CALIFORNIA ENERGY COMMISSION

Project Brochures

Integrated Energy Systems: Productivity and Building Science brochures for each research element

October 2003
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Gray Davis, *Governor*

CALIFORNIA ENERGY COMMISSION

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PREFACE

The Public Interest Energy Research (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.

This document is one of 33 technical attachments to the final report of a larger research effort called *Integrated Energy Systems: Productivity and Building Science Program* (Program) as part of the PIER Program funded by the California Energy Commission (Commission) and managed by the New Buildings Institute.

As the program's name suggests, it is not individual building components, equipment, or materials that optimize energy efficiency. Instead, energy efficiency is improved through the integrated design, construction, and operation of building systems. The *Integrated Energy Systems: Productivity and Building Science Program* research addressed six areas:

- Productivity and Interior Environments (Element 2)
- Integrated Design of Large Commercial HVAC Systems (Element 3)
- Integrated Design of Small Commercial HVAC Systems (Element 4)
- Integrated Design of Commercial Building Ceiling Systems (Element 5)
- Integrated Design of Residential Ducting & Air Flow Systems (Element 6)
- Outdoor Lighting Baseline Assessment (Element 7)

The Program's final report (Commission publication #P500-03-082) and its attachments are intended to provide a complete record of the objectives, methods, findings and accomplishments of the *Integrated Energy Systems: Productivity and Building Science Program*. The final report and attachments are highly applicable to architects, designers, contractors, building owners and operators, manufacturers, researchers, and the energy efficiency community.

This attachment (#A-2) consists of six project brochures that provide supplemental information to the final report. The brochures promote the program's research results and products. The six brochures are listed below:

- "Four New Studies on Buildings and Interior Performance" (Element 2)
- "Optimizing the Design and Control of Large VAV Systems" (Element 3)
- "Building Science Solutions for Packaged Air Conditioners" (Element 4)
- "Effective Skylighting with T-Bar Ceilings" (Element 5)
- "Ducts in Homes: Location, Location, Location" (Element 6)
- "Shedding Light on How We Illuminate the Outdoors" (Element 7)

The Buildings Program Area within the Public Interest Energy Research (PIER) Program produced these documents as part of a multi-project programmatic contract (#400-99-413). The Buildings Program includes new and existing buildings in both the residential and the non-residential sectors. The program seeks to decrease building energy use through research that will develop or improve energy efficient technologies, strategies, tools, and building performance evaluation methods.

For other reports produced within this contract or to obtain more information on the PIER Program, please visit www.energy.ca.gov/pier/buildings or contact the Commission's Publications Unit at 916-654-5200. All reports, guidelines and attachments are also publicly available at www.newbuildings.org/pier.

ABSTRACT

The Project Brochures were produced as a part of the *Integrated Energy Systems: Productivity and Building Science* Program, funded by the California Energy Commission's Public Interest Energy Research (PIER) Program.

The *Integrated Energy Systems* program was comprised of six research projects that focused on integrated design topics to save energy, improve the indoor environment, and reduce operating and maintenance costs. At the conclusion of the program, a brief brochure was developed for each research project to readily communicate the findings and products to that project's key audiences.

The *Productivity and Interior Environments* brochure describes four studies that examine the impacts of daylighting and other indoor environmental factors on occupant performance and organizational productivity in schools, stores and offices. The *Integrated Design of Large Commercial HVAC Systems* brochure summarizes the problems and solutions to variable-air-volume HVAC system performance in large commercial buildings. The *Integrated Design of Small Commercial HVAC Systems* brochure summarizes common system performance problems and their solutions for small packaged rooftop HVAC systems. The *Integrated Design of Commercial Building Ceiling Systems* brochure summarizes information about the effectiveness of lay-in insulation over suspended ceilings, describes skylight performance testing conducted as part of the project, and provides an overview of an integrated ceiling-system design guideline. The *Residential Ducting and Air Flow Systems* brochure describes guidelines for building homes with ducts in conditioned space. Finally, the *California Outdoor Lighting Baseline Assessment* brochure provides an overview of the first comprehensive study of outdoor lighting practices in California.

Author: Cathy Higgins, New Buildings Institute

Keywords: productivity, energy efficiency, indoor environment, daylight, skylight, outdoor lighting, integrated design, HVAC, residential duct

Does Daylighting Improve Productivity?

Daylighting can reduce electric lighting use and utility bills. Another strong motivation for using daylighting in commercial buildings is increasing the productivity of activities occurring in the space, such as student learning, worker efficiency, or retail sales.

A landmark study completed in 1999 showed a positive correlation between daylighting and student performance on standardized tests. Similarly, a 1998 study demonstrated an increase in retail sales in daylit stores. These findings were significant, but the studies raised new questions.

This PIER research was undertaken to expand the prior results and address unresolved issues. These four studies shed new light on the link between productivity, daylighting and other indoor environmental conditions.

The Windows & Offices study correlated worker performance with indoor environmental conditions such as views from windows

Productivity & Interior Environments

This project consisted of four studies addressing productivity and interior environments in three market sectors—schools, retail stores, and offices.

Key results:

- The Daylighting in Schools Reanalysis study confirmed that **daylighting is a strong indicator of student performance**.
- The Windows & Classrooms study found that **students in classrooms with views from windows perform better** on math and reading tests.

Besides reducing utility bills, daylighting may increase retail sales

- The Daylighting & Retail Sales study found that a major retailer experienced up to **6% increase in sales in their daylit stores** compared to non-daylit stores.
- A study of office workers found that **daylight illumination levels were significant and positive in predicting better performance** on a test of mental function and attention. Ample and pleasant **views** were consistently associated with better performance, while **glare** from windows decreased performance.

Saving Energy and Improving Performance

These studies help establish a link between the built environment, the public benefits of reduced energy use, and the benefits of improved health and well-being.

Daylighting and automatic lighting controls can yield significant energy savings

If new buildings in California were designed with daylighting and lighting controls, the following statewide energy savings could be achieved (assuming a 10% market penetration the first year and an increase of 1% per year over the next 10 years):

- **Schools.** Ten-year cumulative electricity savings: 23,595 megawatt-hours (MWh). Savings: $3 million.
- **Retail.** Ten-year cumulative electricity savings: 562,467 MWh. Savings: $77 million.
- **Offices.** Ten-year cumulative electricity savings: 177,535 MWh. Savings: $24 million.
- **Total statewide benefits:** Ten-year cumulative electricity savings for these three sectors: 748,397 MWh. Savings: $103 million.

Interested?

The *Productivity & Interior Environments* reports offer valuable data and compelling insights into the effects of commercial building systems on individual performance and organizational productivity.

Who will benefit from these reports?

- Facility owners and managers concerned with offering tenants a high-quality workplace
- School facility administrators and teachers who want to improve learning environments
- Retailers wishing to understand the effects of daylight on sales
- Managers interested in the links between worker performance and indoor environments
- Policymakers and leaders in building standards and technologies
- Building-science and human-health researchers

Key next steps include:

- *Building owners, managers & designers:* Use daylighting with lighting controls in stores and classrooms. Design classrooms and offices with views from windows. Check with utility companies for efficiency program information.
- *Policymakers:* Promote building practices that save energy and enhance productivity and health.
- *Researchers:* Support the development of better indoor environmental monitoring and assessment tools.

This project was part of the *Integrated Energy Systems: Productivity & Building Science* program. To learn more, visit www.newbuildings.org/pier.

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Productivity & Interior Environments

Four New Studies on Buildings and Human Performance

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Large HVAC: A Systems Perspective

Large HVAC systems typically are not designed with a systems' perspective. Component selection is usually based on the features of individual components rather than on system-wide impacts. As a result, large HVAC systems use significantly more energy than necessary.

This project conducted an in-depth investigation of the problems causing sub-optimal performance.

Relief fan

The research focused on the air side of built-up VAV systems in commercial buildings larger than 100,000 square feet and quantified problems with component and system selection, building controls, and operation that cause energy inefficiencies.

This data was used to determine potential savings and develop a *Design Guide* for smarter, energy-efficient designs that can have a dramatic impact on large HVAC design.

Advanced VAV System Design Guide

The* Advanced VAV System Design Guide *promotes efficient, practical designs that can be implemented successfully today.

The *Design Guide* addresses the air side of variable-air-volume (VAV) systems with chilled water plants. Key research findings include:

- Reduce design system static pressure.
- Employ demand-based static pressure reset.
- Use low-pressure plenum returns/relief fans.
- Employ demand-based, supply temperature reset to reduce reheat energy and extend economizer effectiveness.
- Design fan systems to turn down and stage efficiently.

Air-flow monitoring station at fan inlet

- Size terminal units to balance energy impacts of pressure drop and minimum air flow control.
- Set terminal unit minimums as low as required for ventilation. Use intelligent VAV box control schemes to prevent stratification.
- Employ demand-based ventilation controls for high-density occupancies.
- Design conference rooms to provide ventilation without excessive fan energy or reheat.
- Design 24/7 loads to allow efficient system turn-down and use of economizer cooling.

Building and Statewide Energy Savings

The type of large HVAC system addressed by this research accounts for an estimated 20% to 25% of the state's cooling capacity. For buildings that follow the *Design Guide's* recommendations:

- HVAC electricity savings would be approximately 25%, equal to 12% of total building electricity consumption.
- Natural gas heating savings would be approximately 41%.

If the recommendations in the *Design Guide* were implemented in 10% of California office buildings with VAV reheat systems over each of the next 10 years, the following savings could be achieved:

- First-year statewide electricity savings: 2,220 MWh. Savings after 10 years: 22,200 MWh/yr.
- Cumulative electricity savings: 122,100 MWh ($16.7 million).
- Cumulative gas savings: 6,980,000 therms ($5.8 million).
- Total net savings over 10 years: $22.5 million.

Relief fan discharge

INTERESTED?

The *Advanced VAV System Design Guide* provides recommendations to help engineers improve the efficiency of large HVAC systems. It focuses on built-up variable-air-volume (VAV) systems in multi-story commercial office buildings in California or similar climates. But much of the information is useful for a wider range of system types, building types, and locations. For example:

- Selection guidelines for VAV terminal units apply equally well to systems using packaged VAV air handlers.
- Recommendations on zone cooling load calculations are relevant regardless of system type.

Key next steps include:

- *HVAC engineers:* Adopt the best practices recommended in the *Design Guide.*
- *Owners/managers of large commercial buildings:* Encourage HVAC engineers and mechanical systems staff and contractors to read and use the *Design Guide.* Check with utility companies for efficiency program information.
- *HVAC equipment manufacturers & building simulation developers:* Integrate the PIER results into HVAC design and modeling tools, and further develop the fan models created by the PIER researchers.

This project was part of the *Integrated Energy Systems: Productivity and Building Science* program. To learn more, visit www.newbuildings.org/pier.

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INTEGRATED DESIGN OF LARGE HVAC SYSTEMS

OPTIMIZING THE DESIGN AND CONTROL OF LARGE VAV SYSTEMS

New Buildings, Broken Systems

Single-package direct-expansion (DX) air conditioners are the workhorses of the HVAC industry, serving 44% of the total floor space of California's new commercial buildings. Packaged systems are popular because they seem affordable, easy to select and install. But in reality they are often have poor field performance due to design, installation, operation and maintenance problems

A frequent problem: shoddy maintenance

This project developed comprehensive design guidelines to address the major problems identified during field monitoring and testing of small rooftop HVAC units. These problems include (% of units tested):

- Economizers not working properly (64%)
- Improper refrigerant charge (46%)
- Inadequate ventilation air (38%)
- Fans running during unoccupied periods (30%)
- Simultaneous heating and cooling (8%)

Optimizing the Performance of Single-Package Rooftop HVAC Units

Based on this important new study's findings, the researchers developed the Small Commercial HVAC System Design Guide, which provides best practices for the design, installation, and operation of single-package rooftop HVAC systems.

Integrated design problems include poor coverage of lay-in insulation and ducts located in unconditioned space

Design Guide topics include:

- Integrated design strategies
- Unit selection (efficiency, capacity, features)
- Distribution systems (fan power, duct leakage and insulation, ductwork location, building pressurization)
- Ventilation (continuous, demand-controlled, dedicated ventilation systems)
- Thermostats (functionality, default settings, programming, user interface, small energy management systems)

Best Practices For Comfort & Savings

As this new study shows, most small packaged cooling systems fail to provide optimal comfort, indoor air quality, and energy efficiency. If the systems were designed, installed, operated, and maintained according to the best practices recommended in the *Design Guide:*

- Average building electricity savings would be 8%. Natural gas savings would be 30%.
- Combined average energy cost savings would be $0.26/sq. ft.

If new buildings in California adopted the *Design Guide's* best practices, the following statewide energy savings could be achieved (assuming 10% market penetration the first year and an increase of 1% per year over the next 10 years).

- First-year electricity savings: 6,942 MWh. Cumulative savings over 10 years: 496,360 MWh ($68 million).
- First-year natural gas savings: 97,107 therms. Cumulative savings over 10 years: 6,943,000 therms ($5.8 million).
- Total savings over 10 years: $73.8 million.

Thermostatic expansion valves and direct drive economizer actuators can improve unit reliability

INTERESTED?

The *Small Commercial HVAC System Design Guide* provides valuable data and recommendations for the integrated design of small rooftop HVAC systems.

Who will benefit from the *Design Guide*?

- Facility owners and managers
- Designers and manufacturers of small packaged HVAC systems
- Companies that distribute, install and maintain small HVAC systems

Key next steps include:

- *Facility owners & managers:* Learn about equipment performance problems and the benefits of fixing them. Require HVAC contractors to follow the best practices recommended in the *Design Guide*.
- *HVAC designers, Distributors, installers & maintenance companies:* Follow the best practices recommended in the *Design Guide*. Check with utility companies for efficiency program information.
- *Manufacturers:* Improve performance through product design changes and reliability enhancements. Support the development of an advanced packaged rooftop unit and a performance-based specification.

This project was part of the *Integrated Energy Systems: Productivity and Building Science* program. To learn more, visit www.newbuildings.org/pier.

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INTEGRATED DESIGN OF SMALL HVAC SYSTEMS

BUILDING SCIENCE SOLUTIONS FOR PACKAGED AIR CONDITIONERS

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Removing Barriers to Effective Skylighting

Low-rise commercial buildings that can take advantage of skylights with suspended ceiling systems (T-bar and acoustical tile) include offices, retail spaces, grocery stores and schools. Illuminating these buildings with skylights offers dramatic potential for saving lighting and cooling energy.

Skylighting isn't widely used, however, because it requires careful integration of equipment and components from many different manufacturers. But now—as a result of this project—data, research protocols, and *Design Guidelines* are available to help remove many of the barriers to effective skylighting.

Approximately 75% of new retail construction uses dropped ceiling systems

To create the *Design Guidelines,* the researchers developed new test protocols and conducted tests on common skylight and light-well combinations. They performed testing activities for U-factor, solar heat gain coefficient (SHGC), and visible transmittance, and developed extensive photometric data.

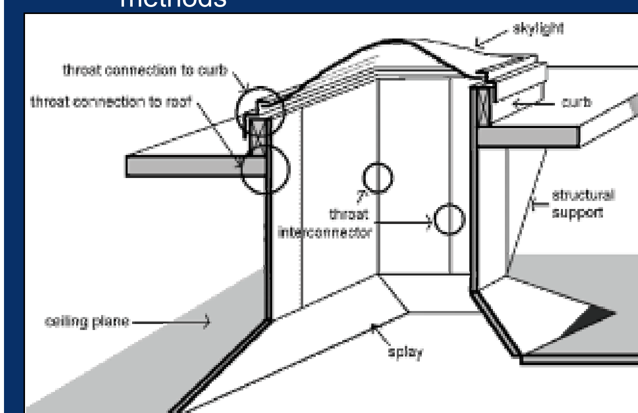
Design Guidelines for Skylights with Suspended Ceilings

These* Design Guidelines *provide tools for the effective use of skylights with suspended ceilings. Key strategies include:

- Use two-part light wells with throat and splays to reduce the number of skylights, improve lighting uniformity, and increase design flexibility
- Develop modular skylight/light-well products, including standardized interconnectors between skylights and ceilings

The researchers also tested skylights for light transmittance, heat transfer, and solar gains, with these key results:

- Photometric data are now available for skylight systems
- Light wells reduce solar heat gains
- New data on effective visible transmittance and U-factor will likely influence skylight rating and simulation methods



Standardized interface techniques will cut costs and speed up design and installation

Energy Savings and Better Design Tools

Lighting designers and software developers now have the same predictive tools for designing with skylights as they do for electric lighting. These tools allow for more accurate and confident designs, easing the use of skylights.

The Design Guidelines *can help building owners reap the benefits of daylighting*

Following the best practices in the *Design Guidelines* will result in skylight/light-well systems that provide optimal energy performance and superior lighting quality. The *Design Guidelines* are applicable to about 16.5 million square feet per year of California's commercial building construction. Assuming that 10% of this market follows the recommendations in the first year, with a 1% per year increase of market penetration over the next 10 years, statewide energy savings would be:

- First-year electricity savings: 1,614 MWh; cumulative electricity savings: 115,429 MWh.
- Cost savings over 10 years: $16 million.

Interested?

The *Design Guidelines* provides valuable information on modular skylight systems. The new photometric files predict lighting characteristics of skylights and light-wells.

Who will benefit from this research?

- Commercial building owners who want to exploit the energy savings potential of skylights
- Building designers and contractors looking for more effective ways to integrate skylights with T-bar ceilings
- Manufacturers of skylights and ceiling-system products who want to expand their markets and enhance their products

Key next steps include:

- *Building owners/managers:* Look for opportunities to include skylights in new and retrofit construction projects. Check with utility companies for efficiency program information.
- *Building designers/contractors:* Use the information in the *Design Guidelines* to design and build skylight/light-well systems.
- *Skylight & ceiling-system manufacturers:* Explore opportunities for expanding market share, including developing modular skylight/light-well systems.
- *Lighting software developers:* Include the PIER photometric results in product updates.

This project was part of the *Integrated Energy Systems: Productivity and Building Science* program.

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Integrated Design of Commercial Building Ceiling Systems

Effective Skylighting with T-Bar Ceilings

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The Problem with Unconditioned Space

New homes in California are typically built with the air handler and ductwork located in an unconditioned attic. The resulting air leaks, reduced airflow, and increased infiltration can lead to significant energy losses and comfort problems.

Leaks on the supply side of the system result in air loss to the unconditioned attic and to the outdoors, while leaks on the return side result in unconditioned air being brought into the system, increasing the space conditioning load. In addition, attic temperature is well above the outdoor air temperature in summer, causing more energy to deliver cool air to the home.

Locating ducts inside the conditioned space can reduce energy use

This project identifies energy-efficient options for building homes with ducts located in conditioned space while also:

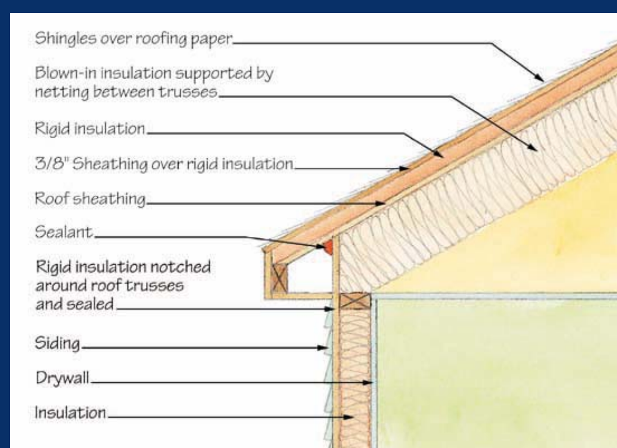
- maximizing marketable floor area
- minimizing energy cost
- minimizing construction costs
- simplifying the construction process

Building Homes with Ducts in Conditioned Space

The Homebuilder's Guide to Ducts in Conditioned Space (Builder's Guide) describes techniques for constructing new homes with ducts in conditioned space.

The Builder's Guide presents three design approaches: dropped ceiling, cathedralized attic, and plenum truss. It provides sufficient detail so that a builder can modify current house designs to incorporate ducts in conditioned space, including:

- strategies for overcoming market barriers
- cost estimates
- energy, demand, and energy-cost benefits
- construction drawings and descriptions of each approach

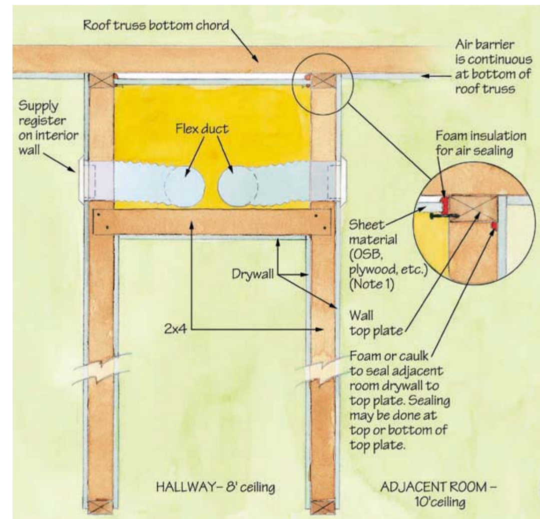


Detail of Cathedralized Attic approach

Benefits of Ducts in Conditioned Space

This study's findings confirm that building houses with ducts in conditioned space is technically feasible, and can be done at fairly small cost increments with valuable returns in energy savings.

- Cost impact to builder: 0% to 3% of construction costs
- Estimated annual electricity savings: 1% to 19%
- Annual energy cost savings per house: $0 to $1,285



Detail of Dropped Ceiling approach

Assuming the practices in the *Builder's Guide* achieve a 0.1% market penetration in California the first year, increasing to 10% after 10 years, statewide benefits would be:

- First-year electricity savings: 266 MWh. Ten-year cumulative savings: 178,768 MWh.
- Ten-year net energy cost savings: $22.9 million.

INTERESTED?

The *Home Builders Guide to Ducts in Conditioned Space* provides valuable information on how to design and build homes to save energy and reduce utility bills. Separate publications address the interests of energy code officials, building code officials and homeowners.

Who will benefit from this research?

- Residential builders, subcontractors, developers, and architects
- Energy and building code developers and officials
- Homeowners

Key next steps include:

- *Home Builders:* Adopt the approaches recommended in the *Builder's Guide.* Check with utility companies for efficiency program information.
- *Homeowners:* Support builders who build energy-efficient homes with ducts in conditioned space.
- *Building code officials:* Review your code's attic-venting requirements in light of the solutions recommended by this project.
- *Policymakers:* Promote the use of ducts in conditioned space.
- *Researchers:* Pursue side-by-side tests of houses with and without ducts in conditioned space.

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BUILDING HOMES WITH DUCTS IN CONDITIONED SPACE

DUCTS IN HOMES: LOCATION, LOCATION, LOCATION

Understanding Outdoor Lighting

Step outside at night in any California city or suburb. Does it seem like there are more outdoor light fixtures and brighter lamps than ever before? How much energy are we using to light up our nights? Are today's outdoor lighting practices effective—or do they waste money and energy or even create visibility problems?

Until now, there was little data about the amount of outdoor lighting energy used in California. There was even less information on the types of outdoor lighting practices in the state. The *California Outdoor Lighting Baseline Assessment* is the first major study to provide real data about commercial building outdoor lighting in the state. This report:

- Identifies statewide outdoor lighting design practices
- Estimates energy demand and consumption
- Provides a framework for outdoor lighting standards in California and future investigations of outdoor lighting

Lighting survey toolkit used to gather data for the baseline assessment

California Outdoor Lighting Baseline Assessment

This groundbreaking study provides a valuable snapshot of commercial and industrial outdoor lighting practices in California. For example:

- Incandescent lamps represent 31% of all lamps installed
- 58% of all outdoor lamps at apartment and condominium buildings are compact fluorescent lamps
- 48% of parking lots have high pressure sodium lamps

Wallpack light fixture at night

This research will likely influence outdoor lighting designs, codes and standards in California and beyond.

Key findings include statewide energy use by functional use area:

Area	Energy Use (GWh)	% of Total Energy Use
Parking	967	32%
Walkway	686	22%
Signage	623	20%
Security	208	7%
Storage	160	5%
Outdoor Retail	140	5%

Major Study Yields Valuable Data

The *California Outdoor Lighting Baseline Assessment* analyzes data collected from visits to over 300 sites throughout California, encompassing 20 different categories of businesses as well as multi-family residential buildings.

Field surveyor taking light readings

The study provides extensive data and valuable insights, including:

- Lighting power density (LPD) levels by building type, functional use area (parking lots, walkways, façades, etc.), and lighting zone
- Types of lamps and fixtures at each site
- Illuminance levels, glare and light trespass readings
- Use of lighting controls

The study also determined the state's commercial outdoor lighting energy use:

- Annual energy consumption: 3,067 GWh (1.34% of California's total energy use)
- Peak demand: 809 MW, occurring from 7 PM to 8 PM in the winter

Interested?

The *California Outdoor Lighting Baseline Assessment* provides data and insights that will be useful to:

- Energy and building code developers
- Facility owners and managers
- Lighting designers, manufacturers and researchers
- And many others

Key next steps include:

- *Facility owners/managers*
  Select outdoor lighting equipment and control strategies to save money, reduce energy use, and improve lighting quality.

- *Code developers*
  Implement code changes that effectively meet outdoor lighting needs while reducing energy use.

- *Lighting researchers*
  Apply this study's methodologies and results in future studies.

This project was part of the *Integrated Energy Systems: Productivity and Building Science* program. To learn more, visit www.newbuildings.org/pier.

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California Outdoor Lighting Baseline Assessment

Shedding Light on How We Illuminate the Outdoors