and Air-Conditioning Engineers

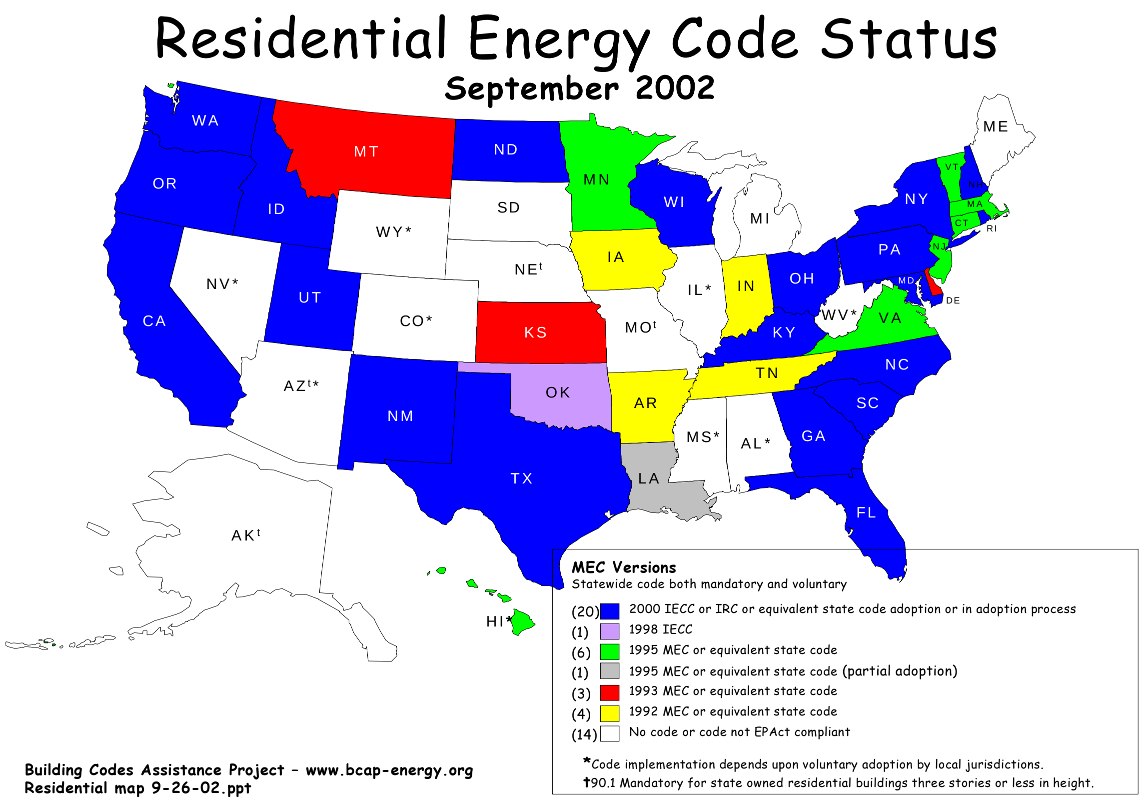

Figure 2 – Residential Code Adoption by State

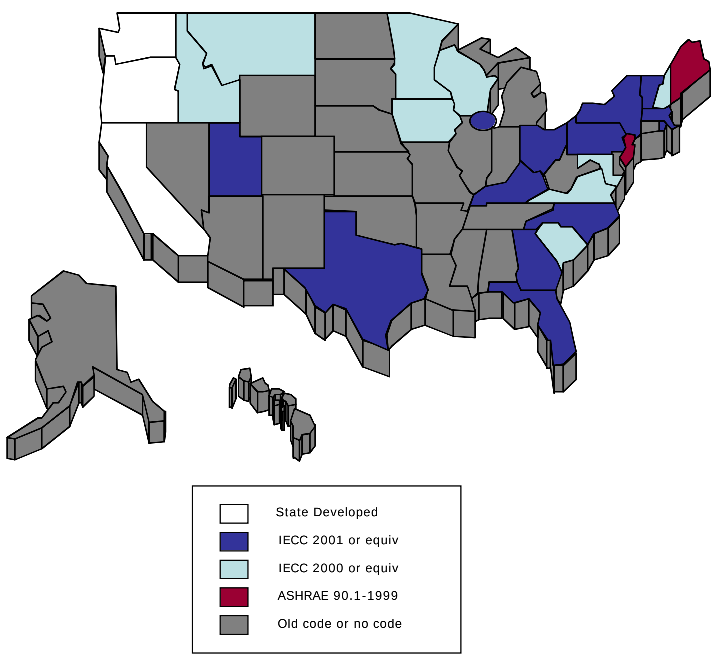

Figure 3 – Commercial Code Adoption by State, May 2003

Nonresidential Lighting Efficiency Standards

Nonresidential energy codes have the following standard components: applicability criteria, mandatory features and devices, and prescriptive or performance based lighting power densities.

Most states, including California, require that any newly conditioned space where lighting will be installed shall comply with applicable code requirements. For remodels and additions, a California criterion states that if 50% of the lights are moved or lighting load increases, then the requirements are triggered. The three major code types also provide a comprehensive list of exempt lighting. Among them are specialized lights for technical purposes, such as medical examination lights that are for sale, specialized display lighting for galleries, and public monuments.

Mandatory Features and Devices

All major codes also require some type of automated shut off control, for example, a sweep control. Office buildings greater than 5,000 sq. ft. and all school classrooms within the state of Washington, for example, are required to be equipped with automatic controls to shut off the lighting during unoccupied periods. This applies to most states that adopted IECC 2001 (and beyond) and ASHRAE 90.1 1999 code. The automatic controls may be an occupancy sensor, time switch, or another device capable of automatically shutting off lighting.

The City of Seattle developed an energy code that exceeds the state requirements. For example, occupancy sensors are required in buildings greater than 5,000 sq. ft. and all school classrooms. Within these buildings, all office areas less than 300 sq. ft. enclosed by walls or ceiling-height partitions, all meeting and conference rooms, and all school classrooms, are required to be equipped with occupancy sensors. Table 1 compares the mandatory lighting measures for a number of national standards and state adopted codes.

State/ Jursidiction	Auto Shut Off	Separate / Bi-level Switching	Daylight Controls - Exterior	Daylight Controls - Interior	Other
California	Y	Y	Y	Credit	
California 2005	Y	Y	Y	Credit	
Oregon	Y	Y	Y	N	
Washington	Y	Y	Y	N	
New York	Y	Y	Y	N	
Minnesota	Y	Y	Y	N	
Florida	Y	Y	Y	N	
IECC 2000	Y	Y	Y	N	exit signs
IECC 2003	Y	Y	Y	N	exit signs
ASHRAE 90.1	Y	N	Y	N	exit signs

Table 1 – Nonresidential Mandatory Measures Comparison

Prescriptive/ Performance Lighting Power Densities

The most universal mechanism for regulating lighting system energy use is to limit the installed lighting power density, expressed as installed watts per square foot of floor area (W/sf). Using density limitations, the code leaves it up to the lighting designer to select the lamps, ballasts and luminaires that will meet the needs of the occupants, while remaining within the allowed lighting power limit. The standards also typically provide rules for how the installed lighting power is calculated. This usually requires that both lamp and ballast power requirements are taken into account. In some jurisdictions, control credits are available. Control credits allow the designer to discount the wattage of luminaires under the special control. The theory behind control credits is that they are energy neutral. The savings from the operation of the control offsets any additional installed wattage that may be designed into the building as a result of the credit. Originally intended to encourage good design practice rather than to regulate it, these credits have recently come under fire, because no energy savings are guaranteed. Allowed lighting power density usually varies with occupancy type. For illustrative purposes in this report, the following occupancy types are explored: Office, Retail, Restaurant and School. The Illuminating Engineering Society of North America (IESNA) is a joint sponsor in the ASHRAE process to develop the national model energy code, Standard 90.1, and is otherwise active in tracking and advising on code developments. These densities are based on their recommended illumination levels utilizing certain consensus luminaires and common design practice.

The densities for the various codes and standards are illustrated in Table 2.

Lighting Power Densities by Code Location or Type				
State/ Jursidiction	**Office Building LPD**	**Retail Bldg LPD**	**School Bldg LPD**	**Restaurant Bldg LPD**
California 2001	**1.3**	**1.7**	**1.4**	**1.2**
California 2005	**1.1**	**1.5**	**1.2**	**1.2**
Oregon	**1.4**	**1.9**	**1.5**	**1.2**
Washington	**1.2**	**1.5**	**1.35**	**1.0**
New York	**1.3**	**1.9**	**1.5**	**1.7**
Minnesota	**1.4**	**2.7**	**1.77**	**1.6**
Florida	**1.8**	**3.1**	**2.0**	**1.3**
IECC 2000	**1.3**	**1.9**	**1.5**	**1.7**
IECC 2003	**1.1**	**1.7**	**1.4**	**0.9**
ASHRAE 90.1- 99	**1.25**	**3.63**	**1.59**	**1.45**
ASHRAE 90.1-2001	**1.3**	**1.9**	**1.5**	**1.8**

Table 2 – Representative LPDs by Jurisdiction

Many states allow more than one method to calculate allowed densities for a given space. A whole building number may be applied to the entire building, or different densities may be applied to spaces within the building. In the case of the table above, a whole building value (or a representative area, if whole building wasn't available) was used.

The densities are in many cases customized to reflect the unique needs of the space. For example, ASHRAE 90.1 provides for ornamental and display lighting bonus densities in certain occupancies. In other cases, different definitions of space type yield different lighting power densities.

Table 3 below illustrates the range of allowed LPDs when strict and liberal code interpretations are taken:

Lighting Power Densities by Code Location or Type										
State/ Jursidiction	**Office Building LPD**	**Office Low**	**Office High**	**Retail Bldg LPD**	**Retail Low**	**Retail High**	**School Bldg LPD**	**School Low**	**School High**	**Restaurant Bldg LPD**
California 2001	**1.3**	1	2.36	**1.7**	1.7	5.99	**1.4**	1.4	4.26	**1.2**
California 2005	**1.1**	1.1	2.34	**1.5**	1.5	5.96	**1.2**	1.2	2.13	**1.2**
Oregon	**1.4**	1.4	1.4	**1.9**	1.7	3.4	**1.5**	1.5	1.5	**1.2**
Washington	**1.2**	1.2	1.2	**1.5**	1.5	1.5	**1.35**	1.35	1.35	**1.0**
New York	**1.3**	1.3	1.5	**1.9**	1.9	2.1	**1.5**	1.5	1.5	**1.7**
Minnesota	**1.4**	1.11	1.4	**2.7**	1.72	2.7	**1.77**	1.26	1.77	**1.6**
Florida	**1.8**	1.8	2.2	**3.1**	2.7	3.1	**2.0**	2.0	2.0	**1.3**
IECC 2000	**1.3**	1.3	1.5	**1.9**	1.9	2.1	**1.5**	1.5	1.5	**1.7**
IECC 2003	**1.1**	1.1	1.45	**1.7**	1.7	3.3	**1.2**	1.2	1.75	**0.9**
ASHRAE 90.1- 99	**1.3**	1.3	1.5	**1.9**	1.8	2.1	**1.5**	1.3	1.6	**1.8**
ASHRAE 90.1-2001	**1.3**	1.3	1.5	**1.9**	1.8	2.1	**1.5**	1.3	1.6	**1.8**

Table 3 – Range of Allowed LPDs by Jurisdiction

In general, the 2005 proposed changes to the California Code are comparable to the 2003 IECC in terms of stringency.

For more details on the key differences between the various state codes, national standards and voluntary guidelines refer to the detailed task report on the PIER LRP website.

Residential Lighting Standards

Lighting standards for residential buildings are not as widely adopted as they are for nonresidential buildings. This is due to several factors. First, the energy savings opportunities are not as large or as universal, because residential lighting usage is not subject to regular business hours like nonresidential lighting, and the lighting wattages are more limited. Second, much of residential lighting is in plug-in lamps, which are not even present when building officials are inspecting the buildings. Third, there is a general reluctance to intervene in private residences and in the fashion/lifestyle choices implicit in residential lighting.

California, however, is leading a trend to use the energy code to broaden the acceptance of high efficacy lighting in residences. The past five to ten years have seen a large increase in the product offerings for high efficacy residential lighting fixtures, lamps and ballasts, as concerns about quality and consumer acceptance have been addressed by the lighting industry. Many segments of the residential market have already seen widespread acceptance of compact fluorescent technology, especially for areas with long hours of operation such as corridors and outdoor security lighting.

A key area of current concern in residential lighting efficiency is the growing trend in the use of recessed downlights, especially in kitchens. These are problematic for two reasons: first, they tend to use incandescent lamps and because of their limited throw and spread there tend to be many of them; second, they frequently penetrate the ceiling insulation and so become a heat leak in the building envelope. Because kitchens are one of the most heavily used rooms in the residence, the resulting energy waste can be significant. Advances in high efficacy luminaires are cited as a good potential solution to this problem. Energy code limits on the installed incandescent wattage can also provide a solution.

For details on similarities and differences between the various residential lighting codes refer to the detailed task report on the PIER LRP website.

Outdoor Lighting Standards

Historically, there has been little impetus to regulate outdoor lighting. The electric utility industry has generally viewed outdoor lighting as a good load balancing mechanism, using off-peak generation capacity and increasing profitability. A large share of outdoor lighting is for security purposes, and a large majority of people feel that outdoor lighting reduces crime and vandalism (although researchers have not been able definitively to prove this assertion). Another large component of outdoor lighting is advertising and signage, which many view as a commercial necessity.

Nevertheless, a great deal of outdoor lighting is wasted energy. Poorly designed fixtures send lighting energy up into the sky where it does no good. Large areas are lit throughout the night for little apparent reason. There is an escalating competition among commercial interests to be brighter lit than their neighbors. For example, some gas station canopies are lit to provide 100 foot-candles of illumination at the pumps, a level almost three times higher than the accepted illuminance level for offices. With the recent energy crises, there is a growing interest in limiting the energy waste from outdoor lighting.

For details on similarities and differences between the various outdoor lighting codes refer to the detailed task report on the PIER LRP website.

Appliance Standards for Lighting Products

Preemption of federal standards over state standards for most federally regulated appliances results in minimal efforts toward state developed code. Regarding fluorescent lamp ballasts and replacement fluorescent lamp ballasts, Table 4 illustrates the current standards for the following types of fluorescent lamp ballasts:

- replacement fluorescent lamp ballasts manufactured on or before June 30, 2010
- fluorescent lamp ballasts manufactured on or after January 1, 1990
- fluorescent lamp ballasts sold by the manufacturer on or after April 1, 1990, and
- fluorescent lamp ballasts incorporated into a luminaire by a luminaire manufacturer on or after April 1, 1991

Application for Operation of	Ballast Input Voltage	Total Nominal Lamp Watts	Minimum Ballast Efficacy Factor
one F40T12 lamp	120 or 277	40	1.805
two F40T12 lamps	120	80	1.060
	277	80	1.050
two F96T12 lamps	120 or 277	150	0.570
two F96T12 HO lamps	120 or 277	220	0.390

Table 4 – Current Standards for Lamp Ballasts

In addition, Table 5 illustrates the future standards for the following types of fluorescent lamp ballasts:

- fluorescent lamp ballasts manufactured on or after April 1, 2005
- fluorescent lamp ballasts sold by the manufacturer on or after July 1, 2005

- replacement fluorescent lamp ballasts manufactured after June 30, 2010, and
- fluorescent lamp ballasts incorporated into a luminaire by a luminaire manufacturer on or after April 1, 2006

Application for Operation of	Ballast Input Voltage	Total Nominal Lamp Watts	Minimum Ballast Efficacy Factor
one F40T12 lamp	120 or 277	40	2.29
two F40T12 lamps	120 or 277	80	1.17
two F96T12 lamps	120 or 277	150	0.63
two F96T12 HO lamps	120 or 277	220	0.39

Table 5 – Future Standards for Lamp Ballasts

PIER LRP Project Review

This section provides a concise summary of the task findings. The complete task report is available on the PIER LRP website. The review was conducted midway through the LRP project development time frame, and looked at the codes and standards connections of the LRP products in their then developmental stage. The review found that the LRP projects were at various stages of development and have varying degrees of connections with codes and standards. Some products are code ready in their current form and are ready for marketing and outreach efforts, other projects need to satisfy cost effectiveness, industry acceptance, and performance verification before their exact code connections can be assessed. Some projects also need modifications in either their product features, or the relevant codes and standards in order to be eligible for compliance.

While this report explored few national codes and standards, the main focus was the California energy standards. HMG provided information on national standards such as IES, NEMA, and ANSI when such information was readily available to the project team and such information was therefore not comprehensive.

When reviewing the monthly reports and the Technology Transfer Plans a common misconception about the codes and standards process was observed. Many projects looked at the standards process as a potential barrier indicating that the tightening of energy standards would result in barriers for their products. This cannot be further from the truth. The standards process often serves as a catalyst to introduce such energy efficient products into the market place, even when their cost benefit ratio is not extremely favorable for mass marketing. The standards process also encourages utilities and other agencies to grant economic incentives through energy efficiency rebates to encourage early adoption of technologies.

On the other hand, the codes and standards process should not be looked at as a means of promoting an energy efficient product that has not been thoroughly tested, both in the laboratory as well as in the field. The standards can support only those products that have demonstrated capabilities, energy savings, market acceptance, and some degree of success in the market place. Also, it is critical that the product capabilities be non-proprietary in order for the product to be considered for codes and standards, especially when forming the basis for a code change.

Analysis also indicated greater opportunities exist for certain technologies and products beyond the current LRP scope and efforts. For example, the bi-level lighting controls requirements have greater implications than just stairwells, and a greater involvement by the manufacturing community in developing various alternatives that achieve similar controls was recommended.

Code Potential Categorization

Table 6 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 detailed task report on the PIER LRP website.

Project #		Code Potential	Relevant Codes/ Standards	Project Status
2.1	LED Exterior Lighting	Long-term Potential	CA Title 24	Under Development
2.2	LED Task Lighting	Long-term Potential	CA Title 24	Under Development
2.3	LED Low Profile Lighting	Long-term Potential	CA Title 24	Under Development
3.1	Retrofit Fluorescent Dimming	Long-term Potential	CA Title 24, CHPS	Under Development
3.2	Load shedding	Long-term Potential	CA Title 24, CHPS	Under Development
3.3	Classroom Photosensor	Long-term Potential	CA Title 24, CA Title 20, NEMA, CHPS	Under Development
4.1	Hotel Bathroom Lighting – Occupancy Sensor	**Near-term Potential**	CA Title 24	**Market Ready**
4.1	Hotel Bathroom Lighting – Integrated Light Fixture	Long-term Potential	CA Title 24	Under Development
4.2	ENERGY STAR® Residential Fixtures	**Near-term Potential**	CA Title 24, Energy Star	**Market Ready Soon**
4.3	Retrofit Energy Efficient Downlights	**Near-term Potential**	CA Title 24, CA Title 20, Energy Star	**Market Ready Soon**
4.4	Portable Workstation Lighting – Berkeley Lamp II	Long-term Potential	CA Title 24	Under Development
4.4	Portable Workstation Lighting – Finelite	Long-term Potential	CA Title 24	Under Development
4.5	Integrated Classroom Lighting	**Near-term Potential**	CA Title 24, CA Dept. of State Architect, LEED, CHPS	**Market Ready Soon**
5.1	Bi-level Stairwell Fixtures	**Near-term Potential**	CA Title 24, ANSI	**Market Ready Soon**
5.2	HID Electronic Ballast	Long-term Potential	CA Title 20	Under Development
5.3	Low Glare Outdoor Lighting	Long-term Potential	CA Title 24, IESNA	Under Development
5.4	DALI	Long-term Potential	CA Title 20, NEMA	Under Development

Table 6 – Code Assessment Summary

Complementary Lighting Research Needs

This section provides a discussion of the research context around each of the PIER Lighting Research Program (LRP) projects. This context includes prior and ongoing research that compares the general approach taken by each project with other possible approaches, research that suggests specific improvements that could be made to prototype products, and research that suggests future directions for a specific project either within or beyond the LRP. Awareness of parallel efforts and applications creates opportunities to contact other researchers and manufacturers that are involved with the same technologies to leverage each other's efforts. The complete task report is available on the PIER LRP website.

Summary of Research Findings and Recommendations

The following list is not exhaustive; it summarizes the most important or relevant findings and recommendations for each of the LRP research projects. For details, refer to detailed task report available on the PIER LRP website.

2.1 Light Emitting Diode (LED) Luminaires for Exterior, Porch and Perimeter Lighting

The features, performance, and aesthetics required of outdoor luminaires by homeowners are not well understood, due to the fragmented nature of the residential outdoor fixture market. For instance, it is not known whether homeowners buy outdoor luminaires primarily to provide light for wayfinding, or for security, or for aesthetic reasons. It is not known whether homeowners will see a need for 'standby' lighting. Research including focus groups and surveys may help to ensure market success for the prototype fixtures.

Another research issue is the Color Rendering Index (CRI) commonly used to describe the color quality of lamps. The CRI metric does not seem to describe narrow-band (monochromatic) sources such as LEDs very well, and is under review by CIE. Until this review is complete, product developers should always visually assess the color quality of LEDs under various conditions, rather than relying on the CRI.

2.2 LED Task Light Utilizing New Materials to Reduce Thermal Stress on High Brightness LEDs

The development of new materials, manufacturing methods, and designs in the LED market is very fast-paced.

The performance and service life of the prototype task light could be improved by increasing the rate of convective air flow over the LED heat sinks and the fixture body. Every additional degree of temperature reduction will improve both the efficacy and life of the LED source.

2.3 LED Low Profile Fixtures

The efficacy of the prototype fixture is lower than that of currently available fixtures using incandescent lamps.

The efficiency of the first prototype luminaire was limited by the design of the reflector.

The efficacy of commercially-available LEDs is expected to continue to increase rapidly; the efficiency of the fixture will increase in the same proportion.

It may be possible to use the experience gained in project 5.1 to develop a bi-level elevator luminaire that takes advantage of the increased life and increased efficiency of LEDs at low output levels.

3.1 Retrofit Fluorescent Dimming with Integrated Lighting Controls

The controls infrastructure developed within this project allows a wide range of possible control algorithms to be used. Commercially-available systems tend to use only a narrow range of options, but research shows that options common outside the United States (such as switching the fixtures on at the same level they were set to when switched off) can result in significant energy savings. Research indicates that certain features are appreciated by occupants and these could be designed into the control algorithm.

The prototype system allows luminaires to be controlled in small groups with no additional wiring. The use of small control groups (1, 2, or 3 luminaires) has been shown to further increase energy savings and improve occupant satisfaction compared to the use of larger control groups.

The economic viability of the system may not be as good as reported in the technology transfer plan, and vary significantly between one building and another. The challenge may be to find existing buildings with high energy consumption that are undergoing lighting retrofits in which the prototype control system can be installed cheaply.

Triac-based control systems are being developed that may provide competition to the prototype system. However, this system may offer advantages in terms of power quality, and it might be worthwhile to quantify the power quality impacts of both systems.

3.2 Energy Efficient Load Shedding Technology

Lighting load shedding may be the cheapest per-kW option available to utilities who wish to expand their load shedding capability, so widespread adoption is possible.

Each year, lighting load shedding might create between 1 and 3MW of sheddable load in California. This is only a few tenths of a percent of the total sheddable load in the state, but since the annual contribution of lighting load shedding would increment over time, the eventual contribution could be 10% or more, assuming 10% market penetration by load shedding ballast systems.

The LRC has performed a series of experiments that suggest that office occupants are unlikely to object to the use of lighting load shedding, as long as they are informed about the ecological and societal reasons for it, and as long as it occurs infrequently. It should be noted that conventional daylight-linked lighting control systems function in much the same way, and that well-commissioned daylight-linked systems are well accepted by occupants.

One pilot study is being performed in an office building owned by a utility company. This pilot will be valuable in terms of trialing the functionality of the system, but real-world trials will be required to demonstrate the persistence of participation in any load shedding program.

3.3 Classroom Photocell and Control System

The effect of daylight and electric light distributions on the wellbeing and performance of students and teachers in classrooms is not well understood. For instance, it may be important to maintain electric light levels on the ‘teaching wall’ when the classroom is daylit, to retain the visual focus of students. Monitoring of installed systems may lead to a better understanding of the key determinants of success for a lighting control system, and this project presents a good opportunity to carry out this monitoring, since the functioning and responses of the system are well understood. Any monitoring should take into account the widest possible range of variables, including non-lighting features of the classroom. Post-occupancy assessments of photocontrol systems in sidelit spaces will be conducted by Heschong Mahone Group during 2004 to inform the 2008 Title 24 standard.

The target illuminance level for the photosensor of 500 lux used in this project is on the higher range of what is required by students or teachers per codes and standards such as those set by IESNA and CIE. If the system works successfully at 500 lux, it could be tested at lower target light levels in order to further reduce energy use.

The photocell used in this project may be overly susceptible to upward specular reflections of sunlight that lead the sensor to set inappropriately low electric light levels. Simple design changes to the photocell may reduce the probability of this occurring.

The ability to easily manually override a lighting control system greatly increases the chance that users will accept and continue to use the system. The override features of the system have been intelligently addressed by the design team, and should be considered and tested in detail before the final commercialized system is ready for manufacture. Reasons and triggers for occupant override are not well understood.

The installation and commissioning of lighting control systems is often not carried out well by contractors. An opportunity exists within this project to work with other controls manufacturers to develop standard design, installation, and commissioning procedures for their systems. A guide to these procedures could be produced for use in schools, and could be used as a template for other similar guides for other building types.

4.1 Hotel and Institutional Bathroom Lighting Project

It might be possible to achieve significant market success as well as progress in codes and standards if the project team is able to demonstrate experimentally that this system provides adequate light for wayfinding and orientation, specifically for the demographic groups likely to live in varying types of institutions.

Title 24 2005 does not provide incentives for the use of energy-saving control systems in hotel and motel bathrooms, and may require an inappropriately short delay time for the motion sensor; this could be changed for the 2008 edition.

The color of the LEDs chosen for the bathroom fixture may have an effect on the degree of circadian disruption caused to hotel guests. Red LEDs would likely minimize the impact whereas blue LEDs would likely maximize it.

4.2 Energy Star Residential Fixture Project

If this project is successful, research data suggests that it might be fruitful for a future project to address improved designs for energy-efficient outdoor residential lighting.

The features, performance, and aesthetics required of both indoor and outdoor luminaires by homeowners are not well understood, due to the fragmented nature of the residential fixture market. For instance, it is not known whether homeowners buy indoor luminaires primarily to provide task lighting, or for general illumination, or for aesthetic reasons. Research including focus groups and surveys may help to ensure market success for the prototype fixtures.

4.3. Development of Energy Efficient Retrofit/Remodel Alternatives to Incandescent Downlights

There may be safety concerns regarding the use of twin-lamp ballasts in residential fixtures. When one of the lamps controlled by the twin-lamp ballast burns out, the other lamp will also be powered OFF. In the absence of consistent labeling that identifies which lamps are wired in tandem, the user may be confused as to why replacing one of the lamps does not fix the problem, and may be tempted to tinker with the fixture electronics.

The thermal performance of residential indoor luminaires varies widely, and ballast case temperatures sometimes exceed manufacturers' recommendations and may lead to early ballast failure. No standardized thermal test procedure exists for residential luminaires; a standard thermal test might usefully be adopted into the ENERGY STAR® requirements. Pacific Northwest National Laboratories have conducted extensive thermal testing and have developed fixture design guidelines that could be adopted more widely.

Thermal testing of the fixture has been carried out, but the test fixture did not include a gasket or caulking between the fixture and the sheetrock, as required by Title 24 2005. The fixture should be tested with a gasket in place as a final check on thermal performance.

The light distribution of the fixture is optimized for the cut-off requirements of office lighting rather than residential lighting. Other reflector options might increase the acceptance (both short-term and long-term) of CFL luminaires by homeowners. The persistence of residential hardwired (bi-pin) CFL fixtures is not known.

4.4 Portable Office Lighting Systems

Portable office lighting systems represent a very large opportunity for energy saving, compared with ceiling-based lighting. This potential is not recognized by Title 24 which does not address the use of portable fixtures. It might be justifiable to include a Power Adjustment Factor in Title 24 2008 to recognize this potential energy savings. Portable systems also offer benefits to occupants by increasing the degree of control and the autonomy that occupants feel over their environment.

The photometrics and aesthetics of the fixture in real office environments have already been considered by the design team, but will require close attention to ensure successful commercialization. It appears to be photometrically possible to use portable fixtures in offices with standard-height ceilings.

The experience of companies already attempting to market similar products in the United States should be leveraged by the design team. Patent checks should be carried out.

4.5 Integrated Classroom Lighting System

This system offers a wide range of non-energy benefits that have not yet been incorporated into the marketing plan for the system. These are described in full below.

As with project 3.3, this project offers a valuable opportunity to investigate whether alternative strategies for photocontrol (such as using photocells pointed at the teaching wall, or multiple photocells) offer benefits in terms of perceived lighting quality or energy saving.

This system fulfils the power density and control requirements for the forthcoming 2005 edition of the Title 24 standards, and offers a variety of usability features that go beyond Title 24 recommendations and may increase the robustness and utility of the system. Nevertheless, the system may not achieve lower energy consumption than classrooms that have only bi-level manual switching, since research indicates that those classrooms already have comparatively low energy consumption. Monitored data will be required in order to demonstrate savings.

Existing commercially-available wiring and cabling technologies and systems should be leveraged to reduce the installation cost of the packaged system. Design advice and installation, and commissioning guidelines will be an integral part of the marketing success of the system.

A factory-commissioned photocell should not be relied upon to control the luminaires, since classroom geometry, surface reflectances, and daylight distributions change from one classroom to another and may change during construction. Some type of on-site commissioning will always be required. The LRC's self-commissioning photocell may be useful in this context.

Classrooms are often well daylit and are occupied during afternoon peak times, so they present an opportunity to reduce peak electrical lighting loads. The value to electrical utilities of daylight-linked control systems in classrooms should be investigated as a major benefit of this system.

5.1 Bi-Level Stairwell Fixture Performance

Code changes in Title 24, such as Power Adjustment Factors might help to create a market for this type of fixture. Although the fixture is cost effective in the long term, the price may be too high to make the fixture attractive to specifiers without additional incentives. Since the fixture itself is not inherently costly to manufacture, its price can be expected to decline rapidly as the market for it expands. Research on the reliability of motion sensors and detailed monitoring of the energy savings from the system will be required to justify a code change. Motion sensor reliability is particularly important because failed motion sensors may result in dangerously low light levels for visually impaired people.

It is not clear whether the bi-level fixture will have a detrimental effect on lamp life; it is possible that the fixture will actually extend lamp life, but monitoring of several lamp-ballast combinations is recommended.

The NFPA 1 fire code requires "fail-safe" operation of motion sensors, but there is currently no detailed description of what fail-safe means. It may be possible to incorporate a definition into the forthcoming California fire code.

The NFPA 1 fire code also requires minimum 15-minute duration for illumination timers. It's possible that this would have a significant impact on the achieved energy savings, but it should be possible to estimate the magnitude of this effect by analyzing the usage data from stairways monitored by the project team. The possibility of exempting bi-level fixtures from the 15-minute requirement in the forthcoming California fire code could be investigated.

Photometric calculations should be performed to ensure that, for typical stairwell geometries, the light distribution from the fixture would allow it to meet the requirement of NFPA 1 that the failure of any single fixture should not result in an illuminance less than 2.2 lux in any designated area, while the stairs are lit to a design illuminance of 108 lux. This failure-mode requirement may be particularly problematic in retrofit applications where the stairwell design illuminance is only required to be 10.8 lux.

At this point in time, the California Building Standards Commission (CBSC) has not yet decided on whether to adopt the new NFPA 1 standard that would increase stairwell light levels ten-fold. On one hand, the new standard would render a bi-level stairwell fixture more cost effective, as there would be greater energy consumption and greater energy savings. On the other hand, the combination of the new standard with the bi-level fixtures would consume more energy than lighting to the existing standard with no controls. The CBSC should check that the NFPA 1 standard is based on peer-reviewed research showing a significant increase in fire safety before adopting a standard that would result in increased energy use.

5.2 Evaluations of Electronic Ballasts and Related Controls for HID Lighting Systems

The results reported in the Performance Characterization report (deliverable 5.2.1a) seem broadly to agree with figures quoted by manufacturers. This shows both that LBNL's testing facility is well calibrated, and that the figures quoted at least by major manufacturers can generally be relied upon for accuracy. The accuracy of manufacturers' data is further corroborated by their participation in the NVLAP laboratory accreditation program. Future enquiries into the performance of lighting technologies could make more extensive use of manufacturers' data.

5.3 Low Glare Outdoor Retrofit Luminaire

There appears to be a significant potential for both energy and cost savings through the use of twin lamp fixtures along roads and other areas in which "curfew" dimming is possible. Future research could investigate this possibility.

There are currently few performance goals set for the prototype fixture. Goals for semi-cylindrical or vertical illuminance, for veiling glare, and for sky glow would be appropriate. The goal of achieving 5 lux at a range of 40-45' from a 15' mounting height seems to be incompatible with the goal of limiting veiling glare.

The proposed fixture is not dissimilar in photometric terms to stadium or parking lot floodlights, so it may not be possible to improve significantly on the photometric performance of existing fixtures of that type.

The approach to photometric analysis used in this project could be adapted to analyze the ideal spacing and mounting heights of full cut-off streetlights, which are often used with excessive spacing and overly powerful lamps, which leads to high levels of sky glow and glare.

5.4 DALI Lighting Control Device Standard Development

The DALI protocol seems to offer a unique opportunity to reduce the design cost, installation and commissioning cost, and the failure rate of lighting control systems. DALI already allows specifiers the freedom to use ballasts from a variety of manufacturers and to be sure that any DALI-compliant ballast will function properly within a DALI system. This project will expand the DALI protocol, and allow specifiers the freedom to use control system modules such as motion sensors and photosensors from a variety of manufacturers.

It is possible to conduct automatic testing and monitoring of emergency lighting using the lamp error feedback signals already incorporated into DALI. Several manufacturers already offer systems with this functionality, using their own proprietary protocols. This or a future project could attempt to develop standard protocols for automatic testing and monitoring of emergency lighting.

Prioritized Lighting R&D/Standards Connections

The goal of this task was to identify the most promising LRP project results that could be adopted into the efficiency standards. However, a technology must have a proven 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 the necessary market presence. This task therefore considered the prospects for the adoption of the LRP technologies into an incentive program run by California utilities. The criterion for inclusion in the utility programs included – opportunity for code improvement, TRC ratio, demand savings and strategic benefits.

Each of these criterion are studied separately since a given product may have excellent energy savings but not have great demand savings, or vice-versa; a product that has very good energy savings may still not be a good fit for codes and standards due to enforceability issues. Thus instead of ranking the products in a particular ranking scheme, the results are presented as a matrix. Each product will have different needs for marketing, utility rebates and code adoption.

A summary of the analysis is presented in this section and detailed background and data for the analysis is referenced in Appendix A.

Opportunity for Code Improvement

Table 6 provides a snapshot of the code potential analysis conducted. Details on each of the projects and the nature of code opportunities and barriers are referenced in Appendix A.

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. Thus products that have a TRC ratio of less than one cannot be expected to succeed in the marketplace based on energy savings alone.

This section describes TRC calculations performed for five of the PIER LRP projects that were farthest in their product development and market readiness:

- 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.

<table>
<tr><th>Project number</th><th colspan="3">Project Title</th><th>TRC Ratio</th><th>Incremental Measure Cost</th><th>Incremental measure cost required to make TRC=1</th></tr>
<tr><td>3.3</td><td colspan="3">Classroom Photocell</td><td>0.78</td><td>$719</td><td>$553</td></tr>
<tr><td rowspan="2">4.1</td><td colspan="3">Hotel Bathroom Lighting (“business hotel”)</td><td>0.32</td><td>$65</td><td>$21</td></tr>
<tr><td colspan="3">Hotel Bathroom Lighting (“vacation hotel”)</td><td>0.82</td><td>$65</td><td>$53</td></tr>
<tr><td>4.3</td><td colspan="3">CFL Downlights for Kitchens</td><td>4.22</td><td>$10</td><td>N/A</td></tr>
<tr><td rowspan="5">4.5</td><td rowspan="5">Classroom Lighting</td><td>Scenario A</td><td>2-row switching, estimate from case study</td><td>0.66</td><td>$619</td><td>$409</td></tr>
<tr><td>Scenario B</td><td>2-row dimming, estimate from case study</td><td>0.48</td><td>$994</td><td>$477</td></tr>
<tr><td>Scenario C</td><td>3-row switching, estimate from case study</td><td>0.30</td><td>$1719</td><td>$516</td></tr>
<tr><td>Scenario D</td><td>3-row dimming, estimate from case study</td><td>0.23</td><td>$2219</td><td>$510</td></tr>
<tr><td>Scenario E</td><td>2-row switching, energy saving estimate based on bi-level switching study</td><td>0.30</td><td>$619</td><td>$186</td></tr>
<tr><td>5.1</td><td colspan="3">Bi-level fixture</td><td>1.06</td><td>$277</td><td>N/A</td></tr>
</table>

Figure 4 – TRC ratios and cost reduction requirements

Figure 5 summarizes the values used in the calculation of Total Resource Cost ratio. The letters in parentheses describe how each value is calculated from previous values.

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

† 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

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 California Public Utilities Commission 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.

The calculations of TRC ratio in this report do not include the administrative and overhead costs required to run the programs. These administrative and overhead costs are typically 10-30% of the total program cost. Thus, in order for a product to succeed in a utility program on its own it needs to have a TRC ratio of at least 1.30 if one is to use the TRC ratio as the sole criterion for incorporation into a utility program.

However, as mentioned in the previous section, the TRC ratio is not used by the utilities on a product-by-product basis; rather it is applied to a portfolio of all the products and services that the utility programs support. There are other strategic energy and non-energy benefits as well as demand savings that may warranty the inclusion of a product in the utility program.

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[4] 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[5] for 8.5 EER and a conversion factor of 0.293).

---

[4] Rundquist, R, Johnson, K, Aumann, D, *Calculating Lighting and HVAC Interactions*, ASHRAE Journal 35(11), November 1993, pp. 28-37.

[5] Energy Policy Act 1992, Section 342(2). Retrieved from http://energy.navy.mil/publications/law_us/92epact/hr776toc.htm on 7/12/04

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 – Peak Demand Reduction Costs can be compared with values for the cost of electrical load shedding given in a report from the Peak Load Management Association (Peak LMA)[6]. 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.

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[a]	$152	$635	$82	$2,149	-

[a] See Deliverable 6.3.4: Complementary Research Review

† Business hotels

†† 2 row switching system, energy savings estimated from bi-level study

Figure 6 – Peak Demand Reduction Costs

[6] Peak Load Management Alliance, Final Results of the EEI / PLMA 2002 Demand Response Benchmarking Survey, retrieved from www.peaklma.com/files/public/DRSurvey2002FinalReport0503.doc on 2/4/2004

Lighting Standards and Fundamental Lighting Research Needs Assessment

The goal of this task was to identify research needs for codes and standards enhancements and to identify fundamental lighting research needed to improve understanding of lighting issues, improve technology application and promote future codes and standards that enhance our biological and physiological needs for lighting in addition to saving energy.

2005 Code Change Review and Remaining Issues

This section briefly describes the major revisions in the California Title 24 standards that take effect in 2005. It also describes which measures were dropped due to industry opposition or lack of reliable information. This helped identify holes in current knowledge that have to be addressed if some measures are going to be considered for inclusion in the standards. Detailed information on these measures is referenced in Appendix B.

Nonresidential Lighting

Lighting related changes to the nonresidential sections of Title 24 account for a significant share of the total energy savings estimated from the adoption of the 2005 Title 24 nonresidential requirements. Some of the more significant changes involved revising the allowable Lighting Power Densities (LPDs) in both the whole building and area category methods. Changes were also made to the LPD allocations in the tailored lighting method. The 2005 Standards also promote the use of daylighting and daylighting controls in large commercial spaces such as warehouses and retail by introducing requirements for skylights and photocontrols. The Standards also encourage bi-level or multi-level lighting controls and provide credits for automated bi-level controls in various space types. Load shedding is encouraged in the standards through credits for manual dimming with load control. Perhaps the most strategic change is the addition of unconditioned spaces such as parking lots and other outdoor lighting applications to the list of spaces governed by Title 24.

Outstanding Issues with Adopted Nonresidential Measures

While some of the measures recommended for the code change were accepted by all the stakeholders without any significant concerns, a number of measures proved controversial and there were difficulties crafting code provisions that were supportable and enforceable. The issue of appropriate LPDs for space types such as classrooms or retail, and the regulation of certain lighting system types such as task lighting, proved controversial and difficult to resolve.

Of particular interest were the changes made to the tailored lighting method, especially involving the appropriateness of, or need for, the LPD provisions for high end retail applications. The issue of verifiable energy savings from various lighting controls such as occupancy sensors and photocontrols was also brought up during the code change deliberations. One of the code change proposals suggested the elimination of any lighting control credits and making controls mandatory as is done in the ASHRAE 90.1-2001 and the IECC (International Energy Conservation Code) energy codes. Another proposal suggested granting a power adjustment factor for dimming ballasts in order to encourage their adoption in the market, independent of their energy savings.

Dropped Nonresidential Measures

A number of the code change proposals were dropped due to either lack of sufficient information, a poor cost-benefit ratio, un-verifiable savings, or lack of enforceability. Some of these measures included –

- Redefine daylight zone for sidelighting
- Eliminate lighting control credits
- Provide power adjustment factors (PAF) for bi-level controls in stairwells
- Separate code section for lighting in multifamily buildings

Some of these measures may warrant a revisit in the next round of standards development.

Residential Lighting

Perhaps the most significant change in the 2005 residential standards is the requirement for high efficacy hardwired lighting in residential kitchens, and the requirement for either high efficacy hardwired lighting or lighting control devices such as dimmers and occupancy sensors to reduce lighting power consumption in other rooms.

Residential outdoor lighting is required either to use high efficacy luminaires or to be controlled by a motion sensor with integral photosensor.

Outstanding Issues with Adopted Residential Measures

In developing the standards for high efficiency residential lighting, two options were considered:

1) High efficiency fixtures had to contain high efficacy lamps and this could include screw-in CFLs or
2) High efficacy fixtures had to have a hard wired ballast and a pin-based CFL.

Proponents of screw-in CFLs made note of the popularity of screw-in CFLs, their low cost and flexibility (one can increase light levels by screwing in a different wattage CFL). Proponents of pin-based CFL's declared that screw-in CFL's were not persistent and that once the screw-in CFL burnt out it would be replaced with an incandescent lamp. Both sides agreed that on looking at energy savings and costs of equipment that both technologies were very cost-effective when compared to an incandescent base case. Even though there was little data to make a decision on the persistence of screw-in CFLs, it intuitively made sense to most of the stakeholders that pin-based CFLs would be more persistent and thus they were required.

To give greater flexibility when CFLs are not desired or feasible, dimmers or occupancy sensors were deemed to be a reasonable energy trade-off for high efficacy sources. Concerns were raised whether lighting controls will result in actual verifiable and persistent savings with some arguing these controls be not promoted, and others arguing for making the controls mandatory in certain applications. There is little data to indicate the magnitude of savings from dimmers and occupancy sensors in residential spaces. In the final judgment, it was decided that the savings were likely to be real enough to justify use of the controls, but the need for better data remains.

In order to encourage builders to implement the high-efficacy lighting requirements in the 2005 Title 24 standards, the California Energy Commission (CEC) has provided early compliance credits for those builders who install the 2005 lighting requirements before the requirements actually go into effect in October 2005. The credit allows a builder to do a trade-off between increased efficiency of the lighting measures and reduced efficiency of other building measures. It remains to be seen how this early compliance credit is used and the effect of this trade-off on the other measures.

Dropped Residential Measures

A number of the code change proposals were dropped due to either lack of sufficient information, a poor cost-benefit ratio, un-verifiable savings, or lack of enforceability. Some of these measures included –

- Mandate use of occupancy sensors in some residential spaces
- Develop prescriptive lighting power densities for residential spaces
- Develop an energy budget for lighting in residential spaces similar to those for commercial spaces (LPDs)
- Require electronic ballasts in all residential fixtures (currently required for fixtures >13 Watts)
- Regulate landscape lighting efficacy and controls

A number of these ideas may warrant a revisit in the next round of standards development.

Outdoor Lighting

One of the biggest changes introduced in the 2005 standards is a significant expansion of efficiency requirements outdoor lighting. These changes apply to both residential and commercial spaces.

The 2005 standards will for the first time create "lighting zones" in the state that will govern the maximum allowable LPDs for various nonresidential outdoor lighting applications such as façade lighting, service stations, outdoor sales lots and outdoor dining among others (§147). This set of requirements recognizes that different light levels are appropriate for different tasks and upon different contexts or surroundings. Thus a fairly high lighting power density is allowed for facades in high population density environments and no façade lighting is allowed at all in the middle of a state park.

This first generation of outdoor lighting standards represent a first step in trying to balance social needs for outdoor lighting with increasing concerns about the growing energy use and environmental impacts of nighttime lighting.

Outstanding Issues with Adopted Outdoor Lighting Measures

The above mentioned comprehensive outdoor lighting requirements are a new addition to Title 24 in 2005, and as with many new changes, there was significant debate on the intent, nature and enforceability of the proposed measures among the various stakeholders in the code change process. One of the main arguments was over the definition of the "lighting zones," and whether local jurisdictions could adequately enforce the lighting zone regulations. The issue of appropriate baseline for the lighting zones and allowable LPDs generated debate, as some in the industry viewed the requirements as being too stringent, while others in the environmental field viewed the requirements as too lax. There is concern among some environmental and energy efficiency proponents that in the short run, the outdoor lighting standards may be allowing generous lighting levels in most lighting zones due to their use of IES recommended LPDs. These are viewed to be higher than current lighting practice in some applications and lighting zones.

One of the other significant issues is how the residential and non-residential requirements for outdoor lighting relate to each other. Currently landscape lighting for residential and signage lighting for nonresidential applications are exempt from the lighting requirements.

Dropped Outdoor Lighting Measures

A number of outdoor lighting applications were dropped from consideration due to either lack of sufficient information about their current status, the complexity of design issues involved, or lack of time to consider them,. Some of these application types included –

- Power limits on signs
    - Internally and externally illuminated and un-filtered
    - Animated
- Landscape lighting
- Sports lighting
- Industrial lighting
- Street and highway lighting

A number of these application types may warrant a revisit in the next round of standards development.

2008 Standards Prognosis

HMG conducted and attended various meetings with the California Energy Commission, utility representatives and researchers to understand their perspectives on what code changes could be proposed for the next round of Title 24 changes in 2008. These meetings were extremely useful for the participants to understand each others perspectives, and to develop a matrix of proposed measures that may enjoy broad support. A brief summary of these meetings follows:

California Energy Commission Staff Perspective

HMG conducted meetings with the CEC and PIER representatives to discuss the Energy Commission's priorities for 2008 Title 24 standards. The first meeting was very useful, and the participants expressed a desire to continue discussions, and hence a second face-to-face meeting was conducted. At these meetings, HMG presented the key findings of the PIER LRP projects, and discussed the code potential for the products which are closest to code-ready. However, most of the focus and time was spent on understanding the Energy Commission's needs for future rounds of Title 24 changes.

The CEC staff is interested in researching the impacts of the 2005 standards before tackling the next round of 2008 changes. The 2005 standards have made some significant advancement to the lighting requirements for both residential and commercial buildings, and staff feels it would be prudent to seek feedback on market reaction to this round of changes before undertaking more changes.

Overall the CEC staff felt that the LPDs set out in Title 24 2005 are close to the technology threshold, and barring any significant improvements in lighting technologies (specifically lamps and ballasts), there is not likely to be a significant opportunity to reduce LPDs further.

Lighting controls, on the other hand, are viewed as the likely next frontier in the development of Title 24 codes. It is understood that significant energy savings can be achieved with a variety of control types.

Programmable controls are a whole new area where the standards probably are not keeping up with the state-of-the art in controls technology or applications. Future standards will need to acknowledge smarter control functions; however, regulating their use will need some creative solutions. For example multi-scene controls could be regulated by the code, but it would need new thinking and language to ensure that the reprogrammable features do not defeat the code-intended control strategies, since these controls are basically software and not hardware (like traditional switches). For example, it would be fairly easy to reprogram the control device in a residence so that it controls both the high-efficacy and non-high-efficacy circuits, while Title 24 currently requires these two circuits to be controlled separately by two switches.

The CEC staff anticipates continued problems with electricity reliability in the state of California, and expects demand responsive technologies to play a bigger role in the near future. The CEC/PIER program has therefore taken the lead in the creation of the Demand Response Research Center. The Center will coordinate development of demand responsive technologies.

California Utility Staff Perspective

A meeting was held at PG&E's offices on May 13th where representatives from all the major California utilities, the CEC and several energy efficiency consultants met to discuss potential measures for the 2008 round of Title 24 code changes.

The meeting was relatively informal, consisting of presentations on proposed additions to the 2008 standards by representatives of the PIER program, CEC codes and standards staff and consultants for the PG&E and SCE codes and standards programs. As part of this presentation, the consultants were asked to present what they consider to be the top 3 to 5 important potential measures and to rank their attributes. Figure 7 shows the lighting related measures and the rating by the consultant proposing the measure along the following attributes:

- Economic feasibility (a best guess of benefit/cost ratio, demand reduction potential)
- Technical feasibility (reliability, performance with respect to intended use)
- Industry and market readiness (availability, infrastructure required to support intended use)
- Code enforceability (capability of building officials, acceptance testing requirements, third-party inspection requirements, inspector capability and experience with technology, time needs for field inspection)
- CASE study development effort (market research, economic analysis, model development, availability of market data)

Proposer	Code Enhancement Topic	Economic Feasibilty	Technical Feasibility	Industry and Market Readiness	Code Enforce-ability	Develop-ment Effort	Total Score
HMG, CEC C&S	Update Outdoor Lighting	6	7	3	5	5	*26*
AEC, CEC C&S	Update Outdoor Lighting	6	6	6	6	4	*28*
CEC C&S	Top Lighting - Smaller Buildings / Lower Ceilings						*n/a*
HMG	Tailored Lighting Revisions	6	5	4	7	5	*27*
CEC C&S	Acceptance Requirements / Third Party						*n/a*
HMG	Updates to Treatment of Sidelighting	7	6	6	5	5	*29*
Gabel	Premium T8 Technology as Basis for New LPDs	7	7	5	5	7	*31*
Gabel	Lighting Controls, Nonres Performance Approach	5	5	7	7	5	*29*

Figure 7 – May 13th Workshop – Proposing consultant evaluation of potential 2008 T-24 lighting measures

The ratings were on a scale of 1 to 7 where, 7 reflects the most return in energy savings and the least amount of effort and disruption to the existing market. Measures that were proposed only by the CEC did not have such attribute ratings. Since the consultants were asked to present on what they considered good ideas, the attributes are fairly high in most categories. Though, this rating is very subjective, the low ratings for industry and market readiness indicate some stakeholder opposition to outdoor lighting requirements and eliminating or further scaling back of the tailored lighting provisions.

Code Enhancement Topic	Workshop Participant Votes	Short Description / Comments
Update Outdoor Lighting	11	Revisit and update the requirements for outdoor signs and lighting, organized industry opposition
Top Lighting - Smaller Buildings / Lower Ceilings	7	Expand scope (building area, ceiling heights) where skylights are required.
Tailored Lighting Revisions	7	Would simplify lighting enforcement, but would impact lighting design
Acceptance Requirements / Third Party	5	study implementation--will these need to change?
Updates to Treatment of Sidelighting	5	Large research effort, potentially high reward
Premium T8 Technology as Basis for New LPDs	2	Develop cost-effectiveness data on highest efficiency T8 lamp & ballast technology
Lighting Controls, Nonres Performance Approach		Develop hourly control credits for the performance approach based on best available monitoring data

Figure 8 – May 13th workshop - Participant ranking and description of proposed 2008 T-24 lighting measures

Figure 8 shows the ranking of the measures at the May 13th workshop. It should be noted that this "beauty contest" approach to ranking the measures does not reflect a rigorous analysis of the cost/benefit of measures or the likely statewide energy impact of the measures. However, it does reflect the educated opinions of energy experts in California and the following key results came out of the meeting:

- Outdoor lighting is a new area of code regulation and a significant amount of additional savings are likely from refining outdoor lighting codes.
- Treating daylighting as a required energy measure is also a new area of regulation and will likely yield more savings as the requirements are fine-tuned. An interesting outcome of the voting was that CEC staff were more interested in expanding the scope of the 2005 Title 24 toplighting requirements whereas utility staff were more interested in developing requirements for sidelighting.
- Residential lighting measures were not on the list of high priority measures. This is likely due to the perception that the 2005 standards were very aggressive in terms of residential lighting and it might be best to evaluate how this affects building practice before embarking on further residential lighting requirements.

Research Needed to Improve California Title 24 Lighting Standards

This section lists the specific research topics that can support the development of the 2008 and 2011 building energy efficiency standards. Detailed descriptions of the nature of research needed, and potential research approaches is referenced in Appendix B of this report.

The topics of this research can be characterized in the following categories–

- Better understanding of how people design and use lighting (design and usage baselines)
- Better characterization of pre-existing technologies (LED's, skylight louvers, digital lighting controls, fluorescent lamp cathodes, etc.)

Residential Research Needs

Residential Hardwired Lighting

The 2005 standards have made a significant change to the residential hardwired lighting requirements as discussed earlier in this report. While the expected energy efficiency impacts of the these changes were carefully estimated, the issues of customer acceptance and market availability need further research to understand the impact of the 2005 Title 24 changes on the market in the coming years. In addition, we need better and more up-to-date data on lighting usage patterns to fully quantify the benefits of the standards changes.

- Code question – What is the magnitude and variability in residential lighting energy use in California?
- Code question – Is there adequate market availability and consumer acceptance of pin-based lamps/ballasts in California?
- Code question – How can the quality and reliability of pin-based CFLs being sold in the California market be assured?

- Code question – What is the persistence of screw-based and pin-based CFLs in residential lighting applications?
- Code question – Does the spectral content of CFL's and fluorescent fixtures disrupt circadian health?

Effectiveness of Existing Residential Lighting Controls

The 2005 Title 24 standards support a number of residential lighting controls, including occupancy control, time switches and photocontrols through code compliance requirements. Before regulation can be expanded to more spaces and control types, there needs to be good data on the effectiveness of current controls products in the residential market to ensure that the controls measures are actually achieving the intended energy savings.

- Code question - Do the automatic lighting controls currently promoted by Title 24 perform adequately per code intent?
- Code question – Do manual dimmers on incandescent lighting reduce energy use to levels comparable to high efficacy lighting controlled by traditional switches?

Understanding Consumer and Builder Preferences for Residential Lighting

The residential lighting market is different from the commercial lighting market in that the cost effectiveness and efficiency of lighting may not be the over-riding concerns when the builders or home owners install lighting systems. While encouraging energy efficiency is the goal of the Title 24 standards, it is equally critical to understand the choices, preferences and therefore trends in residential lighting from the perspective of builders and home owners. Understanding their preferences will ensure that high-efficiency lighting products are tailored to their preferences, and therefore have a better chance of achieving market success.

- Code question – What are the current trends in choice of residential lighting by builders and home owners?

Performance of CFL Lamp-Ballast Systems

There are a number of different ways in which electronic ballasts can start CFL lamps; these range from simple instant-start procedures up to more complex programmed-start procedures. There are at least five common descriptions for different lamp starting procedures, and the details vary from one manufacturer to another.

Programmed-start ballasts can significantly extend lamp life in applications where the lamp is switched on for brief periods, as is the case with residential lighting, but some programmed-start ballasts consume more power when switched on than instant-start ballasts do. It might be possible to work with manufacturers to develop a simple specification for a ballast to ensure both high efficiency and long lamp life.

- Code question – What is the consumer preference for lamp starting procedure?
- Code question - What are the energy savings and lamp life implications of various lamp starting procedures?
- Code question – Is there a need for a standard lamp starting procedure? What are the key characteristics of such a procedure?

Programmable Controls

Lighting controls are probably the next frontier for residential lighting standards. The lighting controls industry is rapidly evolving, with more flexible controls offering 'scene' controls in a residence becoming more cost effective for high-end residential sectors. Currently, these controls are not cost-effective for mass consumption; however their availability is increasing and they may replace traditional light switches in at least a portion of the high-end residential market. It is critical to understand how such programmable controls might affect residential lighting energy consumption.

- Code question – What is the energy efficiency potential of programmable lighting controls available currently for the residential market?

Lighting Power Densities for Residential Spaces

The California Energy Commission currently regulates residential hardwired lighting by requiring high-efficacy lighting in certain residential spaces. This approach of allowing only high-efficacy fixtures does not limit the number or wattage of such high-efficacy light fixtures.

An alternative approach would be instead to regulate the total wattage of fixtures installed in the residences, as some anecdotal evidence suggests that lighting use is on the increase as size of residences has increased over the past few years. The rationale for this code change would be to ensure that installed wattages of residential lighting do not exceed reasonable bounds.

On the flip side, developing lighting power density allowances for residential spaces will also enable tradeoff of the lighting measures against other building envelope and HVAC measures. This could potentially have an impact of people using less hardwired lighting in the building and trading off the energy surplus in lighting with lower performance HVAC unit or window glass.

- Code question – Is an LPD requirement appropriate for the residential energy code?
- Code question – If LPD's are appropriate for the residential energy code, what are appropriate LPDs for residential spaces? What are the appropriate operational schedules?
- Code question - Can lighting energy be a tradeoff option in the performance method for residential building compliance with Title 24?

Daylighting of Residential Buildings

- Code question – can daylighting of key spaces in residential buildings cost-effectively reduce energy consumption and peak demand?

Nonresidential Standards

This section summarizes the research topics for nonresidential lighting codes and standards development.

Code Enforcement

Before one can begin to decide what new components to add to the standards, it is useful to start with the question how well are the current codes working?

- Code question – Are California lighting energy codes well understood, and well enforced?

- Code question – Could California energy codes be simplified? Would this increase compliance?

Lighting Controls

Lighting control technology has been evolving at a relatively fast pace. This has created new opportunities for energy efficiency in nonresidential buildings. Energy standards that stay abreast of these technology changes are able to capture additional energy savings that were not possible only a few years ago.

- Code question - Do lighting controls save energy as expected in commercial buildings?
- Code question – Do some lighting controls save energy so consistently and have little drawbacks that they should be mandatory?
- Code question – How can we improve energy savings and demand impacts from lighting controls through future Title 24 standards enhancements?

Toplighting (Daylighting) Requirements

The 2005 Title 24 standards introduced a mandatory requirement that multi-level photocontrols or multi-level astronomical time switches be used to control electric lighting whenever the daylit zone under skylights in a room exceeded 2,500 sf. The option for the astronomical time switch (time clock) was added because most electrical designers and contractors are more familiar with time clocks than photocontrols. It was felt that adding this flexibility would help ease the transition in 2005 for automatic daylighting controls. However, it is thought that astronomical time clocks will not save as much energy as a photocontrol. In the 2005 standards a Power Adjustment Factor is available for photocontrols under skylights to help encourage their use. This PAF is based on the additional savings yielded from a photocontrol as compared to an astronomical time clock control.

If it is found that by the time of the 2008 standards adoption, that photocontrols under skylights are well accepted, understood and providing reliable energy savings and that indeed the astronomical time switch is saving substantially less energy, it would be a natural progression of the standard to eliminate the astronomical time switch option and remove the power adjustment factor credit for photocontrols. Photocontrols would be a mandatory requirement without an exception when the daylit area under skylights exceeds 2,500 sf.

- Code question – Are photocontrols sufficiently accepted in the market and do they save sufficiently more energy than astronomical time clocks that the astronomical time clock alternative to photocontrols are no longer needed for daylight harvesting under skylights?
- Code question – Should the skylighting requirements be extended to smaller buildings?
- Code question – Should the skylighting requirements be extended to buildings with lower ceilings?
- Code question – Should louver controls be added to skylights to gain additional energy savings?

Sidelighting Requirements

Daylighting controls have been in use in a few sidelit buildings (predominantly offices and classrooms) around the state, and there are a number of manufacturers who are developing newer models of photocontrols for sidelit buildings. These controls are purported to save significant amounts of lighting energy in daylit spaces. However, some anecdotes would indicate that the maintained savings is actually low due to these systems being disabled or malfunctioning. Since approximately 36% of commercial floor space is within 15' of the building perimeter (the traditional definition of the daylit area is within 15' of a window) the energy savings opportunity is quite high if we can be assured the savings from daylighting controls are real and can be maintained over time.

A study soon to be commissioned by the California utilities plans to collect data on the effectiveness of daylighting and photocontrols in sidelit buildings through field surveys and monitoring. Data from this study would provide the ability to work on future standards provisions for photocontrols in sidelit buildings.

- Code question – Should the daylighting controls requirements be extended to sidelit buildings?

Lighting Controls as a Load Shedding and Demand Savings Approach

The CEC staff anticipates continued problems with electricity reliability in the state of California. Demand response is already a big issue, and demand responsive technologies are increasingly available. The CEC/PIER program has therefore taken the lead in the creation of the Demand Response Research Center, which will coordinate development of demand responsive technologies. Lighting controls figure to be an increasingly important demand response technology that will be promoted in the months to come. Some researchers and policy makers feel there is a need for the codes and standards to mandate the use of certain demand responsive lighting technologies.

- Code question – How can Title 24 encourage greater use of load shedding lighting technologies?
- Code question – How can daylighting and building design help load shedding and demand control in commercial buildings?

Dimmable Electronic Ballasts

A number of proposed energy efficiency measures, such as daylighting controls, load shedding or multi-scene controls as well as simple lighting reduction from manual dimming, are dependent on the availability and cost effectiveness of dimmable electronic ballasts for fluorescent lighting. The 2005 Title 24 standards encourage the use of dimmable electronic ballasts through a voluntary power adjustment factor for the use of electronic dimming ballasts in conjunction with load shedding. A study conducted for the PIER LRP program, however, demonstrated that dimmable electronic ballasts are 2-3 times as expensive as regular electronic ballasts. Technology differences alone do not account for the price difference.

- Code question – Should dimmable electronic ballasts be promoted further through standards? How?

Programmable Lighting controls

Lighting controls for commercial applications are rapidly evolving, with more flexible controls offering 'scene' controls becoming cost effective for high-end applications. Currently, these controls are not cost-effective for mass consumption; however they are used by a portion of the market, and may replace traditional lighting control functions such as bi-level control and interface with occupancy sensing. It is critical to understand how such programmable controls might affect commercial lighting energy consumption and the related effectiveness of Title 24's lighting control requirements.

- Code question – What are the capabilities of programmable lighting controls available currently for the commercial market?

Lighting Power Densities for Commercial Buildings

ASHRAE recently updated the 90.1-2001 standards through the issuance of an addendum. This addendum includes updates to the lighting power densities in the space-by-space method and building area method. These updates were done in order to make the ASHRAE standards comply with the recommendations in the 9th edition of the IESNA handbook. Part of the reason for changes in the LPD values was the change in the lighting technology efficiencies and light loss factors. The lamp efficacy for each of the 35 generic luminaire/fixture types and the associated lamp lumen depreciation factors were reevaluated based upon current, commonly available technologies. A recent study (Luminaire Dirt Depreciation Study, July 2000, NALMCO No. CX824574-01-0) was used to update these values for most fluorescent luminaire types. The luminaire dirt depreciation value for all remaining types was reviewed against the latest IESNA Lighting Handbook.

The CEC is investigating if the new ASHRAE LPD allowances are lower than the 2005 CA Title 24 LPD allowances. If this is the case, the CEC would be interested in investigating the reasons for the lower LPD specifications, with the aim of possibly modifying the T24 LPD values.

- Code question – What are the differences between ASHRAE 90.1, the 2005 Title 24 LPD allowances, and actual practice?

Revisit Tailored Method of Compliance

The purpose of the tailored lighting method of compliance is to provide flexibility for applications that have unusual lighting requirements, and for which it is felt that the standard lighting power densities are too stringent. On one hand it is seen as the "pressure relief valve," to mute opposition to the relative stringent lighting power densities in the whole building method or area category method of calculating allowable lighting power. On the other hand, the tailored lighting method is complex enough and relies on the lighting designers "judgment" so that it is essentially a carte blanche to install high wattage lighting systems. Thus the concern is that the method is a loophole primarily used by retailers to increase the lighting in their store without really rethinking how much light they need. This in turn leads to "light wars" between retailers as people have a phototropic tendency and are attracted to light.

- Code question – What are the visibility requirements of retail lighting aside from historical design techniques and competition with historical light levels?

Stairwell Lighting Standards

Stairwell lighting typically does not garner much attention in the codes and standards development process. Stairwells are governed by the building and fire codes than the energy codes due to their safety and path of egress concerns.

However, due to the recent horrific attacks on the World Trade Center in New York and a disastrous fire in a nightclub in Rhode Island, public attention has again been focused on the importance of stairwells that are typically out of sight and out of mind.

There are three key factors to the safe use of stairs: visibility, geometry of steps, and handrails. However, only visibility has an ongoing cost impact because building and fire codes demand that paths of egress for most commercial and large, multi-story residential buildings must be lighted 24 hours every day—whether used or not.

To date, energy costs for lighting have been modest because codes have required that exit stairs be lighted to only one foot-candle (1fc or 10.8 lux). Code bodies have been reassessing this requirement and several have already accepted proposals that require lighting for exit stairs be increased to 10fc (108 lux) during occupancy. To mitigate the large jump in energy costs that would accompany such a requirement, these codes are also allowing the use of new lighting control technology that will reduce stairwell light levels back to 1fc (10.8 lux) during unoccupied periods.

The focus on lighting levels is perplexing because two issues that came out of 9/11 survivor reports was that some areas of the building were plunged into darkness – indicating that emergency lighting circuits did not work and that exit doors were chained shut – against the requirements of existing building codes. Increased light levels in stairways require more lighting power which could perhaps be more likely to discharge batteries prematurely and create a more serious problem of no light at all.

It is understandable that building codes should react to measures that can reduce the number of injuries from a terrorist attack or other emergency. However these measures need to be based upon objective technical data.

Given all this background on developing national codes on illumination and controls requirements for lighting in stairwells due to safety concerns in the post-9/11 world, the question of energy impacts of such decisions need to be studied in the California context.

- Code question – what is the illumination level and uniformity needed in stairways to quickly and safely evacuate a building? Is this illumination level based on other aspects of the stairway geometry, reflectance etc?
- Code question – what are the energy impacts of the ANSI/NFPA decision to require 10fc illumination in stairwells when occupied, for the State of California?

Light Emitting Diode Fixtures

A number of industry groups, research institutes and other agencies are actively promoting the development of more efficient and efficacious LED fixtures. Currently, LEDs do not meet the high-efficacy source requirements of the Title 24 standards, and may not meet those requirements for the next few years. Some in the industry have claimed that the current performance metric (lumens/watt) is unfair when it comes to LEDs. The luminous flux metric does not differentiate in terms of distribution of light but rather sums up the luminous flux emitted by a source and divides by the input Watts, LED's are highly directional and it is argued that LEDs can be more efficient when you take their directionality into account.

LEDs have a very narrow beam spread, and can deliver more lumens/watt in that narrow area than other diffused sources like CFLs. Also it is possible to make very low wattage (and low light output) LED products that might replace higher efficiency but significantly higher light output products so that the LED uses less power. In some cases, the monochromatic nature of LED light is also a benefit. When colored light is desired, the LED's system efficiency can be higher than light from an efficient white source that is then filtered. Indeed LEDs may offer efficiency advantages over other sources in certain applications. These three effects are what when combined render LED's valuable for exit signs. Exit signs with less than 5 Watt per face of maximum lamp input power (such as LED exit signs) are exempt from the calculation of lighting power in the 2005 version of Title 24 (§146(a)5).

- Code question – Do LEDs merit consideration for acceptance by the Title 24 standards?

Acceptance Testing Requirements

The 2005 Title 24 standards include acceptance testing requirements for various controls including lighting controls such as occupancy sensors and photosensors. The aim of these requirements is to ensure that all sensors installed in Title 24 compliant buildings meet minimum standard operational specifications, and provide reliable and repeatable savings. Pilot studies are currently being conducted to verify the accuracy and applicability of these acceptance testing requirements for HVAC and lighting controls.

- Code question – How effective are the acceptance testing requirements for lighting controls?

Outdoor Lighting

This section summarizes the research requirements for outdoor lighting codes and standards development.

Update (or Refine) Outdoor Lighting Regulations

The 2005 standards include sweeping new provisions for outdoor lighting, including definitions of applications, LPD limits for many applications, efficiency requirements for some lighting sources, control requirements for some sources, and definition of California Lighting Zones that determine applicable standards. It is unknown how these standards will be received and implemented by designers, building owners, and code enforcement officials. Furthermore, given some of the uncertainties and controversies surrounding the development of the 2005 standards it would be prudent to answer some of these questions before considering any changes in the 2008 code cycle.

- Code question – Is the current baseline for outdoor lighting installed LPDs adequate for future legislation?
- Code question - Are we allowing more lighting energy usage than standard practice as result of the 2005 Title 24 outdoor lighting requirements?
- Code question - What is an acceptable baseline for outdoor lighting energy usage?
- Code question - Will the provisions for bi-level controls in outdoor lighting applications have positive energy and economic impacts?
- Code question –Are the California Lighting Zones sufficiently well defined, communicated and implemented?

Outdoor Signage Lighting

The 2005 standards attempted a first-ever regulation of energy use by outdoor illuminated signs. The initially proposed provisions were controversial and eventually revised to simpler and less aggressive levels in order to accommodate objections, primarily by members of the outdoor sign industry.

- Code question – Is the regulation of illuminated signs feasible and enforceable?
- Code question –Can we establish a more uniform, technology neutral method for appropriately regulating the energy use of illuminated signs?
- Code question –Can we define an appropriate metric for regulating the energy use of LED signs?

Existing Buildings

Currently, the Title 24 requirements for lighting LPDs and controls apply to retrofits in existing buildings when more than half of the lighting fixtures are replaced during the retrofit. However, these requirements are fairly hard to enforce especially in residential buildings. For commercial buildings, tenant improvements may trigger a code compliance requirement if the envelope is being altered, or large scale lighting retrofits are being conducted.

Title 20 appliance efficiency standards also govern some aspects of the lighting retrofit market by regulating the energy efficiency of various components such as ballasts, lamps manufactured and sold in the state of California. There are constraints on the Title 20 regulations due to federal preemption that stipulates same efficiency levels for all the states, and disallows a state to have higher standards than the federal standard. This constraint is only valid for 4 foot (including 2 foot U-tubes) and 8 foot long fluorescent lamps and their ballasts. The remainder of lamps could be regulated by the state of California.

One area where the Title 20 standards could be improved in the specification of lamp/ballast combination efficiency of pin-based CFLs sold in the state. This is especially true of multi-lamp ballasts and multi-wattage ballasts.

- Code question – Is there a need for efficiency regulation of CFL lamp/ballast combinations? Is there a need for better labeling of CFL lamps and ballasts?

Multifamily Buildings

In the 2005 Title 24 code revision process some discussion revolved around the perceived need for a new code section dedicated to lighting in multifamily buildings. The basic context was that the proposed energy efficiency of lighting measures in a multifamily building should be based on schedules and lighting power densities consistent with an average multifamily building lighting energy consumption. Currently (and in the 2005 Title 24 standards) the residential code applies to multifamily buildings up to three stories tall while the nonresidential code applies to buildings of 4 stories or more—i.e., high rise residential. Furthermore, the common areas of multifamily buildings are treated like nonresidential while the dwelling spaces are treated as residential in most cases. The separation of one building type into different code bases is the source of considerable confusion and some unintentional energy efficiency loopholes. For example, corridors and other common areas in multifamily buildings can be considered residential if they are less than 10% of the total building area, while they are considered non-residential if they are above 10% of the total building area. Lighting efficiency requirements for the common spaces can therefore differ significantly from building to building.

A new code section dedicated to lighting in multifamily buildings would allow the standards to specifically address the lighting needs of this building type which by many estimates will be a rapidly increasing percentage of new residential construction in the coming years as land values increase and need for senior and low income housing increases.

- Code question – Is there a need for separate lighting requirements for multifamily buildings?

Fundamental Lighting Research Needs

So far we have discussed the immediate and near-term needs for lighting research based upon the codes and standards development process. While this research is extremely valuable, it is evolutionary research that builds upon existing knowledge of technologies (both established and developing), human response and societal needs. There are however research topics that require a more basic exploration of the fundamental principles underlining our current understanding of lighting. Scientists from diverse fields such as ophthalmology, biology, chemical engineering and electrical engineering are currently working on furthering our understanding of human vision, its response to light and the related technological issues. While these issues may require long-term research, the results will have profound effects on human productivity, health and technological development in the future. This will no doubt influence future codes and standards which will balance the needs for energy savings with human health, societal needs and technological barriers. Below is a brief summary of such research topics:

Human Eye and Perception of Light

While most of the research today concentrates on technologies and human comfort, our understanding of the fundamental principles and processes that guide our visual perception is in a developmental stage. Research in this important area could potentially open new avenues for greater visual comfort and energy savings both.

Spectral Sensitivity of the Human Eye

While much is known about the human eye and its associated systems, much remains to be discovered and described. The limitations in our knowledge of these fundamentals limit, in turn, our ability to make well informed choices of lighting technologies and applications.

- Fundamental research question – What is the spectral sensitivity of the human eye? How can we quantify the human response to different parts of the spectrum of light in a way that is useful for lighting applications?
- Fundamental research question – Does the spectral content of CFL's and fluorescent fixtures disrupt circadian health?

Visibility Requirements for Safety and Security

In the interior of buildings, the issue of appropriate lighting for safety and egress has also been an area where opinions are divided. However, due to the recent horrific attacks on the World Trade Center in New York and a disastrous fire in a nightclub in Rhode Island, public attention has again been focused on the importance of stairwells that are typically out of sight and out of mind. A number of code-setting agencies such as ANSI, NFPA and others have either accepted revisions or are considering revisions to the minimum illumination requirements in stairwells. These recommendations for higher light levels will have an energy impact, but more importantly there is no scientific evidence that higher light levels will result in safer egress conditions. There is need for a scientific study that will inform the appropriate lighting strategies and minimum illumination levels in stairwells.

When the 2005 Title 24 outdoor lighting standards were developed the minimum outdoor lighting requirements were set partially to satisfy security and safety needs at night time. There has been a long held perception among some law enforcement agencies, citizens groups and businesses that the way to make facilities secure at night is to over light the building façade and areas around the buildings. On the other hand some lighting researchers argue that it is better to have lower illumination levels on motion controls in order to enhance security and safety. Currently there is no national standard on minimum illumination levels for safety and security.

- Fundamental research question – What is the minimal illumination requirement for egress in emergency situations in enclosed stairwells?

- Fundamental research question – Does constant, full-level illumination lead to greater security than bi-level, motion controlled illumination levels?

Nighttime Adaptation and Visibility

In order to set appropriate standards for outdoor lighting it is necessary to balance an understanding of the human need for visibility at night with any negative impacts of outdoor lighting.

Human Vision Outdoors at Night

Human beings can "see" under an enormous range of visual conditions, from starlight at less than .01 fc, to full sunlight at 10,000 fc. At the lowest levels of light the eye loses some visual acuity and the ability to perceive colors. There is much, however, that remains to be described about human eye function, its sensitivity over time, how glare works under nighttime lighting conditions, etc. At the same time, current night lighting practice shows a strong tendency toward higher levels of illumination, energy consumption, and light pollution. Addressing these problems requires filling in the knowledge gaps through more research.

- Fundamental research question - What level of illumination (or luminance) is needed for acceptable levels of functioning under nighttime conditions? How do these needs vary for different functions, such as wayfinding on foot, driving, signage, etc.
- Fundamental research question - How do outdoor night illumination needs vary across human populations (age, gender, etc.).
- Fundamental research question - What is the time dimension for human nighttime vision and adaptation? How does it vary with task and population?

Development of a New Predictive Methodology

There is growing interest in the lighting community to develop new digital image processing techniques that will allow illumination standards to be developed based on vision science rather than the consensus processes, based on the individual experience of professional society committee members, which has been largely used to date. While pieces of this scientific understanding exist in a variety of disparate disciplines, they have not yet been synthesized into a predictive tool. In order to reach this goal, there will need to be considerable development (and adoption) of new analysis tools and potentially also some more basic research into human visual response at low light levels.

- Fundamental research question – Can we develop a comprehensive predictive methodology for nighttime visibility?

CONCLUSIONS AND RECOMMENDATIONS

The PIER LRP was deliberately designed to be a short-term creative exercise to develop devices that could be applied immediately in the market place in order to ensure near-term energy savings. Implicit in this process was the assumption that the devices would fill some of the immediate needs for energy efficiency where no such product currently existed. A number of products, including the hotel nightlight occupancy sensor, kitchen downlight retrofit fixtures, bi-level stairwell fixture, and the integrated classroom lighting system, did complete the product development and initial testing phases and are now market ready. These products had an advantage in that they were based on other product ideas the project teams had earlier developed, and the technology was already mature enough to develop a market ready product.

However, a two year program is a relatively short time to take a product from conception to market readiness. There were a number of other projects, such as the LED products and the classroom photocell, where the product development did not result in a market ready product due to the nature of the technology. These projects have long-term energy savings potential, but will require further product and market development to realize these savings potentials.

Energy codes and standards can have a role to play in the mainstreaming of new technologies, but it will depend on the particular product, and on the structure of energy code requirements as they relate to the product. Most of the LRP products and devices did not have a strong linkage with specific energy code requirements, but this part of the LRP study was able to identify and strengthen those linkages. We were also able to identify further research opportunities that could have a stronger link to codes and standards.

Code Connections of the LRP Products

One of the criteria for product success in the LRP was defined in terms of the product's ability to influence future codes and standards. Each of the LRP products was geared towards energy savings above and beyond current best practices. In our analysis we found that the LRP products fell into the following categories:

1. improvements or adaptations of existing products
2. new technology development
3. new protocols

While these goals are perfectly in line with efficient technology development requirements, they are not based upon any specific need for codes and standards development. The codes and standards connections was a desired outcome, but was not the source of the technology development. Many of the projects sought the assistance of energy efficiency standards to promote products that did not have a good cost-benefit ratio, or where the energy savings were not assured. Other projects sought the tightening of standards requirements in order to make their products eligible for code compliance.

Due to the concurrent nature of the 2005 Title 24 standards process and the LRP product development process, products that were based on existing technologies or were adaptations of currently available efficient technology, such as the integrated classroom lighting system, fulfill the code requirements set in the 2005 Title 24, but do not offer significant savings over competing efficient technology to form the basis for future code changes.

Products that use innovative technologies such as LEDs do not meet the existing code requirements due to the lack of energy savings compared to competing efficient sources. While LEDs could possibly receive favorable treatment in the future standards in certain applications, such as 'standby' lighting for wayfinding, these technologies need to show comparable energy efficiency to current high efficiency products if they are to be used more extensively. Products such as task lighting are not governed by the energy efficiency standards since these are considered to be plug loads.

The codes and standards process has significant restrictions on which technologies can be mandated or promoted. For a measure or technology to be incorporated into the building efficiency standards, it must pass a number of tests. It should be noted that mandatory measures have the most stringent eligibility tests, while compliance options and allowances may have a less stringent threshold for inclusion in codes. Not only must the energy savings be well characterized and substantial, but each measure must be shown to be:

- cost-effective based on current installed costs
- commercially available from more than one manufacturer
- feasible and compatible with current building practice
- have no net negative environmental or health impacts

Thus, many of the code-readiness questions related to market acceptance, pricing, and feasibility render the newest, most innovative technologies unlikely candidates for inclusion into the building energy efficiency standards. In general, technologies that are considered for inclusion into energy codes already have a significant market position and a track record of reliable energy savings and known interactions with other building components.

As described in the companion report, "PIER Lighting Research Program: Prioritized R&D / Standards Connections," (Appendix A), "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." This report then goes on to rank the projects by their relative development and their near term total resource cost ranking for inclusion into voluntary energy efficiency programs. Since the projects were not developed or selected to answer energy code questions, but rather to develop innovative technologies, it is not surprising that there was minimal code connection.

While the report identifies few near-term code connections for the LRP products, this does not mean that the products are not applicable in the marketplace. A number of products are excellent applications for retrofit situations where the codes currently do not require high efficiency retrofits, and there are limited products in the market. The marketing efforts of these products have already being focused on such applications. Even without a specific code requirement encouraging them, these products should do well on the strength of their own ability to fill a need and provide savings.

Recommendations for Future Code-Related PIER Strategies

Following are a number of recommendations for the PIER program if they intend to fund additional product development programs.

Utility Program Linkages through Emerging Technologies

Most of the LRP products are dependent on receiving assistance from utility programs in order to successfully enter the marketplace. In order to enter utility energy efficiency programs, these technologies need to be independently verified by the utilities through case studies and onsite performance verification. While many of the LRP products conducted their own case studies, these are not the same as the ones sponsored by utilities. In the future, the utility emerging technologies programs could be better coordinated with the PIER product development phase. This includes both assessing the programs' technology needs, and coordinating case studies and field verification activities.

Long-term Verification of Savings

While the LRP products have undergone limited field verifications, these case studies do not guarantee long-term success and performance. If the products are to influence future codes and standards and to succeed in the market, there needs to be a sustained effort to evaluate energy savings and performance of the products in the field. This is especially true of the products that have long-term code change potential.

Product Development Based on Codes and Standards Needs

As mentioned earlier in this section, the LRP products were intended to influence codes and standards development, but the product development was based on technology readiness, not on proven codes and standards needs. As a result, the LRP products have limited potential to influence future standards, and a few do not meet existing codes requirements. While applying PIER funding to develop products based on their technical merits can be a worthwhile investment, PIER should also emphasize product development through based on proven codes and standards needs, in order to ensure maximum energy efficiency impact. A companion report on Codes and Standards Research Needs (Appendix B) provides a list of codes and standards research requirements that could spur additional product development.

Future PIER Lighting Research Recommendations

The PIER program supports energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace. Thus, technology and product development continues to be a feature of the PIER research program. However, such product development efforts should go beyond simply trying to pick "winning" technologies. A portion of the funding should be used to satisfy the greater needs for codes and standards improvements, and to improve our understanding of environmental and biological impacts of lighting technologies.

Greater Need for PIER Funding for Codes and Standards Enhancement

One strategy to ensure widespread market penetration of PIER products or findings is to have code adoption as an ultimate goal for a PIER project. If a product or finding resulting from PIER is adopted into the state energy codes, then the market effect will be fairly certain, since the codes would then require that the technology, process, or some strategy of equal efficiency to be implemented in all new buildings. Thus, identifying code adoption as an ultimate goal for a PIER program ensures that it will have a large and permanent market impact.

The purpose of the energy codes is to save energy, not create problems. Thus, the standards have to consider whether there are consumer or user acceptance problems, and reliability or other concerns with requirements for a given technology. Since long term savings is desired, there has to be some evaluation of the persistence of the savings.

Some of these questions cannot be answered in the short time period immediately preceding the code adoption hearings. Some of these research questions require medium term data collection periods. This type of applied research fits well with the PIER program's skill set of independent and technically competent third-party research. Outside of the codes and standards sections of the utility efficiency programs, the only other source of funding for this research is by manufacturers of affected technologies – not a recipe for objective analysis.

In general, the thrust of utility programs including codes and standards is for short term acquisition of "resources" to reduce peak demand. The longer term projects to support the fundamental basis of the standards (how well are standards enforced, how do people really design buildings, how do people really operate buildings etc,) need an "owner" like PIER. PIER can complement the technical support that is currently being provided by the codes and standards divisions of the investor owned utilities as part of their public goods programs. Indeed, PIER projects helped develop the knowledge base that was the basis of several changes to the 2005 building efficiency standards including skylighting, duct sealing, acceptance testing, and insulation position measures.

A companion report ("Codes and Standards Needs Assessments" – referenced in Appendix B in this report) presents code adoption driven research activities that have been identified through consultations with the California Energy Commission Staff, California Investor Owned Utility staff, and code consultants in the state of California.

The research recommendations fall into the following three categories –

- Identify how well the current codes and standards provisions are effective in ensuring energy efficiency
- Identify needs for enhancing the codes and standards provisions based upon :
    - Technology development
    - Electric grid stability through demand reduction
    - Minimizing energy wasteful design practices
- Collect baseline data on the existing market conditions, to serve as basis for future codes and standards

Fundamental Lighting Research Needs PIER Funding

While improving energy efficiency is a goal essential to protecting the energy infrastructure, it is equally critical to ensure that the technologies and strategies we promote reduce any unintentional environmental and biological impacts. One such example is the understanding of human vision and the impact of light on human health. Another is the understanding of the effects of electric lighting on the nighttime environment. There is a long list of lighting research topics that could have substantial impacts on our use of electric lighting.

The PIER program should give serious consideration to the creation of an emphasis on fundamental lighting research. This long-term research would balance the program's short-term emphasis on lighting technology development and on applications. By careful selection, PIER could focus on those fundamental lighting research questions that will help in the development of better technologies that save energy, improve human health and better protect the environment against unintentional damage.

PIER is the ideal vehicle for this important research, as these issues are very much in the 'public interest'. Research into the fundamental issues will also have a bearing on future codes and standards improvements. Furthermore, there is a wider research gap that this would address; no other state or federal agency is systematically addressing the fundamental questions of lighting. The PIER program has the resources and longevity to help address this gap.

APPENDIX A: Deliverable 6.3.5b Prioritized Codes and Standards Connections

This report is available for review and download from the following url.

www.archenergy.com/lrp/mkt_connection/deliverable_6.3.5_Prioritized_R&D_Standards-final.pdf.

APPENDIX B: Deliverables 6.3.3b/6b Codes and Standards and Fundamental Lighting Research Needs

This report is available for review and download from the following url.

www.archenergy.com/lrp/mkt_connection/deliverable_6.3.3-6.3.6_Lighting_Research_Needs_final.pdf