CONSULTANT REPORT

LIGHTING EFFICIENCY TECHNOLOGY REPORT

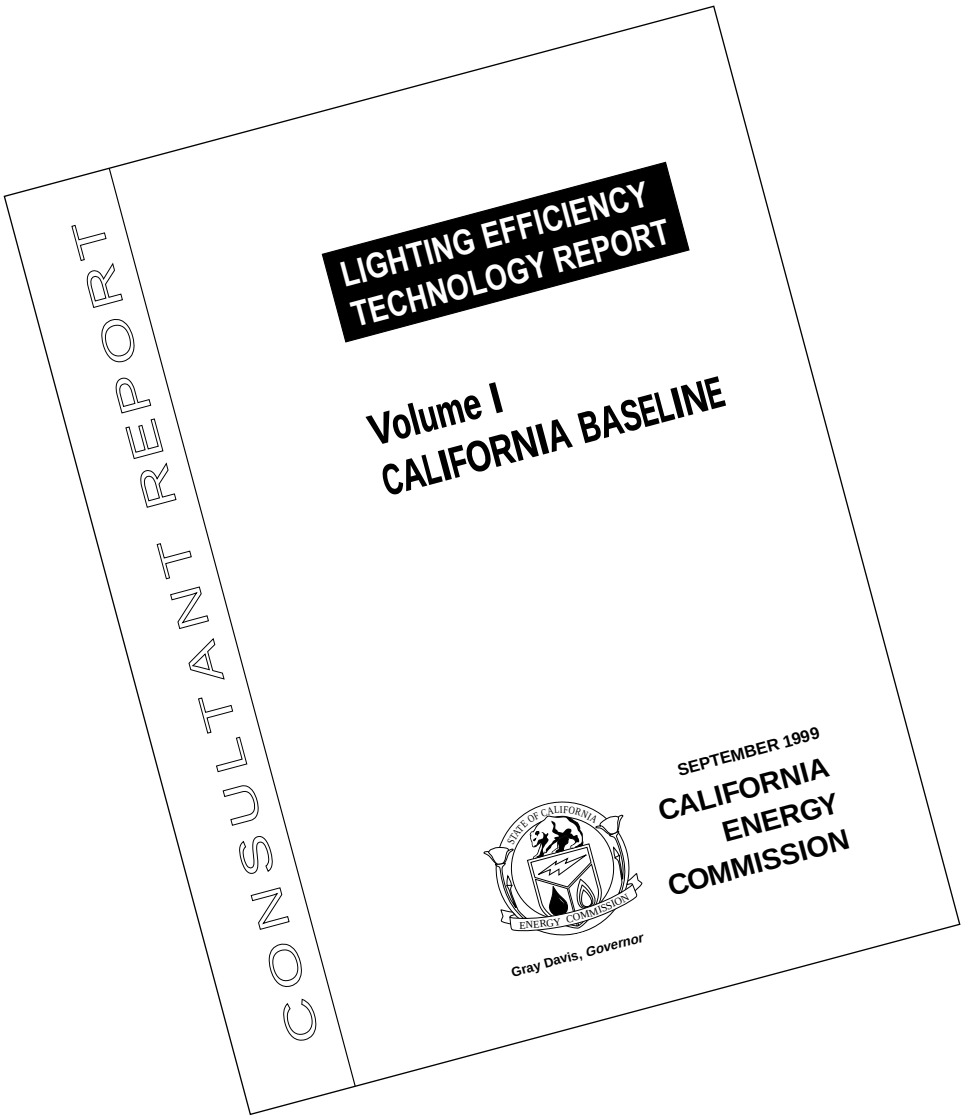
Volume I
CALIFORNIA BASELINE

SEPTEMBER 1999

CALIFORNIA ENERGY COMMISSION

Gray Davis, *Governor*

P400-98-004VI



C A L I F O R N I A E N E R G Y C O M M I S S I O N

Prepared for:

California Energy Commission

Prepared by:

Heschong Mahone Group
Fair Oaks, California
Contract No. 400-95-012

Maziar Shirakh, *Program Manager*
Michael S. Sloss, *Manager*

NONRESIDENTIAL BUILDINGS OFFICE

Scott Matthews, *Deputy Director*

ENERGY EFFICIENCY DIVISION

ACKNOWLEDGMENTS

This report is one of several being prepared under the *Lighting Technology Assessment Study* for the California Energy Commission. The study is being done as part of the Commission's response to the 1993 California Senate Bill SB 639 in which the legislature requested recommendations on ways to improve the efficiency of lighting in California.

The Commission's project manager for this study was initially Fred Berryman, and then John Sugar, with support from David Jones, and Ross Deter. The contractor team was led by the Heschong Mahone Group, Lisa Heschong and Douglas Mahone, Partners. Data analysis was provided by Ken Parris of B.E.A.R. The California Lighting Model was developed and run by Eley Associates, Charles Eley, Principal and Jeffery Luan, programmer. Additional lighting expertise was provided by James Benya and Ken Lim, and market research by Lisa Heschong of Heschong Mahone Group, Doug Oppedal of Benya Lighting Design and Merry Stubbins of SDV/ACCI.

This report has greatly benefited from additional resources provided by many people and organizations. Key in obtaining access to important databases have been Marian Brown of Southern California Edison, and David Lerman of Tacoma Public Utilities. Additional data was provided by members of Los Angeles Department of Water and Power, San Diego Gas and Electric, The City of Sacramento, CalTrans, and Lawrence Berkeley National Laboratory. Barbara Aktinson, Judy Jennings, and Frances Rubenstien of Lawrence Berkeley National Laboratory were particularly helpful in obtaining background information.

Members of the Lighting Efficiency Advisory Group (LEAGue) have provided information and support. Many retailers, manufacturers and professionals provided important background information for the market barriers study and participated in interviews. They were assured that their responses would remain anonymous. We greatly appreciate all their time and thoughtfulness in contributing to this project. The analysis and recommendations in this report, and any errors, however, are solely the responsibility of the authors.

There are four volumes to this Lighting Efficiency Technology Report:

Volume I: California Baseline Report

Volume II: Scenarios Report

Volume III: Market Barriers Report

Volume IV: Recommendations Report

TABLE OF CONTENTS

1. EXECUTIVE SUMMARY ***1***

2. RESIDENTIAL LIGHTING BASELINE ***9***

2.1 Data Sources *9*

2.2 Working Definitions *11*
2.2.1 Residential Lighting Applications 11
2.2.2 Luminaire Types 15
2.2.3 Lamp Types 16
2.2.4 Control Types 17

2.3 Lamp and Fixture Saturations and User Preferences *18*
2.3.1 Lamp Saturations 19
2.3.2 Fixture Saturations 21
2.3.3 Control Saturations 23

2.4 Energy Use Patterns and Hours of Operation *23*
2.4.1 Statewide Lighting Energy Usage 24
2.4.2 Hours of Operation 31
2.4.3 Load Profiles 42
2.4.4 Trends 46
2.4.5 Summary Charts 53

2.5 Title 24 Compliance *84*

2.6 Residential Data Analysis Methodology *87*
2.6.1 The Datasets 87
2.6.2 Analysis of the Datasets 90
2.6.3 Calibrating the Results 95

3. COMMERCIAL LIGHTING BASELINE ***100***

3.1 Data Sources *101*

3.2 Commercial Lighting Energy Use *102*
3.2.1 Hours of Operation 103
3.2.2 Lighting Power Density 105
3.2.3 Confidence Levels 105
3.2.4 Efficacy Levels 107
3.2.5 Load Profiles 108

3.3 Penetration of Technologies *110*

3.4 Commercial Outdoor Lighting *112*
3.4.1 Data Sources 112
3.4.2 Outdoor Lighting by Business Type 112
3.4.3 Outdoor Lighting by Lamp Type 115
3.4.4 Outdoor Lighting Controls 117

4. LITERATURE SEARCH ***119***

4.1 Published Reports *119*

4.2 Bibliography *124*

TABLE OF FIGURES

Figure 1-1 - Statewide Electricity Use, by Sector....1
Figure 1-2 - Baseline Lighting Energy Use, 1995....2
Figure 1-3 - Statewide Residential Lighting Characteristics....2
Figure 1-4 - Statewide Energy Use by Lamp Type....3
Figure 1-5 - Top Six Lighting Applications by Energy Use....3
Figure 1-6 - Average Hours of Operation by Room Type....4
Figure 1-7 - Hours of Operation by Lamp Technology....4
Figure 1-8 - Comparison of Watts and Lumens in Kitchens and Bathrooms....5
Figure 1-9 - Commercial Lighting Energy Use, by Building Type and Lamp Type....6
Figure 1-10 - Lighting Power Densities by Building Type....7
Figure 2-1 - List of Residential Lighting Applications....12
Figure 2-2 - Room Type Definitions....13
Figure 2-3 - Distribution of Room Types....13
Figure 2-4 - List of Fixture Types....14
Figure 2-5- Residential Luminaires Flowchart....15
Figure 2-6 - Control Type Definitions....18
Figure 2-7 - Proportion of Households with Lamp Type....20
Figure 2-8 - Fluorescent Lamp Saturations....21
Figure 2-9 - Average Number of Fixtures by Type, per Household....22
Figure 2-10 - Proportion of Households with Control Types....23
Figure 2-11- Statewide Electricity Use by Sector, per CEC 1996....24
Figure 2-12 - Residential Electricity Use, by End Use, California 1992....25
Figure 2-13 - Statewide Residential Lighting Characteristics, per Unit....25
Figure 2-14 - Statewide Residential Lighting Characteristics, Totals....26
Figure 2-15 - Statewide Energy Use by Lamp Type....27
Figure 2-16 - Percentage of Statewide Energy Use, by Room and Lamp Type....28
Figure 2-17 - Table of Percent of Statewide Energy Use, by Room and Lamp Type....28
Figure 2-18 - Percent of Energy Use by Fixture Type....29
Figure 2-19 - Average Hours of Operation by Room Type....31
Figure 2-20 - Monitored Hours On per Day for All Fixtures....32
Figure 2-21 -Monitored Hours On per Day for Kitchen Fixtures....32
Figure 2-22 - Monitored Hours On per Day for Bedroom Fixtures....33
Figure 2-23 - Hours of Operation by Luminaire Type....34
Figure 2-24 - Hours of Operation by Lamp Technology....35
Figure 2-25 - Hours of Operation by Lamp Type, for TPU Kitchens....36
Figure 2-26 - Hours of Operation by Lamp Type, SCE Monitored....36
Figure 2-27 - Detail of Lamp Technology Characteristics, by Wattage Bins....37
Figure 2-28 - Percent of Households Operating Given Fixture for More than 12 Hours per Day....38
Figure 2-29 - Outdoor Wall Mounted Fixtures, Hours of Operation, by Bin....39

Figure 2-30 - Extended Hours of Use, by Room Type, TPU Data 40
Figure 2-31 - Hours of Use Multipliers for Control Types....41
Figure 2-32 - Load Shapes by Fixture Type....43
Figure 2-33 - Percent of Lights On, by Hour, by Room....44
Figure 2-34 - Percent On by Hour, All Fixtures....44
Figure 2-35 - Average Hours of Operation, by Month....45
Figure 2-36 - Installed Wattage, by Lamp Type, by Vintage of Home....48
Figure 2-37 - Household Incandescent Wattage, by Vintage of Home....48
Figure 2-38 - Household Fluorescent Wattage, by Vintage of Home....49
Figure 2-39 - Installed Wattage, Kitchen/Dining Rooms, by Vintage of Home....50
Figure 2-40 - Installed Wattage, Bathroom, by Vintage of Home....50
Figure 2-41 - Regression Equations for Watts per Household....51
Figure 2-42 - Regression Equations for Energy Use per Household....52
Figure 2-43 - Incandescent vs. Fluorescent, Watts and Lumens in Kitchens and Bathrooms, California....86
Figure 2-44 - Incandescent vs. Fluorescent, Watts and Lumens in Kitchens and Bathrooms, WA & OR.....86
Figure 2-45 - Hours of Operation per Day for Self Reported and Monitored Data....90
Figure 2-46 - Detail of Hours of Operation per Day....91
Figure 2-47 - Comparisons of Monitored vs. Self Reported Datasets by Room Type....92
Figure 2-48 - SDG&E Study of Self Reporting Error for Hours of Operation by Room Type....93
Figure 2-49 - Correction Values for Self Reported Hours of Operation.....94
Figure 2-50 - Confidence for Residential Energy Use....97
Figure 2-51 - Confidence Levels for Residential Installed Wattage....98
Figure 3-1 - 1995 Commercial Square Footage, by Building Type....100
Figure 3-2 - Building Types Definition....101
Figure 3-3 - Space Types Definition....101
Figure 3-4 - Combined Commercial Sample Size....102
Figure 3-5 - Commercial Lighting Energy Use, by Building and Lamp Type....103
Figure 3-6 - Hours of Operation by Building Type....104
Figure 3-7 - Average FTE Lighting Hours by Space Type....105
Figure 3-8 - Lighting Power Density by Building Type....105
Figure 3-9 - LPD Confidence Levels....106
Figure 3-10 - Lumen Output Confidence Levels....107
Figure 3-11 - Commercial Lighting System Efficacy, by Building Type....108
Figure 3-12 - Commercial Lighting Load Profiles (Peak Day)....109
Figure 3-13 - Peak Lighting Load Percent by Building Type....109
Figure 3-14 - 4' Fluorescent Ballast Types, kWh by Building Type....110
Figure 3-15 - Penetration of Control Technologies....111

1. EXECUTIVE SUMMARY

The California Energy Commission, under SB 639 and 1065, has been charged with the task of studying and recommending options for improving lighting energy efficiency in California. This report, part of that effort, looks at the characteristics of lighting in residential and commercial buildings , and describes current, baseline energy use. This energy use is estimated using an analytical model that was developed to calculate the energy savings potential of the various options to be studied.

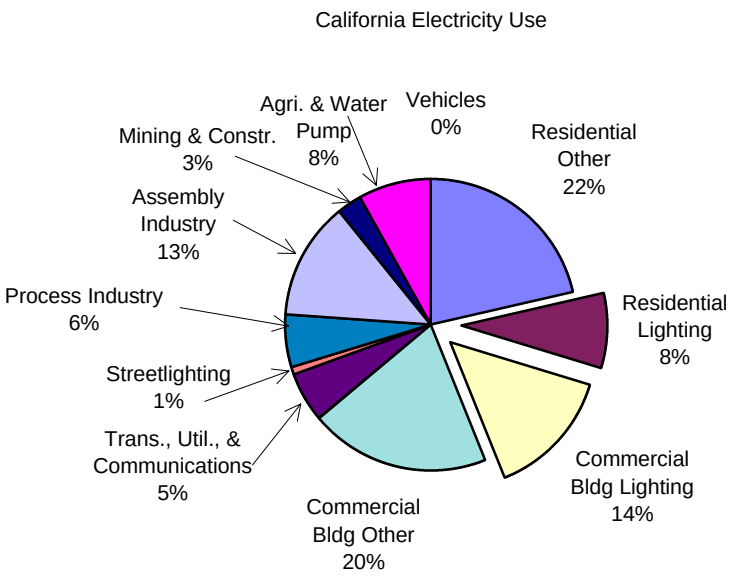


Figure 1-1 - Statewide Electricity Use, by Sector

Overall, residential lighting energy use was found to constitute 8.4% of all electric energy use in the state, as shown in Figure 1-1, or 28% of total residential electricity use in California. This is relatively higher than other states where the proportion of electricity used for space and water heating is much greater. Commercial lighting energy use constitutes 8.4% of all electric energy use in the state.

Figure 1-2 shows the 1995 baseline of installed megawatts and gigawatthours for residential and commercial lighting.

Baseline Lighting Energy Use, 1995	Megawatts Installed	Average Hours of Operation per Year	Gigawatthours per Year
RESIDENTIAL Indoor and Outdoor	22,800	850	19,400
COMMERCIAL Indoor Only	7,500	3,780	28,400
TOTAL	30,300		47,800

Figure 1-2 - Baseline Lighting Energy Use, 1995

Residential Baseline

This report includes definitions of residential lighting applications, including lamps, ballasts, fixtures and spaces associated with the most prevalent types. Energy use patterns and hours of operation are described and ranked according to the most significant energy uses. User preferences for lamp, fixture and control types for each major application are also described, based on site survey data from over 16,000 fixtures in 683 California homes. In addition, hours of operation were derived from monitored data of actual operation of more than 2600 fixtures.

Figure 1-3 shows the statewide average lighting characteristics per household. The average number of 21.3 fixtures per household in the total population is generally lower than reported in previous studies. This is largely a function of including multi-family houses in this study, which have fewer fixtures. The overall average hours of operation for lamps at 2.34 hours per day is also lower than previously assumed. This study is based on a large, representative sample of California households and is also correlated to monitored data, so we believe these figures to be more accurate.

	Fixtures/ Household	Sockets/ Fixture	Watts/ Socket	Watts/ Household	kWh/yr per Household	Average Hours/Day
Single Family	26.2	1.64	57.7	2475	2076	2.30
Multi Family	13.1	1.51	60.3	1194	1084	2.49
Total Population	**21.3**	**1.61**	**58.2**	**1995**	**1704**	**2.34**

Figure 1-3 - Statewide Residential Lighting Characteristics

Figure 1-4 shows the percentage of residential energy use attributable to different types and sizes of lamps (bulbs). Fluorescent lighting is found to account for 13% of statewide residential energy use in the lighting baseline. The majority of lighting energy use is consumed by medium sized incandescent

lamps with wattage in the range of 51 - 100 Watts. The average wattage for all incandescent lamps is 62 Watts, while average wattage for lamps of all types is 58 Watts.

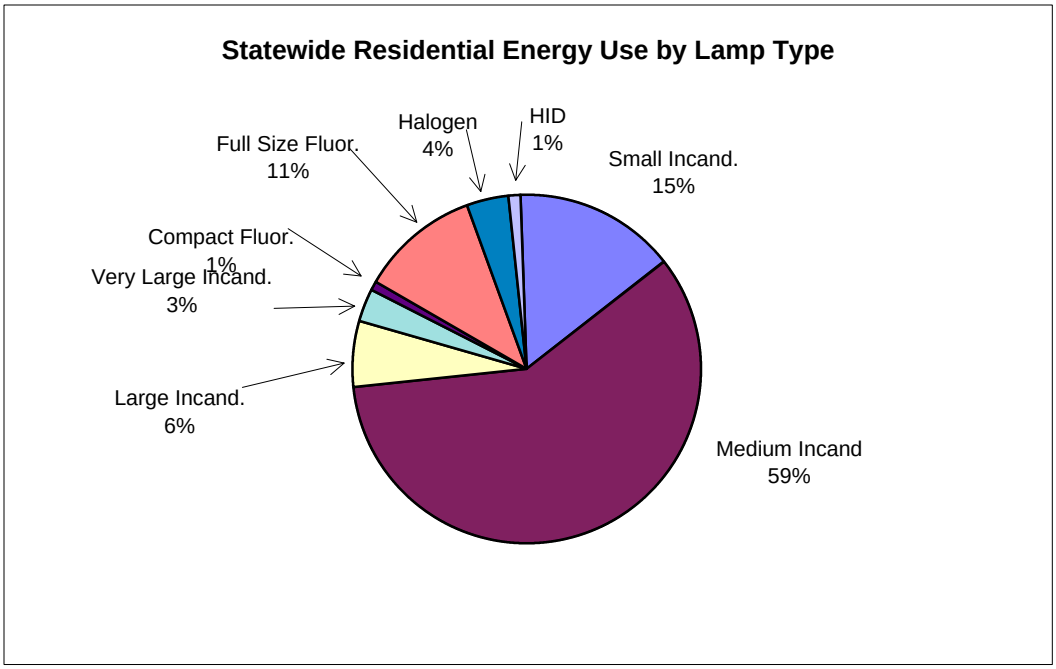


Figure 1-4 - Statewide Energy Use by Lamp Type

The top six residential lighting applications account for almost half of all the energy use. These applications are shown in Figure 1-5. The percentage indicates the share of statewide residential lighting energy use associated with each application.

Residential Lighting Application	**Lighting Energy Use**
1. Outdoor wall-mounted fixtures	10.6%
2. Suspended, ceiling mounted in kitchens and dining rooms	8.3%
3. Table lamps in living rooms	8.1%
4. Recessed, ceiling mounted in kitchens and dining rooms	7.6%
5. Wall mounted fixtures in bathrooms	7.3%
6. Surface, ceiling mounted fixtures in kitchens and dining rooms	6.3%
Total for top six applications:	48.2%

Figure 1-5 - Top Six Lighting Applications by Energy Use

Note that three of the top six applications occur in kitchens and dining rooms. All fixtures in kitchen and dining rooms together represent fully one quarter of statewide lighting energy use in residences.

Kitchen/dining rooms were also found to have the longest hours of operation of any room type. Outdoor lighting had the second longest average hours of operation. Bedrooms, by contrast, were found to have the shortest, and bathrooms, the second shortest, as shown in Figure 1-6 below.

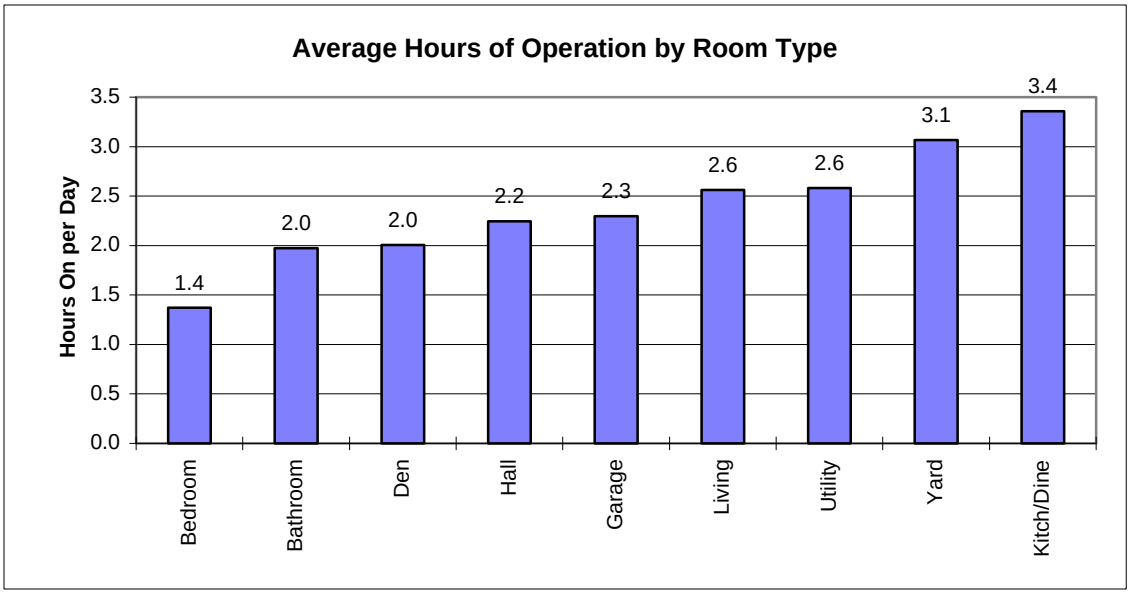


Figure 1-6 - Average Hours of Operation by Room Type

The hours of operation associated with different lamp types are shown in Figure 1-7 below. It is interesting to note that the longest hours of operation are associated with the most efficient sources. Fluorescent lamps have significantly longer average hours than incandescents. This appears to indicate that users have some recognition of lamp efficiency, and tend to make appropriate fixture choices for longer burning applications.

Technology	Avg. Hrs per Day	Avg. Watts/Lamp
Overall Average	**2.33**	**58**
Incandescent	2.22	62
Halogen	2.66	145
Fluorescent	3.10	37
HID	8.81	72

Figure 1-7 - Hours of Operation by Lamp Technology

The Title 24 building energy efficiency standards have attempted to regulate residential lighting efficiency by insisting on the use of fluorescent fixtures in kitchens and bathrooms, at least for the primary lighting. These requirements have not been well enforced, and are widely believed to be ineffective. However,

Figure 1-8 shows that while a majority of lighting watts in these rooms is represented by incandescent lamps, three-quarters of the light (lumens) in kitchens and one-third of the light in bathrooms is produced from fluorescent sources.

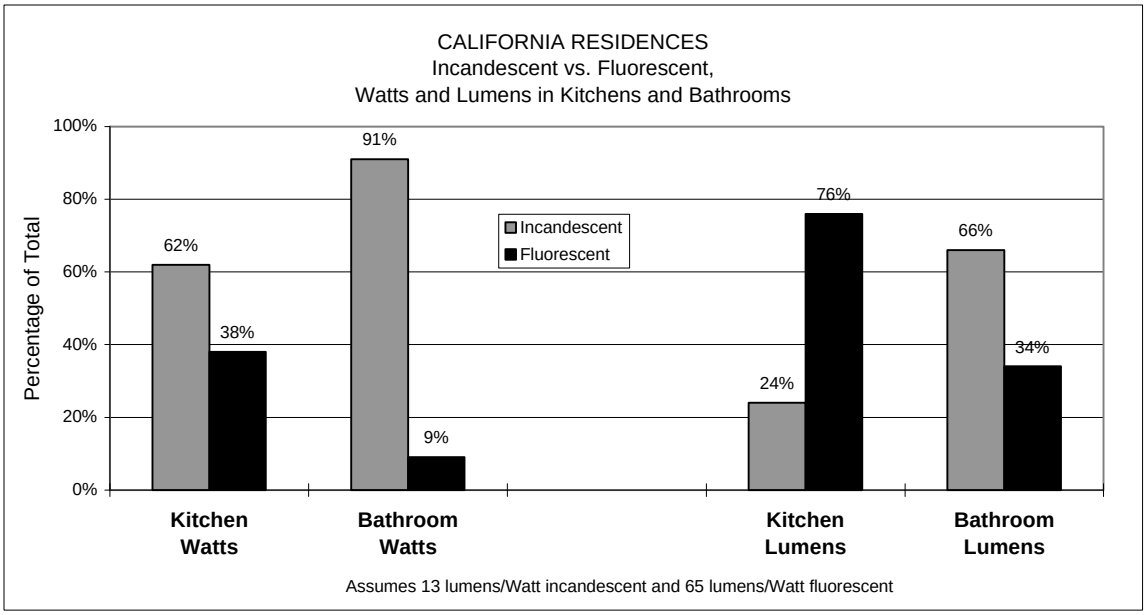


Figure 1-8 - Comparison of Watts and Lumens in Kitchens and Bathrooms

These values are based on a study of new homes in California which did not participate in any utility rebate programs. The values are significantly higher than from comparable homes in the neighboring Pacific Northwest states, suggesting that Title 24 requirements are having a definite influence on the use of higher efficiency lighting.

The results of the statistical analysis and the California Lighting Model were both found to be within the expected range of values from the earlier CEC study of Baseline Energy Use Characteristics.

Commercial Baseline

While the majority of this report deals with residential lighting, commercial lighting is also discussed. This report summarizes commercial lighting parameters, including lighting power densities (Watts/SF), lumen density (lumens/SF) and efficacy levels (lumens/Watts) for various building types. Energy use patterns and hours of operation by building type and space type are described. The relative importance of each building type in statewide lighting energy use, the proportion of energy used by each major lighting technology, and the technology penetrations are also presented.

Retail energy use was found to be the largest lighting energy use of the ten defined building types, shown in Figure 1-9, just slightly higher than lighting energy use in large office buildings. Retail also has one of the largest percentages of energy use form incandescent sources.

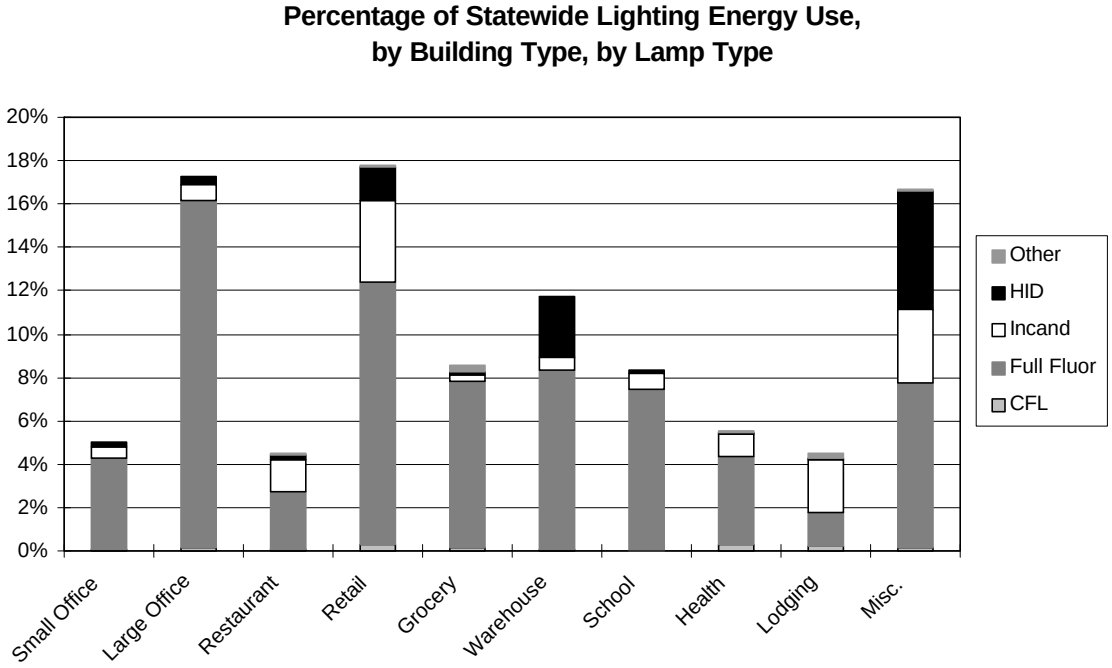


Figure 1-9 - Commercial Lighting Energy Use, by Building Type and Lamp Type

The lighting power density (Watts/SF) by building type, along with the overall system efficacy and mean lumen output per square foot, are shown below in Figure 1-10. Here it is seen that restaurants have the highest lighting power density, while warehouses have the lowest. Lodging has the least efficient systems, and schools and groceries have the most efficient systems.

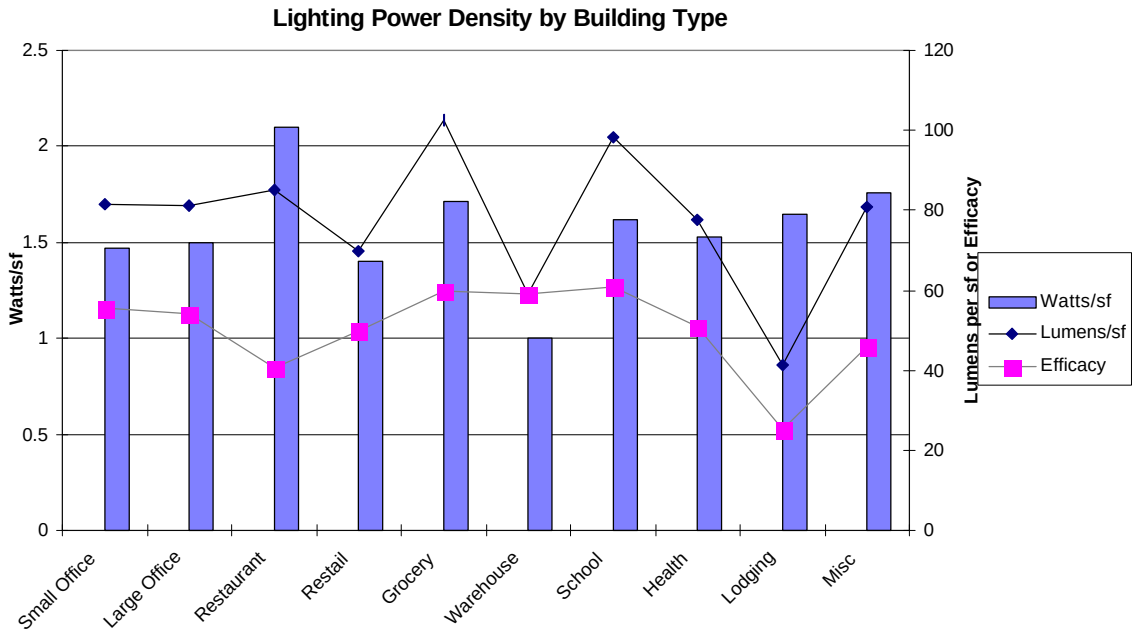


Figure 1-10 - Lighting Power Densities by Building Type

2. RESIDENTIAL LIGHTING BASELINE

A baseline for residential lighting energy use in California was created by analyzing datasets for energy use per household, and relating these values to the statewide population. The datasets allowed us to analyze the characteristics of household lighting down to the level of detail of room type, fixture type, lamp (light bulb) type, and control type.

These baseline characteristics become the basis of subsequent analysis in later volumes of this report.

2.1 Data Sources

The residential baseline described in this study is based on three recent field studies which collected a great deal of detailed information about the characteristics of residential lighting energy use. One was a comprehensive audit of 700 homes, and two were monitoring studies of smaller samples. These datasets were graciously provided to us by the utilities who sponsored the original research, in the hope that further analysis of their data would contribute to the general understanding of residential lighting energy use.

The raw electronic datasets were re-analyzed at a new level of detail for the purposes of this study. The three datasets focused on slightly different areas of interest and used different methodologies for collecting their data. However, the three datasets also complemented each other and had enough overlapping information to allow us to compare and calibrate results between them. The analysis of these three datasets is the basis of the findings presented in this report.

Southern California Edison, Residential Lighting Study, Inventory

Southern California Edison (SCE) commissioned this study from HBRS, Inc. to assess the potential for residential compact fluorescent lamps in their territory. The resulting survey produced a very large and comprehensive database on residential lighting characteristics.

A balanced sample of 700 homes was surveyed in the spring of 1993 for the residential lighting inventory, resulting in a final data set of 683 households. A trained auditor spent approximately one hour in each home, inventoried all of the light fixtures inside and outside of the home, and interviewed the occupants on the hours of use for each fixture, and the customer's lamp purchasing habits and preferences.

The inventory consisted of visual inspection and documentation of every fixture and light bulb in the residence. The data includes information on building type, age, number and size of rooms, fixture types and room location, control types, lamp types, bulb wattage, and customer's estimate of average daily hours of use for about 16,275 fixtures.

Southern California Edison, Residential Lighting Study, Time-of-Use Metering

Using a selected subset of homes in the inventory described above, Edison had 477 time-of-use light meters installed, one fixture per household. Due to attrition, malfunctions, and missing data the final usable sample was 359 meters. The meters ran for 4-8 months each, from the winter or spring to fall of 1993. The intent of this study was to provide a correction factor for the self-reported hours of operation in the larger survey. It also sought an analysis of the time-of-use patterns of residential fixtures. For a variety of reasons, the data did not prove useful in refining the hours of operation estimates, but it is very useful for understanding time-of-use patterns, and diversity profiles by housing type, room type, fixture type, and lamp type.

Tacoma Public Utilities, Metered Residential Lighting

Tacoma Public Utilities (TPU) took the lead in a study for the Bonneville Power Administration on residential lighting energy use. A total of seven utilities participated in this study, which used lighting loggers to monitor the energy use of fixtures in homes throughout Oregon and Washington.

TPU monitored 80% of the fixtures in 161 houses, for a total of 2,641 monitored fixtures. The significance of this study is in having a majority of the fixtures in a household monitored over an extended period. The fixtures were monitored from 4 to 12 months, over the course of a two-year period. The lighting loggers monitored elapsed and total run time, but not time-of-use.

On the one hand, the TPU monitored data is more robust than the Edison monitored data in that it includes four times as many fixtures, for much longer time periods, with less bias in fixture selection. On the other hand, the TPU data is not statistically representative of the Northwest housing stock, let alone that of California.

Analyzing the Data

We performed extensive analysis and comparisons of these three datasets in order to assess their reliability, consistency, and quality of data. We wanted to

understand how consistent the results were between the datasets, and how they could best be used to complement each other.

We ultimately concluded that the Edison inventory provided the most thorough and reliable description of the characteristics of residential lighting in California. The data was thorough and comprehensive. We used the TPU data primarily to compare self-reported hours of operation against monitored conditions, and secondarily to compare California lighting characteristics to out-of-state conditions. The Edison monitored data was used primarily to understand time-of-use patterns and load profiles.

The methodology of the data analysis is more thoroughly described in Section 2.6.

2.2 Working Definitions

To begin the analysis, we established a set of definitions for residential lighting applications based on room type and fixture type, which were consistent with the structure of the available datasets.

2.2.1 Residential Lighting Applications

Residential lighting applications can be categorized in many ways. One could describe applications by their purpose, such as general lighting, task lighting, security lighting, decorative lighting; by their location, such as garage lighting, bedroom lighting, bathroom lighting; or by the fixture type, such as chandeliers, carriage lamps, torchiers. Alternatively, applications could be described by their lighting effect, such as wall washing, spot lighting, counter top lighting.

In organizing this study we were faced with defining a set of residential applications which would be easily recognizable by the lighting industry and public, specifically definable in the data, and useful for a comprehensive analysis of energy use. We chose to adopt a set of application categories that are a combination of the room locations and general fixture categories which could be identified in the Edison inventory.

A fixture type within a given room type defines a "Residential Lighting Application." In the following sections, Room Types and Fixture Types, the logic used to define nine room types and nine fixture types is explained. These nine fixture types within nine room types would produce 81 possible combinations of residential lighting applications. Of those 81 possible combinations, 66 applications actually occurred in the data set.

In the analysis, these applications were sorted by their total statewide energy usage. The applications with the highest statewide energy usage were selected

for more detailed study. These selected applications together represent 90% of all residential lighting energy use in California. The remainder of applications were grouped into two categories, "Other-indoor" and "Other-outdoor." This gave us 30 residential applications to study in depth, listed in Figure 2-1. The energy use characteristics of these applications are presented in detail in the charts at the end of this chapter in Section 2.4.5.

Residential Lighting Applications	
Location:	Fixture type:
Bedroom	Table lamp
Bedroom	Ceiling surface
Bedroom	Ceiling suspended
Bedroom	Wall mounted
Bedroom	Floor lamp
Bathroom	Wall mounted
Bathroom	Ceiling recessed
Bathroom	Ceiling surface
Kitch/dine	Ceiling suspended
Kitch/dine	Ceiling recessed
Kitch/dine	Ceiling surface
Kitch/dine	Under cabinet
Living room	Table lamp
Living room	Floor lamp
Living room	Ceiling suspended
Living room	Ceiling surface
Living room	Ceiling recessed
Den	Table lamp
Hall-entry	Ceiling surface
Hall-entry	Ceiling recessed
Utility	Ceiling surface
Utility	Wall mounted
Utility	Ceiling suspended
Garage	Ceiling surface
Garage	Ceiling suspended
Garage	Wall mounted
Indoors	All other
Yard-porch	Wall mounted
Yard-porch	Ceiling yard
Outdoors	All other

Figure 2-1 - List of Residential Lighting Applications

Room Types

The data was grouped into 9 room types, as defined below in Figure 2-2:

Room Name:	Includes:
Bedroom	Bedrooms, closets, dressing areas
Bathroom	Bathrooms, toilet rooms, lavatories
Kitch/Dine	Kitchens, breakfast nooks, dining rooms
Living	Living rooms, parlors
Den	Family rooms, dens, home offices
Hall	Hallways, entry halls, stairs
Utility	Laundry rooms, basements, attics, misc. rooms
Garage	Garages
Yard	Yards, driveways, porches, balconies.

Figure 2-2 - Room Type Definitions

These room groups were selected so that data could easily be compared between the Edison and the TPU datasets, since the two datasets had varying definitions of rooms types. This list presented the best match between the two studies. Unfortunately, the Edison surveyors found it difficult to distinguish between the range of eating areas that they encountered, from a breakfast nook within a kitchen to a formal dining room, and so decided to group their data into a combined "Kitchen-Dining Room" category. Thus, we were also unable to distinguish between kitchens and dining rooms in our analysis of their data.

The frequency of these room types varied between single family and multifamily homes, listed below in Figure 2-3:

Room Name:	Single Family	Multifamily
Bedroom	2.64	1.62
Bathroom	2.04	1.42
Kitch/Dine	1.72	1.64
Living	1.25	0.96
Den	0.39	0.11
Hall	1.54	0.94
Utility	1.37	0.50
Garage	0.74	0.12
Yard	2.31	0.97

Figure 2-3 - Distribution of Room Types

This chart should be interpreted as saying that single family homes have an average of 2.64 bedrooms and 2.04 bathrooms. They would also have an

average of 1.72 kitchen and dining room spaces -- or most likely, each household has one kitchen and 72% of homes have an additional separate dining room. 74% of single family homes had a garage, while only 12% of multifamily homes had a garage. The value of "2.31 yards" for single family households means that there were on average 2.31 occurrences of yard sub-categories, such as an enclosed porch, a driveway, a balcony, or garden lighting.

It should be noted that the space frequency figures for multifamily homes only include private spaces, and do not include common areas shared by all units. Thus, the numbers do not include common lobbies, hallways, laundry areas, or general outdoor lighting. Such common areas are typically considered commercial floor space, since decisions are made by a single building owner. The multifamily spaces that are included here are generally under the control of the occupant, and thus are similar in purchasing and energy usage decisions to single family homes.

The frequency of these room types becomes important later when we consider which applications have the greatest state-wide energy use. Those applications which occur in the most common room types such as bedrooms, or yards, are likely to have a higher statewide aggregate energy use, even when they have a relatively low intensity of use per application.

Fixture Types

A fixture provides the housing and electric connection for a light source. Thus, a fixture can be a portable table lamp, a chandelier, or your bathroom vanity light. A fixture can have sockets for one or many lamps (i.e. light bulbs). We specifically use the term "fixture" in this report to refer to 9 general fixtures types that are defined in Figure 2-4 below.

<u>Portable:</u>
Table Lamps
Floor Lamps
<u>Hardwired:</u>
Ceiling Mounted - Surface
Ceiling Mounted - Recessed
Ceiling Mounted - Suspended
Wall Mounted
Undercabinet (and rangehood)
Ground Mounted (outdoors only)
All Other

Figure 2-4 - List of Fixture Types

As explained above, one of these fixture types within a given room type defines a residential lighting application for the purpose of this report.

2.2.2 Luminaire Types

The term "luminaire" is generally used to refer to a lighting fixture in combination with its light source, or lamp. However, the term "luminaire" is used here to refer to the common name of a lighting fixture as it would be identified by a retailer or wholesaler, as opposed to the more general "fixture types" listed above. Specific luminaires types were identified within each general fixture type.

A flow chart, shown below in Figure 2-5, explains how the specific luminaire types are related to the more general fixture types.

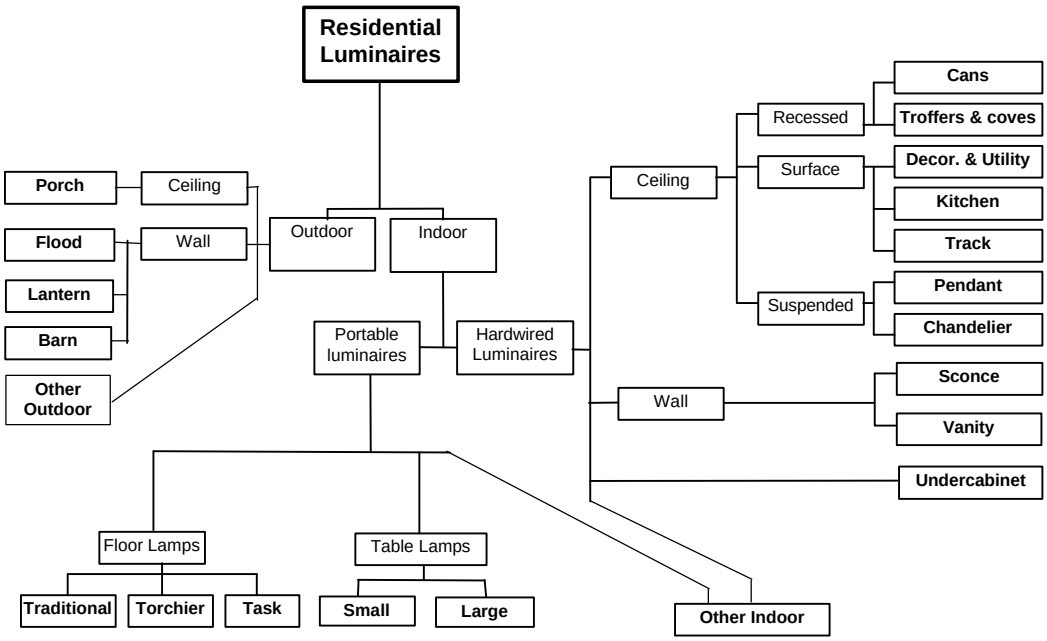


Figure 2-5- Residential Luminaires Flowchart

The list of luminaire types is not exhaustive. It does not describe all possible residential luminaire types. The list attempts to identify those luminaires which could be easily recognized in a home or on a product shelf, and which are common in the applications which were found to have the most significant energy usage in the home. The list is also limited by our ability to uniquely identify a common luminaire type from the descriptors available in the Edison database.

A combination of room location, fixture category, lamp type and wattage were used to specifically identify each luminaire from the data. For example, a "Torchier Floor Lamp" is identified as any floor lamp with an incandescent or

halogen bulb using 150 or more watts, while a "Task Floor Lamp" is identified as any floor lamp with an incandescent or halogen bulb using 50 or less watts.

Sometimes location became a prime determinate. An example is that a "Vanity" luminaire is identified as any wall mounted fixture in a bathroom, while a "Sconce" is any other indoor wall mounted fixture. Outdoor wall mounted luminaires include "Floods," which are fixtures using spot, flood or ellipsoidal bulbs; "Barn" fixtures are identified as those using any high intensity discharge lamp; "Lantern" fixtures include all remaining outdoor wall mounted fixtures. The logic used to identify each luminaire type is described in detail in the appendix of Volume II.

2.2.3 Lamp Types

The term "lamp" is used through out this report to refer to what the consumer commonly calls a "light bulb." Whether it is a standard, Edison-base incandescent "light bulb," a 4 foot fluorescent tube, or a double-ended tungsten halogen tube, any light source is referred to by the more technically correct term "lamp." The two exceptions in the usage of the word "lamp" are "table lamps" and "floor lamps," which refer to the plug-in lighting fixtures commonly used in living rooms and bedrooms.

Lamps were grouped by their general technologies into five groups:

Technology:	Shorthand Name:
■ Incandescent	Incand.
■ Tungsten halogen	Halogen
■ Fluorescent	Fluor.
■ High intensity discharge	HID
■ Other or unknown	Other

HID lamps could be broken down further into sub types, such as Metal Halide, High Pressure Sodium and Mercury Vapor lamps; however the numbers of each type are so few in the residential sector that valid statistical analysis was not possible.

All of the lamp types were broken down into wattage bins to help describe different lamp types, to see if behavior such as hours of operation varied by wattage, and to help identify the specific luminaire types described above. Thus, while we do not specifically identify screw-in compact fluorescent lamps, we do identify fluorescent lamps with wattage between1 watt and 19 watts, almost all of which were likely to be screw-in compact fluorescents when the field surveys

were done. The lamp wattage bins are detailed in Figure 2-27, in Section 0, Hours of Operation by Lamp Type.

2.2.4 Control Types

A control refers to any device used to turn a light source on or off. The most common are the simple on-off switches used for the vast majority of fixtures, including wall mounted toggle switches, and push switches used on table lamps.

Six basic control types were defined for the baseline study:

1.) simple on-off switches, either wall or fixture mounted that simply turn a light on to full power or completely off
2.) three way (or step) switches, that allow a user to select one of three light levels from a fixture
3.) dimmers, that raise or lower the light level continuously
4.) motion detectors, that turn a light on (and/or off) if the control detects the presence of a person
5.) photocells, that turn a light on or off based on surrounding light levels
6.) timers, that turn a light on for a given period of time

These were based on control types which could be identified both in the Edison inventory and the TPU monitored data, so that we could compare between the two datasets. Four of the control types were further broken down into subgroups, based on their observed hours of operation by room type. For example, 3-way switches in bathrooms, bedrooms, kitchen and utility rooms were observed to have shorter average hours of operation than on-off switches in the same room, and therefore were grouped into a category called "3-way, low hours." On the other hand, 3-way switches in the remaining rooms were observed to have average hours of operation that were longer than on-off switches, and so were put into a category called "3-way, high hours."

Motion sensors were split into three groups: those in yards, those in rooms generally with single occupants, and those in rooms with multiple occupants. (There actually were no occurrences of fixtures with a motion detector in multiple occupant rooms the Edison data set.)

Timers were also broken into three groups, and renamed "schedulers" to indicate timers that turn lights on and off at a set time of the day, and "timers" to indicate controls that turn lights off at a given time period, such as after 10 minutes. We looked at the average hours of operation for timers by room type, and used professional judgment to assess where each type was most likely to occur.

The resulting 12 control types are listed in Figure 2-6 below:

Control Name	Room Location
On-Off	On-Off in all rooms
3-Way, higher hours	3-way in Den, Garage, Hall, Living, Yard
3-Way, lower hours	3-Way in Bathrm, Bedrm, Kitchen, Utility
Dimmer	Dimmers in all rooms
Motion D Yard	Motion Detectors in Yard
Motion D multi occ.	Motion Detectors in Living, Den, Kitch, Hall
Motion D single occ.	Motion Detectors in Bedrm, Bath, Utility, Garage
Photocell outdoors	Photocells in Yard
Photocell indoor	Photocells in all other room types
Scheduler yard	Timers in Yard
Scheduler indoor	Timers in Hall, Living, Den, Kitchen
Timer	Timers in Bedrooms, Bath, Attic, Garage

Figure 2-6 - Control Type Definitions

2.3 Lamp and Fixture Saturations and User Preferences

This section describes the saturations of lamps, ballasts and fixture types in California residences and, by extension, the preferences of users in residential lighting. We discuss the various counts of populations of lamps and fixture types, and then discuss the proportion of statewide residential lighting energy use in Section 2.4.1. This discussion presents the known, quantifiable user preferences for hardware types and operational patterns, based on surveys of over 16,000 fixtures in 683 homes. The more qualitative aspects of user preferences is addressed in Volume III: Market Barriers Report, where the subject of market barriers to greater energy efficiency is addressed.

The saturations and energy use are both calculated using the 1995 population of households in the state of California, not by the number of dwelling units. Vacant houses do not have a household in them, and therefore are not included in these numbers. If one is interested in the total population of lamps or fixtures in the state, (rather than just those in use at a given time) one would then also account for the separate vacancy rates of single family and multifamily homes.

It is possible to look at the saturation of lamp types by a number of measures. For a given lamp type, we could look at the:

- percentage of all households that have the lamp type (market saturation)
- percentage of all fixtures that have the lamp type
- average number of lamps per household statewide
- average number of lamps per household that has that type of lamp
- total number of lamps statewide (sockets)
- total wattage by lamp type statewide
- total energy use by lamp type statewide

All of these metrics can be instructive. However, they can also be misleading. Lamps which are very common may have very relatively insignificant wattage. Lamps which have significant wattage, may have very low usage. Only energy use accounts for all of the factors. It accounts for the overall population, the overall wattage (including many cases of 0 wattage), and the usage.

2.3.1 Lamp Saturations

Californians have about 34 sockets for installing various types of lamps in their homes. Single family homes average 43 sockets, and multifamily average about 20 available sockets. The proportion of households that have at least one socket dedicated to a given lamp type is shown in Figure 2-7.

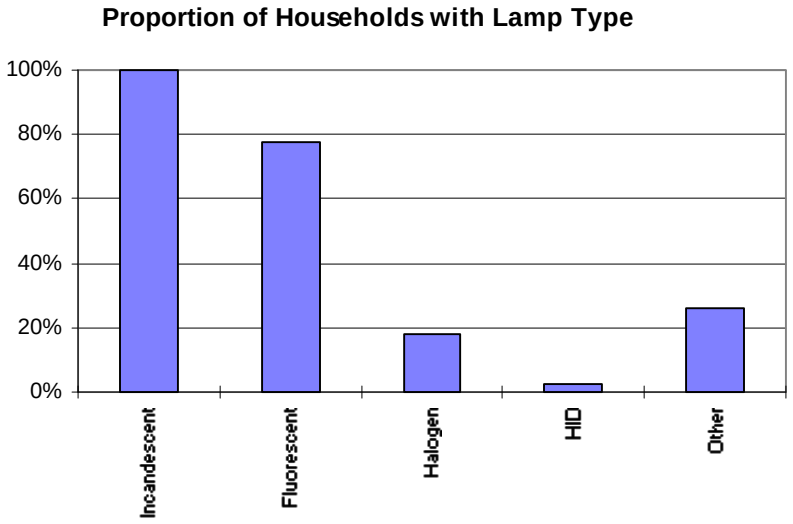


Figure 2-7 - Proportion of Households with Lamp Type

Figure 2-7 shows that 78% of all households have some fluorescent lamps in their home, while 18% have at least one halogen lamp, and only 2% have any HID lamps. Not surprisingly, 100% of households have at least one incandescent lamp installed. (The "Other" lamp category includes anything not identifiable or easily categorized into the other groups, and all such miscellaneous light sources as neon, heat lamps, lava lamps, and sparkle lights. The majority (88%) of fixtures with "Other" lamps have no wattage assigned to them, implying an empty socket or broken lamp or disconnected fixture.)

Californians have an average of 18 incandescent fixtures and an average of 28 incandescent lamps per household. Those households who have halogen lamps average 2.0 halogen fixtures per household and 2.5 halogen lamps. Those who have HID lamps average 1.2 HID fixtures per household and 2.1 HID lamps.

The information for fluorescent lamps is detailed by wattage bins in Figure 2-8. Small compact fluorescent lamps (CFL 1-20 Watts) were found to be present in 20% of households, with an average of 2.1 lamps per household for those that had them. This results in an average saturation of 0.4 small CFL lamps per household statewide in 1993. Mid-sized CFL lamps (21-30 Watts) are found in 27% of all homes with an average of 2.3 lamps in those homes, or a statewide penetration of 0.6 lamps per household. These mid-sized CFLs are most likely to be circline fluorescents or short linear fluorescents used for undercabinet fixtures or desk lamps, since larger screw-in CFLs in that wattage range generally were not available in 1993.

	Percent of households with item	Avg. # lamps for households with item	Avg. # of lamps per household statewide	Total # of lamps in use (millions)
All Fluorescents	77%	6.7	5.2	59.5
Empty or 0 wattage	6%	1.9	0.1	1.3
CFL 1-19 Watts	20%	2.1	0.4	4.8
CFL 20-30 Watts	27%	2.3	0.6	7.3
FFL 31+ Watts	66%	6.1	4.0	46.0

Figure 2-8 - Fluorescent Lamp Saturations

Full sized fluorescent lamps (FFL 31+ Watts) are found in 66% of all households, with an average of 6.1 lamps per household, or a statewide saturation of 4.0 lamps per household. The "Empty or 0 wattage" category accounts for dedicated fluorescent fixtures that are not operating because of a broken or missing lamp. Further information on average wattage per lamp, average hours of operation and energy use is available in Figure 2-27.

2.3.2 Fixture Saturations

Overall, California households average 21 fixtures per home, at 1.61 lamps per fixture. Single family homes average 26 fixtures per household and multifamily homes average 13 fixtures per household.

The saturation of fixture types by household is not very informative, because almost all households have almost all fixture types. Rather, it is more interesting which are the most common fixture types, where these fixture types tend to be located and which are the largest energy users. California households average 16 hardwired fixtures and 5 portable fixtures per home. There are almost 10 ceiling mounted fixtures per home. This is summarized in Figure 2-9.

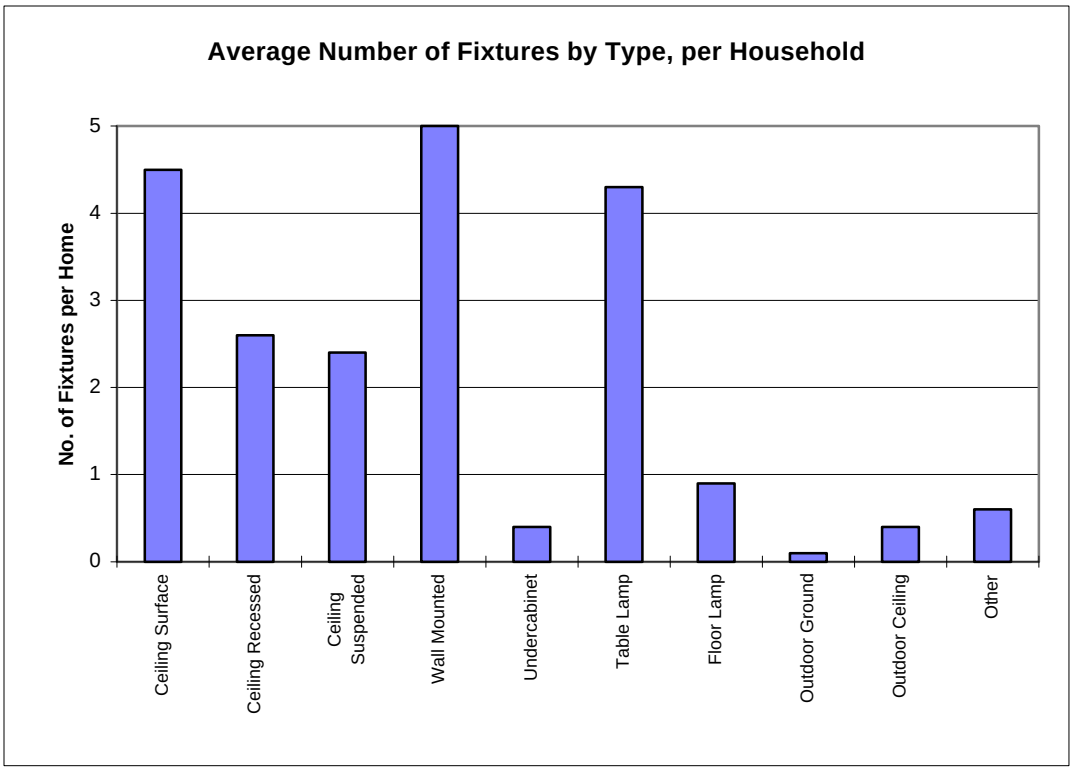


Figure 2-9 - Average Number of Fixtures by Type, per Household

The most common fixture type in California households is wall mounted fixtures at 5.0 per home, with the greatest number being outdoors (2.0 per household) and the second greatest being in bathrooms (1.4 per household).

Surface mounted ceiling fixtures are the next most common fixture type, at 4.5 fixtures per household. Surface mounted ceiling fixtures are most prevalent in bedrooms, kitch/dine rooms, and hallways at .9, .9, and .8 fixture per household respectively.

Table lamps are almost as prevalent as surface mounted ceiling fixtures at 4.3 fixtures per household. Table lamps are most often found in bedrooms (2.2) and living rooms (1.5).

California houses average 2.6 recessed fixtures and 2.4 suspended fixtures per home. These are both most commonly found in the kitchen/dining room area both at 0.9 fixtures per household. In other words, about 90% of household have a recessed fixture in their kitchen/dining room and 90% have a suspended fixture (like a chandelier or drop pendant) in their kitchen/dining room area.

Floor lamps occur at a rate of 0.9 per home, and 60% of them are in living rooms, 27% are in bedrooms. Undercabinet fixtures occur at rate of about 0.6 per home, and 66% of them are in kitchens.

2.3.3 Control Saturations

All households have on-off switches. They average 18.8 on-off switches per household, and 2.5 fixtures with some other kind of control. In other words, on-off switches are present on 88% of fixtures. Over 50% of households have at least one 3-way switch, and of those that do, they tend to have at least two such switches per household. Other control types are far less prevalent, and are graphed in Figure 2-10 below.

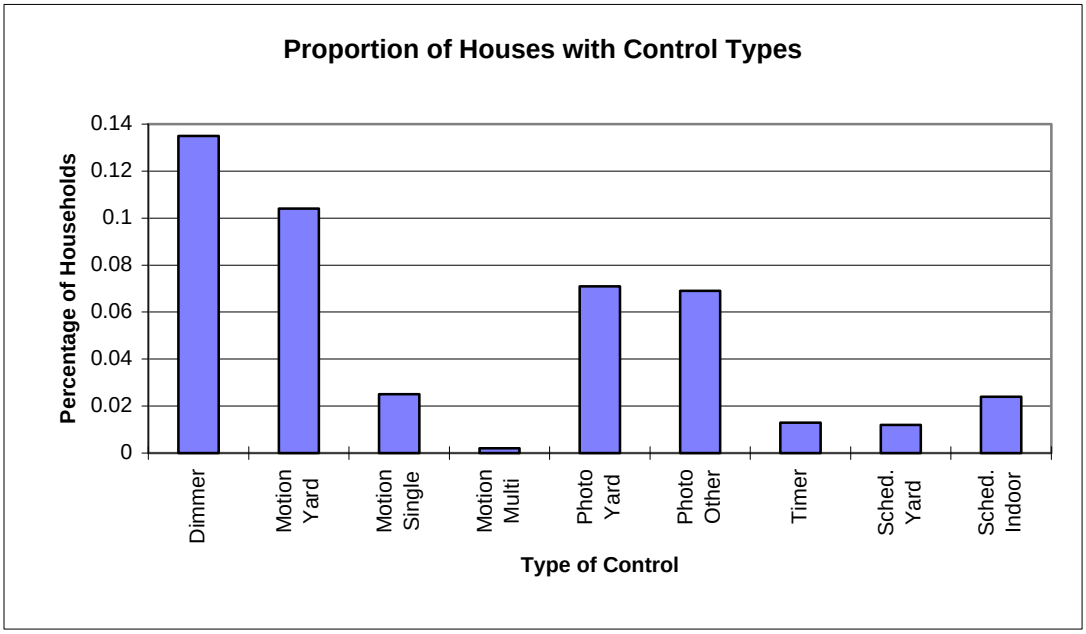


Figure 2-10 - Proportion of Households with Control Types

Dimmers are the next most common, found in 14% of all homes. About 10% of households have outdoor motion detectors. About 7% of households have outdoor photo-controls. Seven percent also have indoor photo-controls. Other control types occur in 2% or less of all households. Those households that have one of the control types listed above tend to average slightly more than one such control per household. Households with dimmers average 1.4 controls per household, and those with outdoor motion detectors average 1.3 controls per home. People with outdoor photo-controls average 1.9 such controls per home.

2.4 Energy Use Patterns and Hours of Operation

In this report, the significance of a given lamp or fixture type is often given as a percentage of statewide energy use. Energy use should be understood as a percentage of total residential lighting energy use in the state of California, unless specifically stated otherwise.

2.4.1 Statewide Lighting Energy Usage

Residential electricity use represents 30% of overall statewide electricity use, as illustrated below in Figure 2-11.

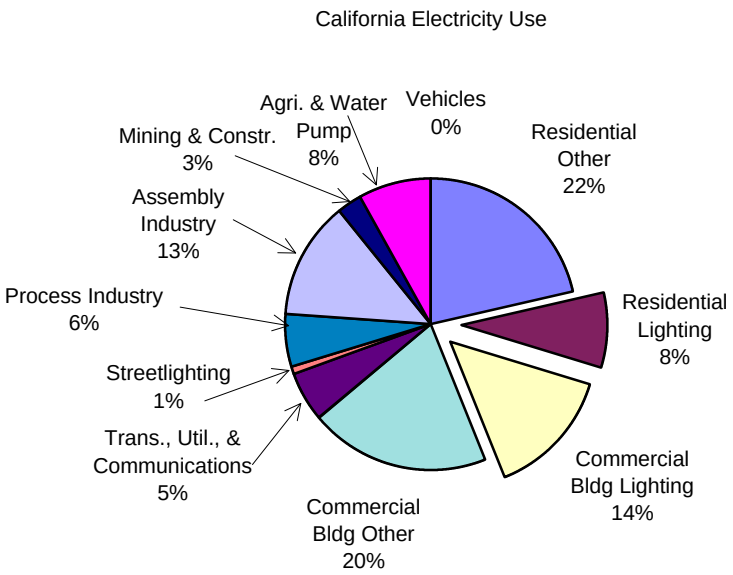


Figure 2-11- Statewide Electricity Use by Sector, per CEC 1996[1]

As such, residential energy use is quite significant when looking at year long totals. However, it is also important to keep in mind when the energy use in each sector occurs. For example, residential energy use has very different patterns in time than commercial buildings. Residential energy use has a major peak in the evening and minor peak in the morning, whereas commercial building energy use tends to peak in the afternoon. Each sector also has different seasonal patterns. We will take a closer look specifically at residential lighting patterns.

Residential lighting was found by this study to represent 28% of residential electricity use. Thus, residential lighting represents about 8.4% of total state electricity usage, a number comparable in magnitude to the agriculture and water pump sector, and slightly larger than either the process industry sector or the transportation, utilities and communications sectors. For comparison, commercial building lighting energy use (both indoors and outdoors) is estimated by the CEC to represent 14% of statewide electricity use. Thus, residential lighting energy use represents about 60% of commercial building energy use.

[1] Numbers provided by the Forecasting Department at the California Energy Commission, September 1996.

Residential electricity use by end use is illustrated in Figure 2-12 below. In general, lighting energy use is more significant in California homes because much less electricity is devoted to home heating and cooling and water heating than in other areas of the country.

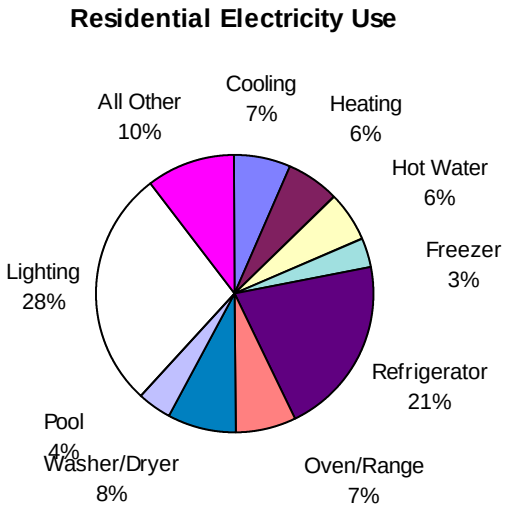


Figure 2-12 - Residential Electricity Use, by End Use, California 1992

Statewide lighting energy use was found to be 19,485 gigawatthours per year or 1,704 kWh/yr. per household. This amounts to about 28% of all residential electric energy use, estimated at 6,191 kWh per household per year by the California Energy Commission.[2]

	Fixtures/ Household	Sockets/ Fixture	Watts/ Socket	Watts/ Household	kWh/yr per Household	Average Hours/Day
Single Family	26.2	1.64	57.66	2475	2076	2.30
Multi Family	13.1	1.51	60.33	1194	1084	2.49
Total Population	**21.3**	**1.61**	**58.24**	**1995**	**1704**	**2.34**

Figure 2-13 - Statewide Residential Lighting Characteristics, per Unit

Single family homes use about twice the lighting energy use of multifamily homes per household (2078 vs. 1084 kWh/yr. per household). However, single family homes consume 76% of all residential lighting energy use in California. This proportionally higher energy use is because single family homes are more numerous (63% of all households). These numbers, based on the1995

[2] *Baseline Energy Use Characteristics, Technology Energy Savings, Volume I*, California Energy Commission, May 1994, publication p300-94-006.

population of California, are detailed in Figure 2-13 above and Figure 2-14 below.

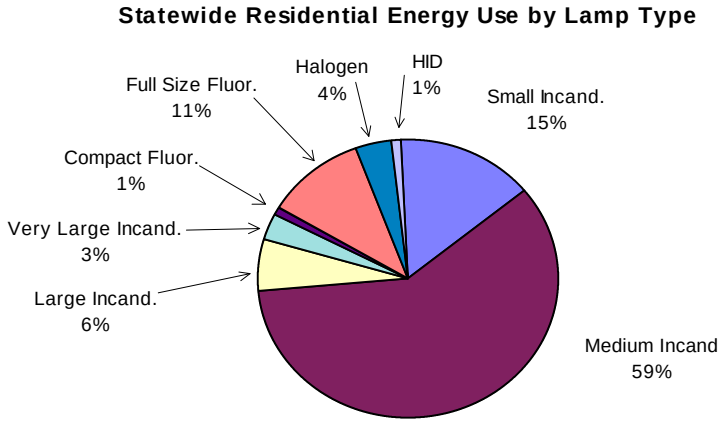
	1995 Total Households 1000s	Total Fixtures 1000s	Total Sockets 1000s	Total Mega Watts	Total Giga Wh/yr
Single Family	7,150.0	187,232.7	306,835.5	17,692.9	14,840.1
Multi Family	4,285.1	56,205.1	84,830.9	5,117.7	4,644.7
Total Population	**11,435.1**	**243,437.8**	**391,666.4**	**22,810.6**	**19,484.8**

Figure 2-14 - Statewide Residential Lighting Characteristics, Totals

We found an average of 21.3 lighting fixtures per household, with 1.6 sockets per fixture at an average of 58 watts per socket, i.e. per light bulb. This results in an installed wattage of 1995 Watts per household, operated for an average of 2.34 hours per day. Installed wattage for single family homes is about twice that of multifamily homes, however average hours of operation per fixture are slightly less for single family homes, since there are more fixtures per person, and thus each fixture is likely to be used less intensely. Figure 2-14 provides the total quantities from which the unit values are derived.

Statewide Energy Use by Lamp Type

Percent of energy used by lamp types shows that incandescent lamps use a total of 82% of all residential lighting energy use in California, and are installed in 85% of all fixtures. Fluorescent lamps represent 13% of all lighting energy use, and also 13% of all fixtures. Remaining lamp types represent 5% of the energy use, and 2% of the fixtures. Statewide residential lighting energy use by lamp type is summarized in Figure 2-15 below.



Lamp Type	Wattage
Small Incand.	1 - 50
Medium Incand.	51 - 100
Large Incand.	101 - 150
Very Large Incand.	151+
Compact Fluor.	1 - 30
Full Size Fluor.	31+
Halogen	all sizes
HID	all sizes

Figure 2-15 - Statewide Energy Use by Lamp Type

Incandescent lamps are by far the largest users of energy, at 82% of all statewide residential lighting energy use. The majority of this is by medium sized incandescents (51-100 Watts). The largest users of incandescent lighting energy are kitchen/dining rooms at 18% of all statewide lighting energy, living rooms at 16%, yards at 13%, bathrooms at 11% and bedrooms at 9%. Breakdown of lighting energy use by room is illustrated in Figure 2-16.

Fluorescent lighting accounts for 13% of statewide use. The largest use of fluorescent lighting is in the kitchen/dining room which accounts for 7% of all statewide lighting. The second largest use is in garages (3% of all lighting), followed by bathrooms (1%) , then utility rooms (<1%).

Of the fluorescent energy use in kitchen/dining rooms, the majority is by full size fluorescents (32+ Watt fluorescents), which amounts to over half (52%) of all energy use from fluorescents. Another 4% of fluorescent energy use is from medium sized compact fluorescents (20-31 Watts) also in kitchen/dining rooms. Compact fluorescents have their greatest energy use outdoors, followed by the living room. However, this energy use by compact fluorescents is insignificant at a statewide level.

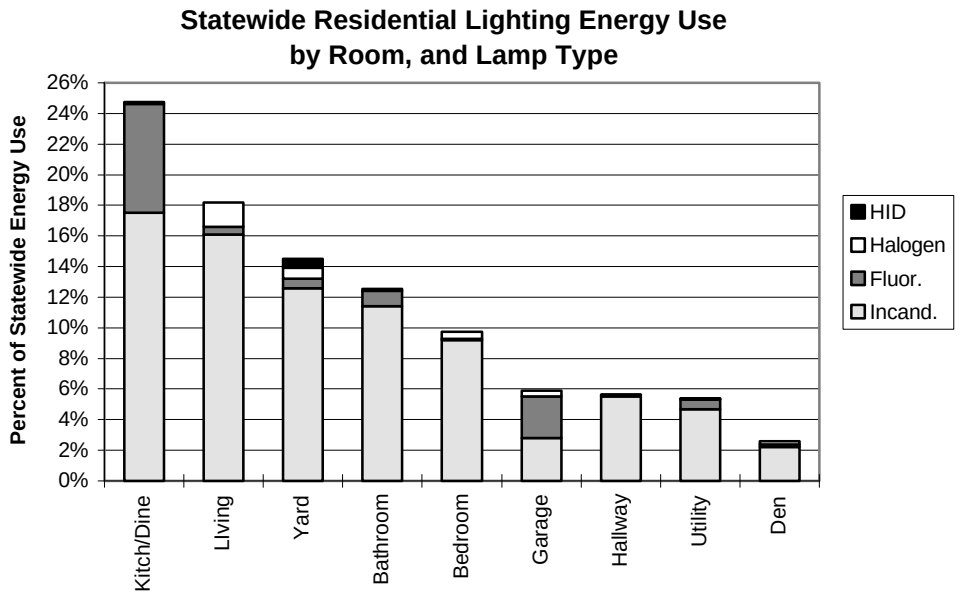


Figure 2-16 - Percentage of Statewide Energy Use, by Room and Lamp Type

All halogen use amounts to 4% of statewide residential lighting energy. It is interesting that 59% of this, equaling 2% of all statewide residential lighting energy is from the largest halogen lamps with more than 151 watts/lamp. The largest use of halogen lighting is in living rooms, at 43% of all halogen use.

HID use is even less significant, at only 1% of statewide energy. The largest use of HID lamps is outdoors, representing 91% of all HID use. The next most common is garages at 9% and utility rooms at 1%

Further detail for lamp energy use by room type presented in Figure 2-16 is provided in Figure 2-17 below. (The grand total in Figure 2-17 is less than 100% because of trace energy usage for room/HID lamp combinations and the "Other" lamp category which was not included in the chart.)

	Incand.	Fluor.	Halogen	HID	Total
Kitch/Dine	17.5%	7.1%	0.2%	-	24.8%
Livingroom	16.1%	0.5%	1.6%	-	18.2%
Yard	12.6%	0.6%	0.7%	0.6%	14.5%
Bathroom	11.4%	1.0%	0.1%	-	12.5%
Bedroom	9.2%	0.1%	0.5%	-	9.8%
Garage	2.8%	2.7%	0.4%	-	5.9%
Hallway	5.5%	0.1%	0.0%	-	5.6%
Utility	4.7%	0.6%	0.1%	0.1%	5.4%
Den	2.2%	0.2%	0.2%	-	2.6%
Total	82.0%	12.9%	3.7%	0.7%	99.3%

Figure 2-17 - Table of Percent of Statewide Energy Use, by Room and Lamp Type

Statewide Energy Use by Fixture Type

Outdoor fixtures represent 15% of statewide energy use and indoor fixtures represent 85% of all residential lighting energy. Breakdown of energy use by fixture type is illustrated in Figure 2-18 below. Further detail is provided for both general fixture types, and more specific luminaires, on saturations and percent of statewide energy use in Figure 2-23.

Percent of Statewide Energy Use by Fixture type

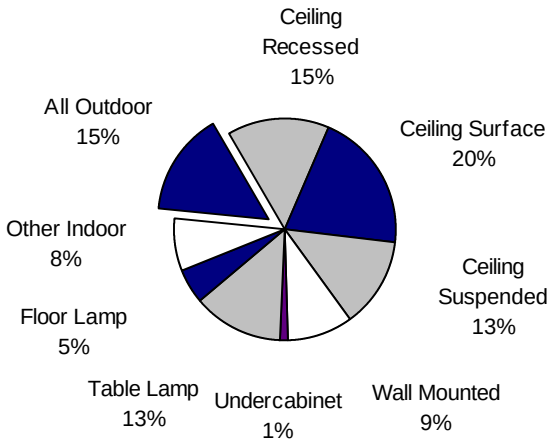


Figure 2-18 - Percent of Energy Use by Fixture Type

Hardwired vs. Portable Fixtures

Another interesting way to categorize fixtures is by whether they are hardwired or portable. Hardwired fixtures are permanently built into the house, either at the time of construction, or during remodeling. Once installed they have a fairly long life span, even when new residents move in. Portable fixtures on the other hand, are purchased by and move with the resident.

Fixtures which are built in or "hardwired" to the house structure represent 70% to 76% of all fixtures, and 76% to 80% of all energy use. The lower numbers do not include the "Undercabinet" and "other" fixture categories, which could be interpreted as either hardwired or portable.

The two main categories of hardwired fixtures are ceiling mounted and wall mounted fixtures. Ceiling mounted are the most common, at 47% of all fixtures and 53% of all energy use. Ceiling mounted fixtures are broken down into three sub-groups: surface mounted, recessed, and suspended. Surface mounted ceiling fixtures are the most common, at 21% of all fixtures and 21% of all

energy use. Recessed fixtures represent 12% of all fixtures, but 15% of all energy use, and suspended fixtures represent 11% of all fixtures, but also 15% of all energy use. The greatest energy use for all types of ceiling-mounted fixtures is seen in kitchen and dining room spaces, totaling 22% of all residential lighting energy use.

Wall mounted fixtures represent 23% of all fixtures and also 23% of energy use. Outdoor wall mounted fixtures are the most common, at 9% of fixtures and 11% of energy use, and bathroom wall mounted fixtures are the next most common and energy intensive, at 7% of fixtures and 7% of energy use.

Undercabinet fixtures represent less than 3% of fixtures, and just over 1% of energy use. All other fixtures, including ground mounted outdoor fixtures, also represent about 3% of fixtures, and 3% of overall energy use.

Portable Fixtures

Portable fixtures generally include table lamps and floor lamps. Some undercabinet fixtures might be considered portable if they have a plug. Together, portable fixtures represent 24% of fixtures, 22% of installed watts, and almost 20% of energy use for residential lighting.

Table lamps were found to represent 20% of all fixtures, with half of all table lamps in bedrooms, and the majority of the remainder in living rooms, family rooms, dens and offices. However, table lamps represent only 14% of kWh consumed, with their greatest energy use intensity in living rooms. Bedroom table lamps averaged only 1.2 hrs of operation per day, while living room table lamps averaged almost 3 hrs of operation per day.

Floor lamps were found to represent 4% of fixtures, but almost 6% of kWh. This increase in the proportion of energy used is due to the higher wattage and longer hours of operation of floor lamps in living rooms.

2.4.2 Hours of Operation

Hours of Operation by Room Type

Average hours of operation per day for all lighting[3] is 2.34hrs. This is further broken down in Figure 2-19 below by room type. Kitchen/Dining rooms are noted to have the longest average hours of operation, and bedrooms to have the shortest.

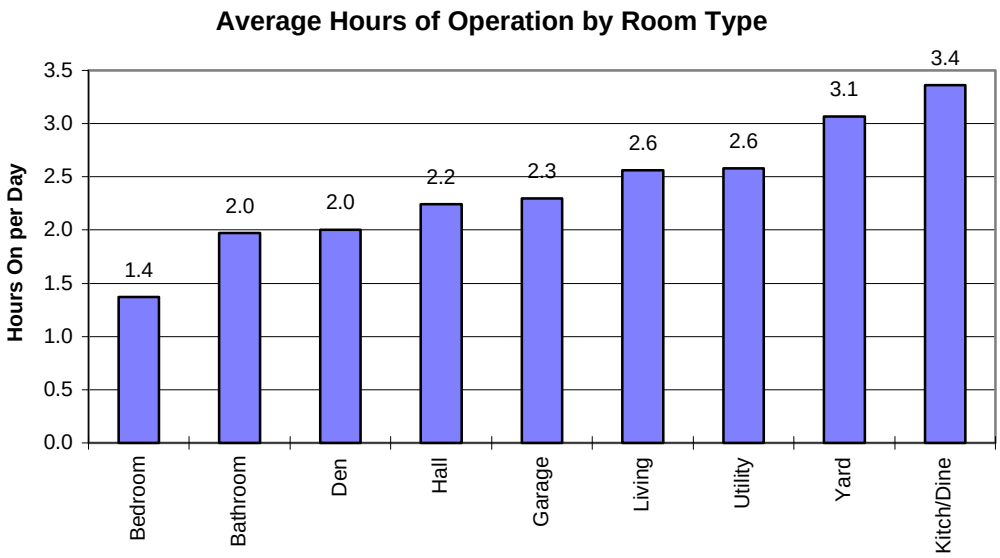


Figure 2-19 - Average Hours of Operation by Room Type

The graphs below help us to understand these average values in greater detail. Figure 2-20 shows the typical pattern showing the percentage of all fixtures which are on for a given number of hours per day[4]. Nine percent are always off, 48% are on for one hour or less per day, 17% are on for two hours per day, and 3% are on for 12 or more hours per day. It is interesting to compare this pattern to two extremes, the room types with highest and lowest average hours of

[3] This 2.34 hrs/day is calculated based on total statewide residential lighting kWh divided by total installed wattage. A similar value can also be calculated averaging the hours of operation for all fixtures, rather than all wattage. That value is 2.43 hr/day. The difference is because more efficient, and lower wattage fixtures tend to have longer hours of operation.

[4] Actually these next three graphs shift the peak towards slightly longer hours of operation. The data were binned hourly by "always off," "one hour or less," two hours or less," etc. Thus, a continuous plot might shift the peak even further to the left by 1/3 or 1/2 hour.

operation, bedrooms at 1.4 hrs per day, and kitchen/dining rooms at 3.4 hrs per day.

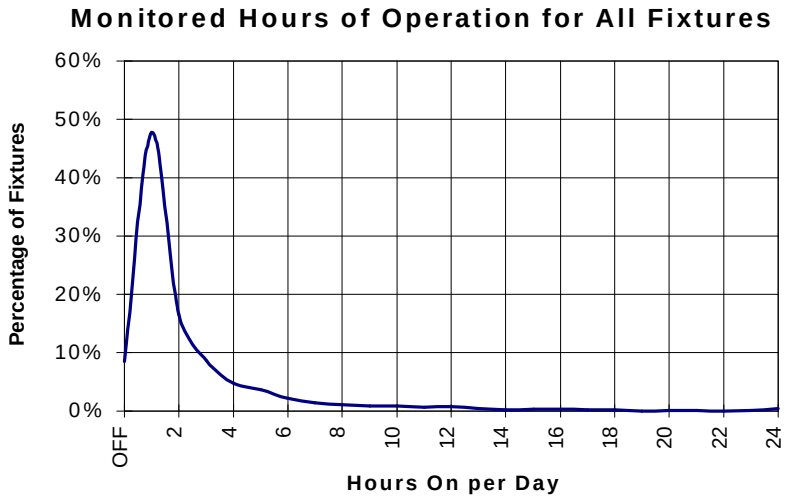


Figure 2-20 - Monitored Hours On per Day for All Fixtures

The plot for kitchen/dining rooms in Figure 2-21 below shows a much broader shoulder as more fixtures are used for longer hours. There are fewer fixtures which are never turned on (4%), fewer on for just one or two hours, and more fixtures on 4 and 6 hours per day. A slight increase in the percentage of fixtures on for 12 or more hours per day (totaling 4%) also has a significant impact on the average hours or operation for all fixtures.

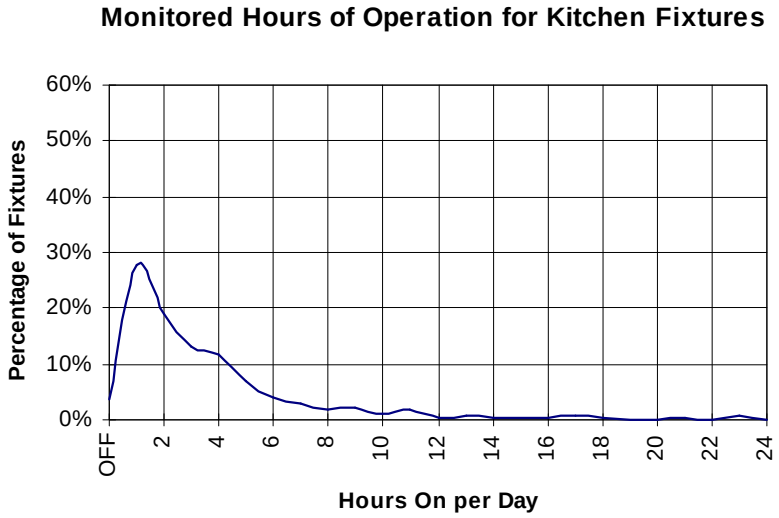


Figure 2-21 -Monitored Hours On per Day for Kitchen Fixtures

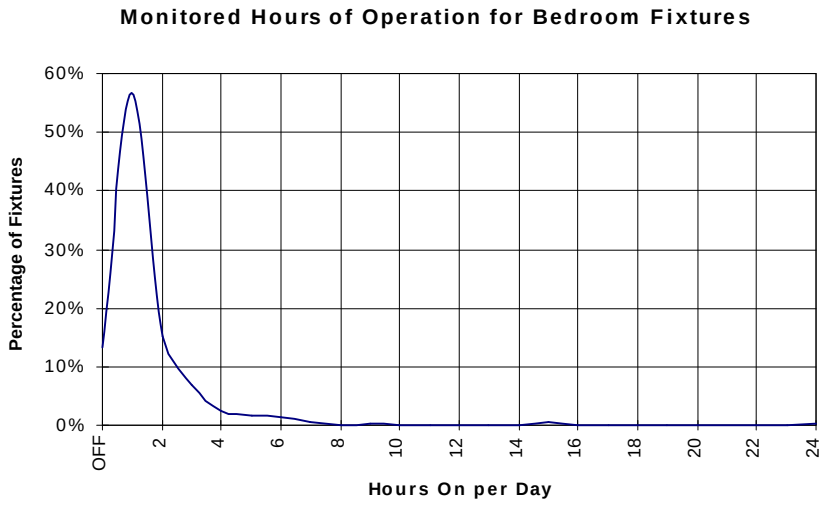


Figure 2-22 - Monitored Hours On per Day for Bedroom Fixtures

The plot for bedrooms in Figure 2-22 has the opposite trends. In comparing with kitchen/dining rooms, a greater percentage are never turned on (13%), and the majority of fixtures (57%) are only turned on for one hour or less per day. In bedrooms, only 1% of the fixtures are left on for 12 or more hours per day.

Hours of Operation by Luminaire Type

The energy characteristic of luminaires are summarized in Figure 2-23 below. This chart includes detailed hours of operation by luminaire type, and also the percentage of all fixtures, percentage of installed watts statewide, and percentage of statewide energy use.

Fixture Type		Luminaire	% of all Fixtures	% of all Watts	Avg. Hrs per Day	% of all kWh
INDOOR FIXTURES*:						
CEILING	RECESSED	CANS	7.8%	9.7%	2.04	8.4%
CEILING	RECESSED	TROF/COVE	3.8%	4.1%	3.79	6.6%
RECESSED Subtotal			11.5%	13.7%	2.56	15.0%
CEILING	SURFACE	DECOR/UTIL	10.7%	10.2%	1.97	8.6%
CEILING	SURFACE	KITCHEN	1.2%	0.8%	3.95	1.3%
CEILING	SURFACE	TRACK	9.3%	9.1%	2.69	10.4%
SURFACE Subtotal			21.2%	20.1%	2.37	20.4%
CEILING	SUSPENDED	PENDANT	6.1%	5.0%	2.18	4.7%
CEILING	SUSPENDED	CHANDELIER	3.6%	8.0%	2.42	8.3%
SUSPENDED Subtotal			9.6%	13.0%	2.33	13.0%
CEILING MOUNTED Total			**42.4%**	**46.9%**	**2.41**	**48.4%**
WALL	MOUNTED	SCONCE	3.6%	2.6%	1.94	2.2%
WALL	MOUNTED	VANITY	7.1%	8.8%	1.93	7.3%
WALL MOUNTED Total			**10.6%**	**11.5%**	**1.93**	**9.5%**
UNDER	CABINET	KITCHEN	1.8%	0.9%	2.32	0.9%
UNDERCABINET Total			**1.8%**	**0.9%**	**2.32**	**0.9%**
TABLE	LAMP	SMALL	3.7%	1.5%	1.61	1.0%
TABLE	LAMP	LARGE	15.2%	14.1%	1.99	12.1%
TABLE LAMP Total			**18.8%**	**15.6%**	**1.96**	**13.1%**
FLOOR	LAMP	TORCHIER	0.7%	2.1%	2.31	2.1%
FLOOR	LAMP	TRADITIONAL	2.8%	2.9%	2.30	2.8%
FLOOR	LAMP	TASK	0.5%	0.4%	2.18	0.3%
FLOOR LAMP Total			**4.0%**	**5.4%**	**2.30**	**5.3%**
OTHER	INDOOR		9.6%	7.6%	2.32	7.6%
ALL INDOOR Total			**87.2%**	**87.9%**	**2.25**	**84.7%**
OUTDOOR FIXTURES:						
OUTDOOR	CEILING		1.8%	1.5%	3.10	2.0%
OUTDOOR	WALL	FLOOD	1.3%	3.0%	2.06	2.6%
OUTDOOR	WALL	LANTERN	8.6%	6.7%	2.97	8.6%
OUTDOOR	WALL	BARN	0.1%	0.1%	10.55	0.4%
OTHER	OUTDOOR		1.0%	0.8%	5.16	1.7%
ALL OUTDOOR Total			**12.8%**	**12.1%**	**2.96**	**15.3%**
Grand Total			**100.0%**	**100.0%**	**2.33**	**100.0%**

Figure 2-23 - Hours of Operation by Luminaire Type

While these numbers are interesting, they are the least precise presented in this section. Any category representing less than 1% of all fixtures will have relatively high uncertainty in the resulting average energy characteristics. Also, these luminaire types are analyzed only for the top 30 application types. Thus, the figure for undercabinet includes only undercabinet fixtures in kitchens. All of the undercabinet fixtures are lumped into "Other-Indoor". The definition of these luminaire types might easily be misinterpreted, so please refer to the appendix of Volume II for full definitions of each luminaire type.

Hours of Operation by Lamp Type

Average hours of operation were found to vary significantly by lamp type. Average hours of operation, and average bulb wattage for each major lamp technology are summarized below in Figure 2-24, along with average wattage per lamp type.

Technology	Avg. Hrs per Day	Avg. Watts/Lamp
Overall Average	**2.33**	**58**
Incandescent	2.22	62
Halogen	2.66	145
Fluorescent	3.10	37
HID	8.81	72

Figure 2-24 - Hours of Operation by Lamp Technology

People apparently use more efficient lamp technologies for fixtures that they operate for longer hours. These values should not be interpreted to have a causal relationship. They could be a result of many factors. The low hours of operation for incandescents could be a result of a greater proportion of incandescent lamps having 0 hours of operation. For example, incandescent light bulbs in closets which are always off or rarely used decorative table lamps may significantly bring down the overall average for incandescents. For extended periods of work, people may selectively choose to operate a more powerful, full-size fluorescent fixture instead of a neighboring smaller incandescent fixture, and then use the smaller incandescent just for short tasks. Fluorescent fixtures may selectively get left on as night lights more often than incandescent fixtures, which would also bring up their overall average hours of operation. Likewise, people may selectively install compact fluorescent lamps in fixtures that they know that they use the most, just as most utility DSM campaigns have encouraged them to do.

These theories tend to be borne out by a more detailed look at the monitored hourly data for kitchens in the TPU data set. Analysis suggests that fluorescent fixtures are selectively operated for longer hours, especially 12 or more hours per day. This is illustrated in Figure 2-25, below. Whereas 30% of all TPU kitchen fixtures are fluorescent, 70% of those operating for 12 or more hours are fluorescent. This graph also shows that fixtures which are typically off, or on for one hour or less per day, are disproportionately incandescent. While 69% of the TPU kitchen fixtures overall are incandescent, 76% of those which are always off and 77% of those on for one hour or less per day are incandescent.

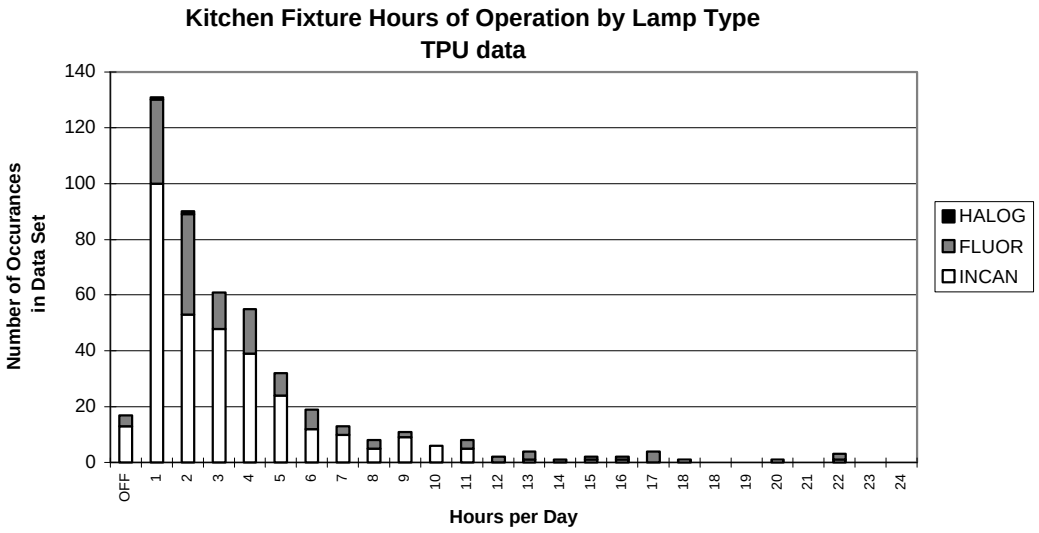


Figure 2-25 - Hours of Operation by Lamp Type, for TPU Kitchens

The Edison monitored data also bears out the assumption that more efficient lamps are selectively used for longer hours of operation. Across all indoor fixtures, the Edison monitored data found that 26% of fluorescent fixtures, while only 14% of incandescent fixtures, were on for 4 or more hours per day, as show below in Figure 2-26.

Hours of Operation	Incandescent Lamps	Fluorescent Lamps
Less than 1 hr/day	31.1%	14.3%
1 - 4 hrs/day	55.3%	60.0%
4 - 8 hrs/day	12.5%	21.4%
8 or more hrs/day	1.0%	4.3%

Figure 2-26 - Hours of Operation by Lamp Type, SCE Monitored

Average hours of operation by lamp type does not seem to vary significantly by the size or wattage of the lamp when looked at in the greater detail. Figure 2-27 is a chart which sorts each lamp technology into bins of wattage sizes. Average

wattage for each bin, average hours of operation per day, percentage of total state-wide installed watts and percent of total state-wide residential lighting energy use is also summarized. It can be seen that the largest group is incandescent lamps between 51 to 100 watts, which represent 59% of statewide energy use for residential lighting. It can also be seen that almost 90% of the installed fluorescent lighting energy use is represented by full size fluorescents, 31 watts or greater, with an average wattage of 43 watts and 2.2 lamps per fixture, operating 3.11 hours per day.

Lamp Type	Wattage Bin	Avg. Watts per Lamp	Sockets per Fixture	% of total State Watts*	Avgerage Hours per Day	% of Total State kWh*
Incandescent	**Overall Avg**	**62**	**1.6**	**86.8**	**2.22**	**82.6**
INCAN1	1-50	32	2.1	15.2	2.32	15.1
INCAN2	51-100	73	1.3	61.9	2.22	58.8
INCAN3	101-150	147	1.3	5.6	2.30	5.5
INCAN4	151+	217	1.2	4.1	1.82	3.2
Halogen	**Overall Avg**	**145**	**1.2**	**3.3**	**2.66**	**3.7**
HALOG1	1-50	43	1.6	0.3	2.54	0.3
HALOG2	51-150	99	1.3	0.6	2.81	0.7
HALOG3	151+	301	1.0	2.4	2.64	2.7
Fluorescent	**Overall Avg**	**37**	**1.9**	**9.6**	**3.10**	**12.7**
FLUOR1	1-19	15	1.3	0.3	3.28	0.4
FLUOR2	20-30	22	1.3	0.7	3.13	0.9
FLUOR3	31+	43	2.3	8.5	3.11	11.4
HID	**Overall Avg**	**72**	**1.8**	**0.2**	**8.81**	**0.7**
HID1	1-100	64	3.1	0.1	8.43	0.3
HID2	100+	182	1.3	0.1	9.22	0.3
Other	**Overall Avg**	**7**	**1.3**	**0.2**	**2.56**	**0.2**
OTHER1	1-100	54	1.2	0.2	2.86	0.2
OTHER2	101+	204	1.0	0.0	0.11	0.0
All Lamps	**Overall Avg**	**58**	**1.6**	**100%**	**2.33**	**100%**

Figure 2-27 - Detail of Lamp Technology Characteristics, by Wattage Bins

Long Hours of Operation

Long hours of operation are of particular interest for two reasons. First those fixtures with the longest hours of operation use the most energy over the course of the day. In general, the classic 80/20 rule seems to apply here, in that often about 80% of the energy is consumed by about 20% of the fixtures. This ratio obviously varies by room and fixture type, as discussed further below.

Secondly, those fixtures with long hours of operation are the best candidates for a retrofit with more efficient lamps and/or a control system to reduce the net hours of operation. There will be the greatest energy savings, and the fastest payback for efficiency improvements for these fixtures.

Twenty two percent of the respondents to Edison survey reported that their homes had at least one fixture that operated 12 or more hours per day. When the sample weights and self-reporting hourly correction factor were applied, the estimate of this percentage is raised to almost 40%. The actual percentage may be somewhere in between[5]. Those homes that had at least one fixture operating for 12 hours or more, averaged 2.5 fixtures operating for those long hours. In other words, only a minority of homes seem to operate fixtures for very long hours, but when they do, they usually are running 2 or 3 fixtures in that manner.

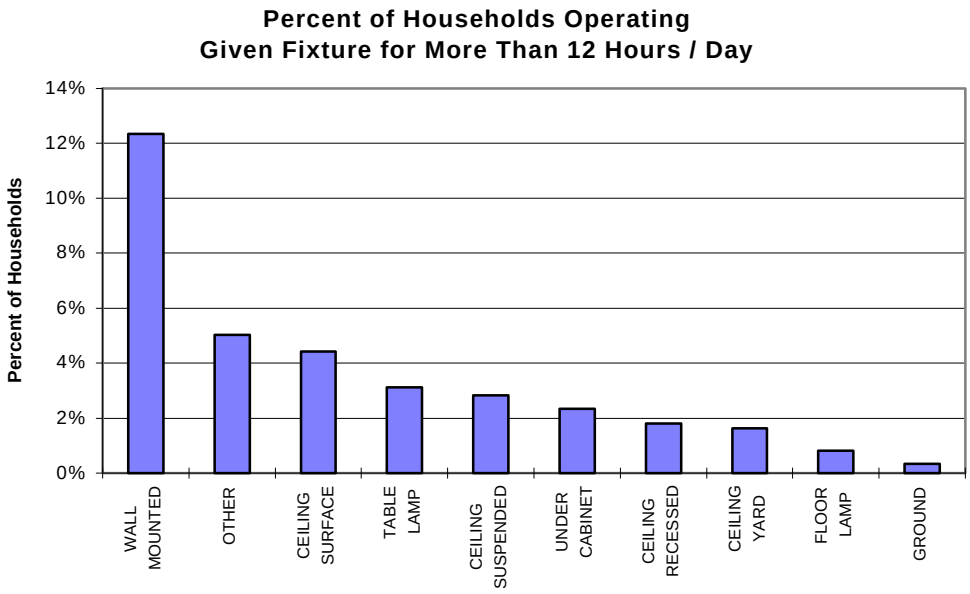


Figure 2-28 - Percent of Households Operating Given Fixture for More than 12 Hours per Day

It is clear from Figure 2-28 that wall mounted fixtures are the largest category of fixtures which are operated for long hours. At least one wall mounted fixture (and rarely more than one) is operating for more than 12 hours per day in slightly more than 12% of all households. The majority of these are outdoor wall mounted fixtures, however, all nine room types have a significant number of wall mounted fixtures with long hours of operation.

[5] The two values are presented here to establish a range of probable values. If a household reported that a fixture operates for 12 hours or more there is a high certainty that indeed it does, since over-reporting hours of use is an uncommon error. On the other hand, self-correction factors could easily have incorrectly pushed hours of use for some fixtures beyond the 12 hour point, over representing the proportion of homes operating their fixtures in this manner in the weighted data analysis. All other numbers presented in this section are based on the weighted, corrected data set.

Ceiling fixtures are the next most common, with 2%, 3% and 4% of all households having at least one recessed, suspended or surface mounted ceiling fixture operating for more than 12 hours. Again, of the households that do this, there is generally only one of that fixture type being operated that way, suggesting that it is not a case of general forgetfulness, but rather a conscious selection of one particular fixture to act as a night light or security light per house.

Outdoor wall mounted fixtures had an average of 2.03 hours per day, but 74% of total energy use is consumed by fixtures representing only 17% of the total installed watts, from those fixtures operating 6 or more hours per day. This is illustrated below in Figure 2-29.

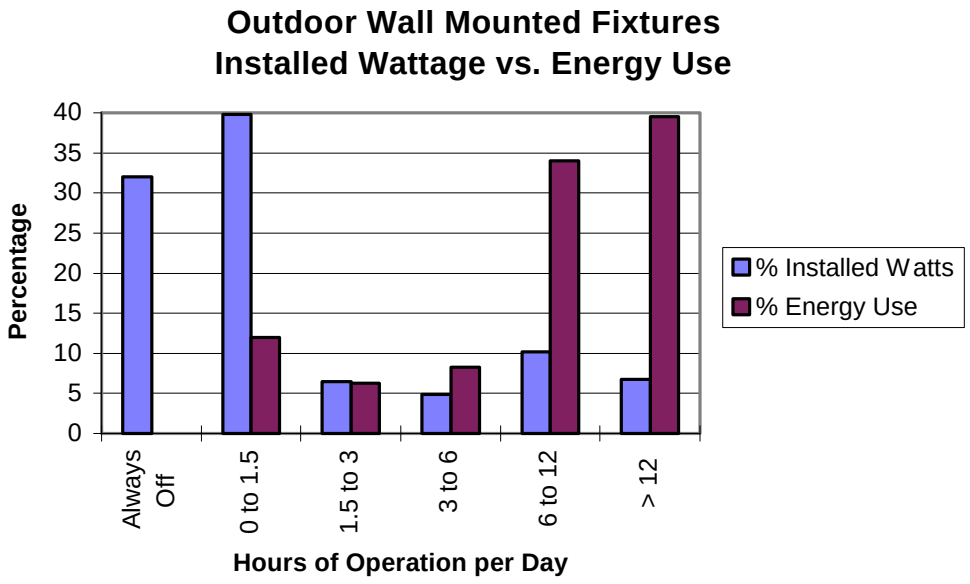


Figure 2-29 - Outdoor Wall Mounted Fixtures, Hours of Operation, by Bin

For living room table lamps, 15% of the installed watts account for 40% of the energy use, for lamps used for 6 hours or more per day. 20% of the installed watts are never turned on at all, i.e. they have 0 hours of operation, and 22% are on for less than 1.5 hours per day.

Although the average hours of operation are relatively short for kitchen ceiling mounted fixtures, there is a significant amount of energy consumed by fixtures left on for long periods, i.e. for 6 or more hours per day. Kitchen surface mounted fixtures average 3.5 hours of operation, but 16% of the installed watts use 89% of the energy by operating for 6 or more hours per day. Similarly, 18% of the installed watts for recessed kitchen fixtures use 88% of the total energy by

operating for 6 or more hours per day, while the average hours of operation is 3.7 hours per day.

Seasonal Variation in Long Hours of Operation

Tacoma Public Utilities found a significant seasonal variation in patterns of long hours of operation with their monitored data. The areas with the most fixtures used for an extended period (an average of 3 or more hours per day) are the kitchen, living room, and outdoor porches. Depending on the monitoring season, these areas had from 30 to 50% of their fixtures operating for these extended hours. Bedrooms and bathrooms had only 10% to 20% of their fixtures operating for longer hours. Overall, 20% to 25% of all household fixtures were found to operate for 3 or more hours per day. This information is presented in Figure 2-30 below.

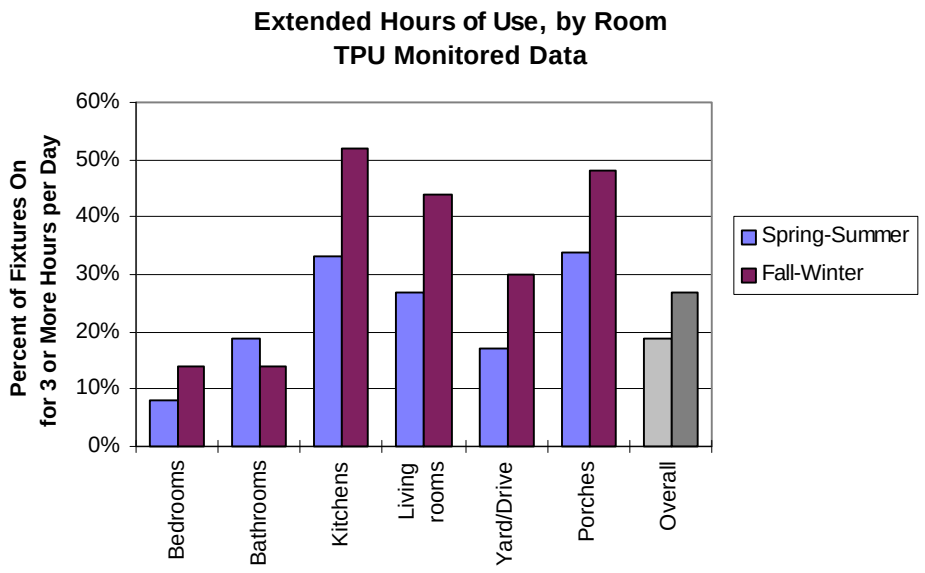


Figure 2-30 - Extended Hours of Use, by Room Type, TPU Data

Controls

The self-reported hours of operation from the Edison inventory were not considered reliable enough to study average hours of operation by control types. While people might be expected to have some knowledge of how much they operate a fixture that they directly switch on and off, they are less likely to be aware of how long a fixture which is under an automatic control is really operating. Instead, we analyzed the impact of control types on hours of operation directly from the TPU monitored data set, avoiding a self-reporting error. See Section 2.6.2 for a discussion of the analysis.

The total duration of use is likely to vary from California to the Northwest, therefore we have calculated the impact of control types as a multiplier on the average hours of operation for on-off controls rather than presenting the information as average hours of operation per control type. These multiplier values, presented in Figure 2-31, below, are most accurately applied by multiplying the control type multiplier times the average hours of operation for on-off switches for the applicable residential lighting application.

These numbers imply that while some control types are associated with shorter hours of operation than a typical on-off switch, there are others that are associated with significantly longer hours of operation. Perhaps most interestingly, photo-sensors located outdoors are found to increase the effective hours of use by a factor of 4. Outdoor motion detectors also seem to be associated with longer hours of operation, with an increase of 14%.

Control Type	Hours of Use Multiplier
Motion Detector, indoor	0.46
3-Way Switch, low hours	0.57
Scheduler, yard	0.84
Dimmer	0.92
On-Off Switch	1.00
Timer	1.10
Motion Detector, yard	1.14
3-Way Switch, high hours	1.25
Photo-sensor, indoor	2.37
Scheduler, indoor	2.61
Photo-sensor, outdoor	3.94

Figure 2-31 - Hours of Use Multipliers for Control Types

The level of certainly of these numbers is low because the number of monitored controls is generally quite small, with the exception of on-off switches, 3-way switches and dimmers[6]. Nor can any casual effect be interpreted from these numbers. Changing a fixture from an on-off switch to a dimmer will not necessarily reduce its hours of operation by 8%. More likely, dimmers are just selectively installed on fixtures that tend to have shorter than average hours of operation.

[6] Sample sizes from the TPU data for control types are: on-off switches--3,500, 3-way switches--335, dimmers--187, motion detectors--45, photocells--39, timers--28, total--4,134

Fifty-one percent of small HIDs and 42% of large HIDs use simple on-off switches. While 34% of small HIDs are on schedulers, 15% are on photo-controls. Motion detectors are reportedly used for 35% of large HIDs[7], with 23% of large HIDs on photo-controls.

Controls are much more common with halogens than any other lamp type, and the larger the halogen, the more likely it is to be on a control. Only 47% of all halogen watts are on on-off switches, the same installed wattage is also on dimmers. Motion detectors control 3% of the halogen wattage.

2.4.3 Load Profiles

The patterns of load shapes of residential lighting fixtures (average load in watts per bulb) and the diversity profiles (percent of time a given fixture is operating per hour) are very similar in appearance. They generally have a major peak at about 8 PM and a minor peak in the morning around 7 am.

The information for load shapes is presented in Figure 2-32 for four major fixture types. Table lamps and floor lamps are seen to have their most significant peak in the evening, while ceiling and wall fixtures have a lesser evening peak and more even distribution of load throughout the day.

[7] A motion detector would seem to be an incompatible technology with most HID lamps, since the long strike and longer re-strike time of most HID lamps would be contraindicated by frequent switching often caused by motion detectors. While this statistic may indicate a problem with the data, we could not go back to the individual sources to resolve the discrepancy.

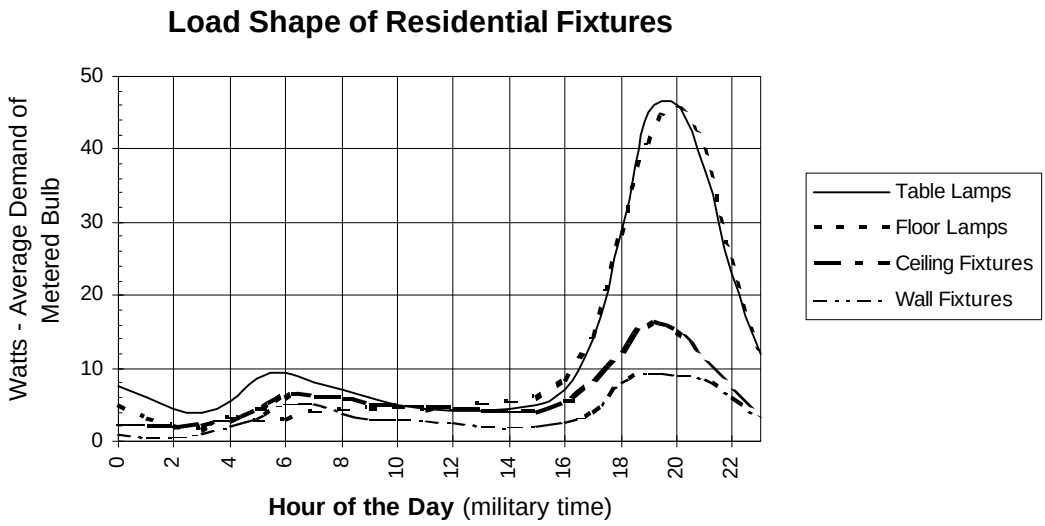


Figure 2-32 - Load Shapes by Fixture Type

The diversity profile by room type, or "percent of fixtures on" for a given hour, follows a very similar pattern. This information is presented below in Figure 2-33. Living rooms and dens, which are most commonly lit with floor and table lamps, follow the high evening peak of such lamps, while bathrooms and hallways, more commonly lit by wall and ceiling fixtures, follow the lower profile pattern for those fixtures.

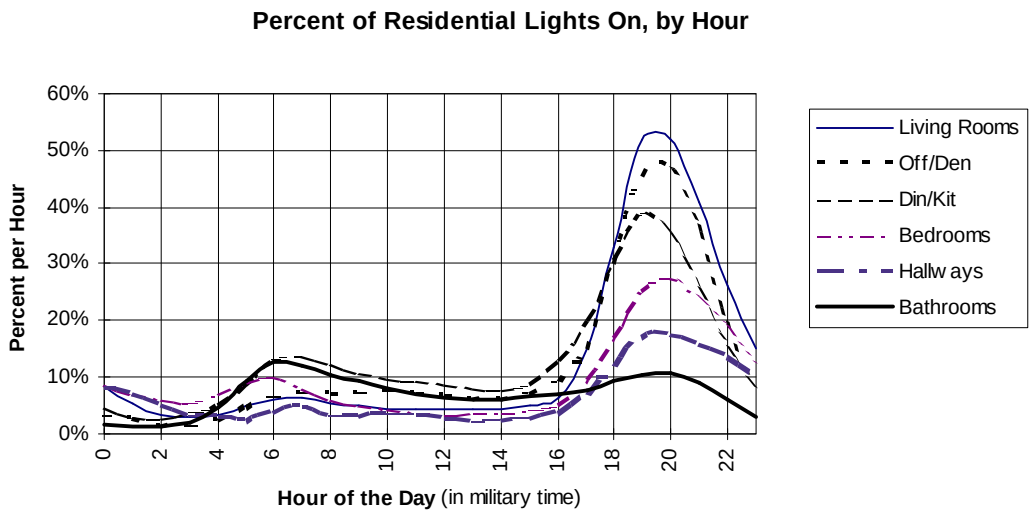


Figure 2-33 - Percent of Lights On, by Hour, by Room

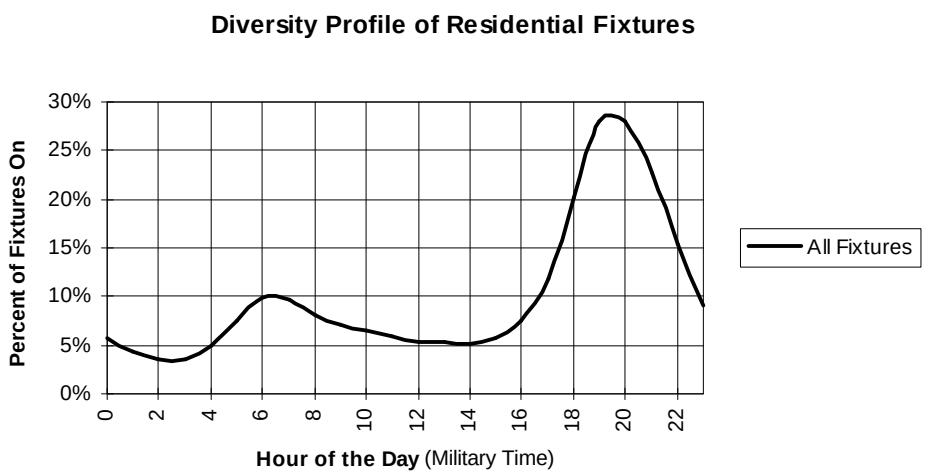


Figure 2-34 - Percent On by Hour, All Fixtures

The information in Figure 2-33 is summed in Figure 2-34[8], also accounting for the frequency of each room type within the general population. It should be remembered that none of these load shapes include outside lights, or lights in garages or utility spaces.

[8] The plot in Figure 2-34 is very similar to the summary plot presented on page IV of the Edison report, with the exception that the evening peak is slightly lower, at 28% vs. 34% in the Edison report. The summation methodology for the Edison report is not known.

Weekly and Monthly Patterns of Hours of Operation

The values presented above should be interpreted as yearly averages. In addition to the time-of-day variations in load described above, residential lighting also should be expected to have monthly or seasonal variations and also day-of-the-week variations.

Residential lighting hours of operation have generally been observed to be longer in the winter and shorter in the summer. Nighttime comes 2 to 3 hours earlier in the winter than in the summer, and people tend to spend more time at home and indoors in the winter. There is also some variation to be expected between weekday operation with working and school schedules, and weekend operation when people are more likely to have leisure time.

The Edison report notes that the summer weekday lighting load peaks at 8 PM while in the winter it peaks at 7pm, maintaining the same basic shape for both weekdays and weekends. The much smaller morning peaks occur at 6 am for both seasons' weekdays, and occur later on weekends, 7 am in summer and 8 am for winter weekends.

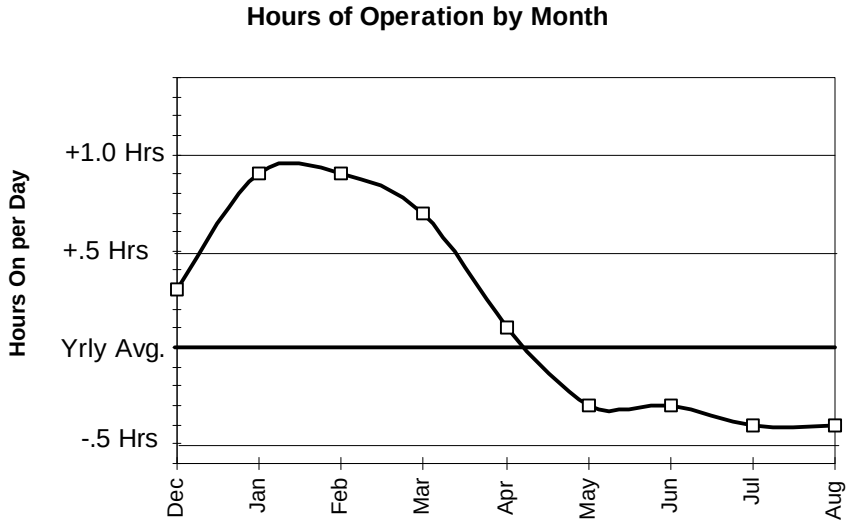


Figure 2-35 - Average Hours of Operation, by Month

Figure 2-35 is derived from the Edison monitored data[9]. This study found about a one hour variation between the highest average hours of operation in January and February, and the lowest average hours of operation in July and August.

[9] Andrew Goett, HBRS, Inc., *Residential Lighting Study: Time-of-Use Metering Results*, prepared for Southern California Edison Company, Ed Lovelace, project manager 1993.

This variation would seem to be most obviously related to the amount of daylight available; however the curve does not strictly follow the length of daylight available per month. Rather, the highest use lags winter solar solstice in December by one or two months, and the lowest use lags summer solar solstice in June by one or two months. The plot more closely follows the average daily temperature and traditional summer and winter behavior patterns. The usage in April, the month after the solar equinox, most closely approximates the yearly average. Data are not available for the months September through November.

It should be noted that the Edison monitored data did not include all household fixtures, but rather only those in five main room types: living room, kitchen/dining, hallways, bedrooms and bathrooms. Outdoor lights are most notably excluded, and are likely to have a more exaggerated seasonal pattern of variation, more closely tied to the length of days. The Edison monitored study also focused on the most commonly used fixtures within each room. The one hour variation found between summer and winter average usage might be reduced in magnitude if less commonly used fixtures had also been included.

The Tacoma Public Utilities study also found a seasonal pattern of variation, reported as a 1/3 reduction in total lighting energy use during the spring and summer combined compared to fall and winter.[10]

2.4.4 Trends

Increases in Installed Wattage

The Edison data set was analyzed by vintage of the homes to see if there were any clear trends in lighting energy use in California homes that could be observed. 73% of the homes in the sample were built before 1978 and 27% after 1978, when the Title 24 Residential Energy Standards first went into effect.

Statistical regression analysis was used to isolate the effects of the age of a home relative to the amount of installed wattage per household.

It was observed that over time California homes have consistently been increasing their installed lighting wattage per household by 10 Watts per year, or 100 Watts per decade. This represents about a 0.5% increase in installed wattage per household per year relative to the average of all stock. This was observed with 99% certainty, and a 3.7 Watts standard error. The Watts per household regression is detailed in Figure 2-41.

[10] Tribwell, Lyle and David Lerman, Tacoma Public Utilities, *Baseline Residential Lighting Energy Use Study*, in 1996 ACEEE Summer Study on Energy Efficiency in Buildings.

This increase in wattage is largely explained by a correlated increase observed in square footage per home of about 5.4 square feet per year, at 1.5 Watts of installed lighting per additional square foot in the home. There is a very slight increase in installed wattage, 1.6 Watts/home, which is observed to be independent of the square footage increase, and has much less certainty.

Performing the same kind of analysis on energy use per home resulted in observing a 9 kWh increase in energy use per home per year built. This was observed with 95% certainty and a 4.5 kWh standard error. This also represents a 0.5% increase in energy use per year. The energy use per household regression is detailed in Figure 2-42 below.

Changes in Installed Wattage by Lamp Type

Changes in the patterns of installed wattage per vintage of home were also studied for control types, fixture types, and lamp types. No clear patterns or trends were observed for control types or fixture types. The installation rates of lamp types, however, did have some interesting patterns in California homes.

The households in the sample were grouped into four time periods by the age of their home, related to changes in the Title 24 residential energy standards. The installed wattage of the four basic lamp groups were compared by the age of the homes, as illustrated below in Figure 2-36. There is a clear dip in the installation of incandescent wattage in the 1978-1983 time period when the Title 24 Residential Standards first went into effect, and then a rebound to even higher levels in the later years.

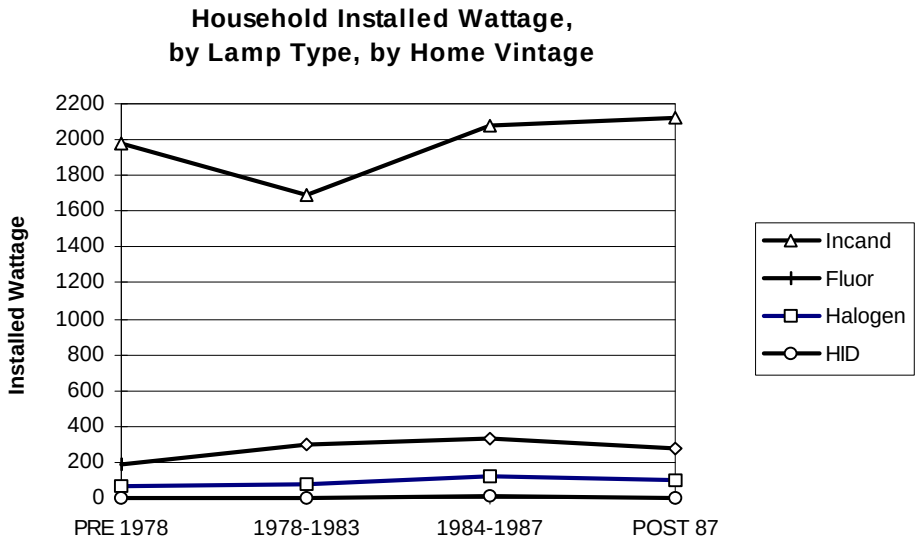


Figure 2-36 - Installed Wattage, by Lamp Type, by Vintage of Home

A closer look at the sizes of incandescent and fluorescent lamps is presented in the two graphs below. Figure 2-37 graphs changes in rates of installing incandescent lamps, and Figure 2-38 looks at the installation rates of fluorescent lamps.

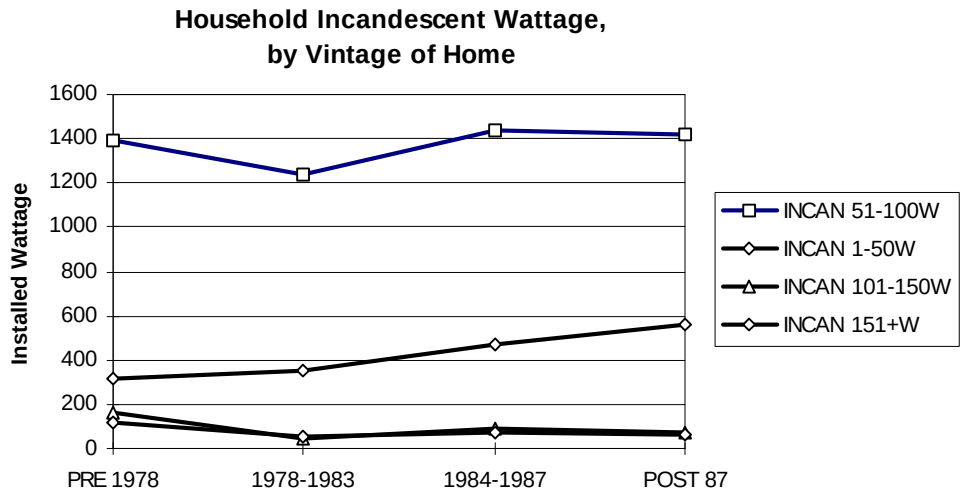


Figure 2-37 - Household Incandescent Wattage, by Vintage of Home

The smallest incandescent wattage lamps, in the range of 1-50 Watts, are seen to increase steadily in installed wattage over time, by about 20% per year. The larger incandescents, from 51-100W, 101-150W, and 151+W, all have a significant drop in installation rates in the 1978-1983 time period, with a rebound

afterwards. The mid-sized incandescents return to slightly higher installation levels, and the larger two groups remain below the initial pre-1978 levels.

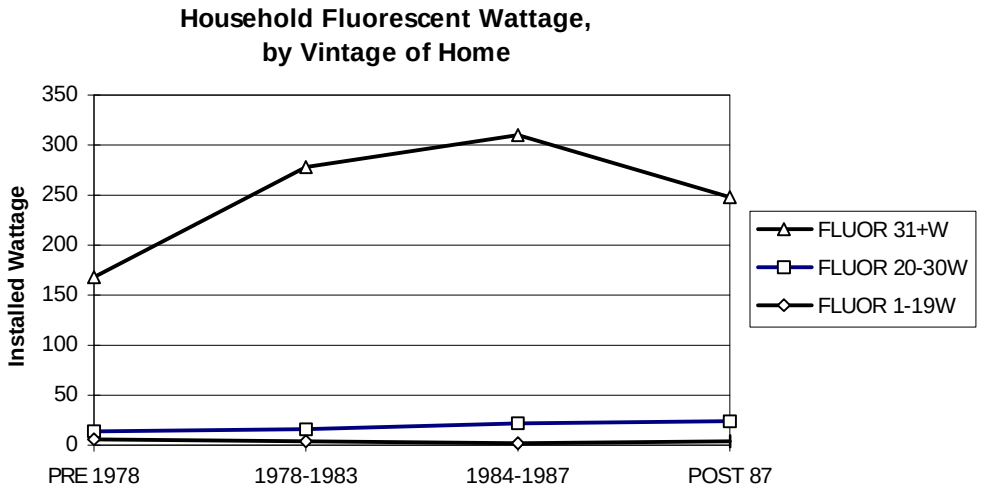


Figure 2-38 - Household Fluorescent Wattage, by Vintage of Home

Large fluorescent lamps, basically standard four foot tubes, are show to increase dramatically with the implementation of Title 24 residential standards in 1978, increase again in the next time period, and then drop substantially in homes built after 1987. Smaller 20-30W fluorescents, most likely circline lamps and two foot tubes, have a minor increase in homes over time, and the smallest, 1-19W compact fluorescents are very stable over time, suggesting that they have been primarily a retrofit technology equally distributed across homes of all vintages.

Taking a similar look at these patterns specifically for kitchen & dining rooms, and then for bathrooms, in Figure 2-39 and Figure 2-40 below, we see the same dramatic dip in installed incandescent wattage in the 1978-1983 period, with a strong rebound after. Fluorescent use in both cases increases strongly and then declines somewhat.

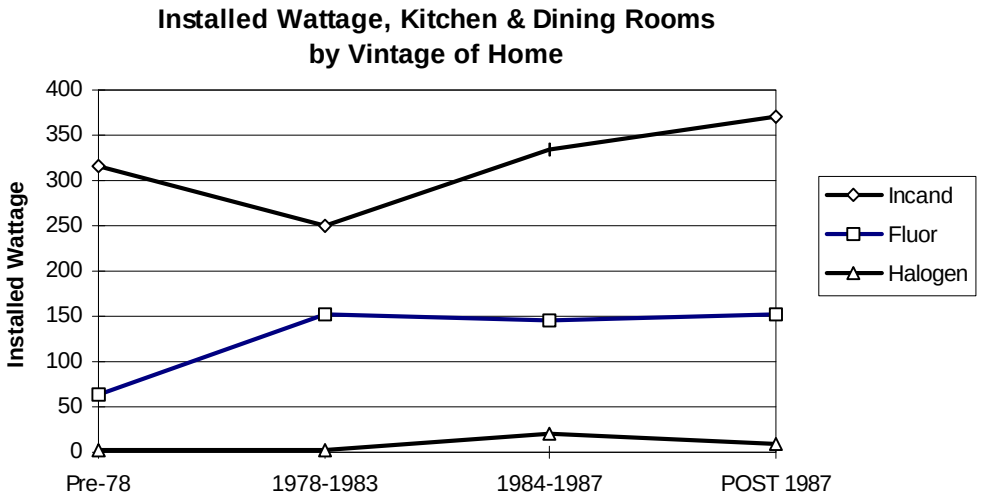


Figure 2-39 - Installed Wattage, Kitchen/Dining Rooms, by Vintage of Home

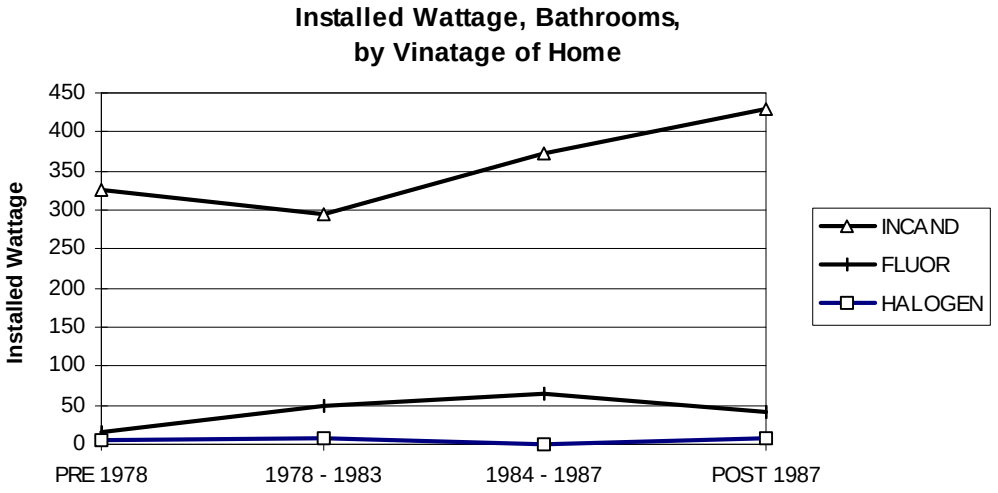


Figure 2-40 - Installed Wattage, Bathroom, by Vintage of Home

The percentage of fluorescent wattage in kitchen and dining rooms combined reached a peak in 1978-1983 at 38% of installed watts and about 73% of installed lumens. Fluorescent installation in bathrooms reached a peak in 1984-1989 at 15% of installed watts and about 38% of installed lumens.

These numbers can also be compared to the Title 24 studies reported in Section 2.5. It should be remembered that the study of Edison data discussed above combines all data for kitchens and dining rooms, while the other studies reported in Section 2.5 can distinguish results for kitchens alone.

Regression Equations

Model: Model1
Dependant Variable: Watts

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	P Value	Prob>F
Model	2	2.8919	1.4459342	42.251	0.0001
Error	537	1.8377	34,222,519,828		
C total	539	2.1269			

Root MSR	184,993.30	R-Square	0.136
Dep Mean	2,274.30	Adj R-Sq	0.1327
C.V.	8,134.08		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for HO: Parameter=0	Prob>|T|
Intercept	1	-18192	7329.3935	-2.482	0.0134
Vintage	1	9.9491	3.7215	2.673	0.0077
SF/MF	1	1286.0644	141.2811	9.103	0.0001

Model: Model1
Dependant Variable: Watts

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	P Value	Prob>F
Model	3	1.0543	3.5144081	175.62	0.0001
Error	536	1.0726	20,011,449,980		
C total	539	2.1269			

Root MSR	141,461.83	R-Square	0.4957
Dep Mean	2,274.30	Adj R-Sq	0.4929
C.V.	6,220.02		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for HO: Parameter=0	Prob>|T|
Intercept	1	-3155.764	5657.1918	-0.558	0.5772
Vintage	1	1.6391	2.8773	0.57	0.5692
Sq. Feet	1	1.5397	0.0787	19.554	0.0001
SF/MF	1	69.2922	124.6753	0.556	0.5786

Figure 2-41 - Regression Equations for Watts per Household

Model: Model1
Dependant Variable: CKWH/YR

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	P Value	Prob>F
Model	2	1.6751	837,561,312,804	16.47	0.0001
Error	537	2.7308	50,853,137,774		
C total	539	2.8983			

Root MSR	225,506.40	R-Square	0.0578
Dep Mean	1,904.84	Adj R-Sq	0.0543
C.V.	11,838.61		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for HO: Parameter=0	Prob>|T|
Intercept	1	-16033	8934.5138	-1.795	0.0733
Vintage	1	8.7769	4.5365	1.935	0.0536
SF/MF	1	970.9359	172.2213	5.638	0.0001

Model: Model1
Dependant Variable: CKWH/YR

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	P Value	Prob>F
Model	3	6.3452	2.1150589	50.078	0.0001
Error	536	2.2638	42,235,225,685		
C total	539	2.8983			

Root MSR	205,512.11	R-Square	0.2189
Dep Mean	1,904.84	Adj R-Sq	0.2146
C.V.	10,788.96		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for HO: Parameter=0	Prob>|T|
Intercept	1	-4286.367	8218.6225	-0.522	0.6022
Vintage	1	2.2846	4.1801	0.547	0.5849
Sq. Feet	1	1.2029	0.1144	10.515	0.0001
SF/MF	1	20.3289	181.1250	0.112	0.9107

Figure 2-42 - Regression Equations for Energy Use per Household

2.4.5 Summary Charts

The following charts provide summary information on residential lighting applications, sorted in several ways, as well as additional energy and operating characteristics.

1. **Residential Lighting Applications, Ranked by kWh**
2. **Residential Lighting Applications, Sorted by Room Type**
3. **Residential Lighting Applications, Sorted by Fixture Type**
4. **Luminaire Types, Ranked by kWh**
5. **Energy Characteristics of Luminaires, Grouped by Fixture Types**
6. **Lamp Energy Characteristics, by Wattage Bin**
7. **Average Hours of Operation per Day for Fixtures with On-Off Switches, Ranked by Hours of Use**
8. **Average Hours of Operation per Day for Fixtures with On-Off Switches, Sorted by Room Type**
9. **Energy Correction Factor for Control Types**

Residential Lighting Applications, Ranked by kWh

Residential Lighting Applications, Ranked by kWh

kWh RANK	Room	Fixture	fixtures 1000s	sockets 1000s	Percent Total Watts	**Percent total kWh**	Cum % total kWh	
1	YARD-PORCH	WALL MOUNTED	22974	28433	8.98%	**10.55%**	10.55	
2	KITCH/DINE	CEILING SUSPENDED	9288	35248	6.65%	**8.33%**	18.88	
3	LIVING ROOM	TABLE LAMP	17322	20456	6.45%	**8.06%**	26.93	
4	KITCH/DINE	CEILING RECESSED	10231	22102	5.02%	**7.62%**	34.55	
5	BATHROOM	WALL MOUNTED	16147	40577	8.85%	**7.29%**	41.84	
6	KITCH/DINE	CEILING SURFACE	10646	17449	4.30%	**6.33%**	48.18	6 = 50%
7	LIVING ROOM	FLOOR LAMP	6118	8355	3.49%	**4.10%**	52.28	
8	BEDROOM	TABLE LAMP	25631	28597	8.11%	**4.03%**	56.31	
9	GARAGE	CEILING SURFACE	5273	8954	2.33%	**3.00%**	59.31	
10	BATHROOM	CEILING RECESSED	7512	11240	4.31%	**2.97%**	62.28	
11	HALL-ENTRY	CEILING SURFACE	9433	11792	2.91%	**2.61%**	64.89	
12	UTILITY	CEILING SURFACE	7443	9126	2.56%	**2.56%**	67.45	
13	BEDROOM	CEILING SURFACE	9941	17242	4.61%	**2.55%**	70.01	
14	LIVING ROOM	CEILING SUSPENDED	4039	11286	2.31%	**1.96%**	71.97	
15	YARD-PORCH	CEILING YARD	4524	6499	1.48%	**1.96%**	73.93	
16	HALL-ENTRY	CEILING RECESSED	5417	6304	1.91%	**1.70%**	75.63	16=75%
17	LIVING ROOM	CEILING SURFACE	2237	4312	1.11%	**1.67%**	77.31	
18	LIVING ROOM	CEILING RECESSED	2321	3106	1.10%	**1.65%**	78.96	
19	BATHROOM	CEILING SURFACE	5994	7947	2.28%	**1.65%**	80.60	
20	GARAGE	CEILING SUSPENDED	4248	8540	1.71%	**1.30%**	81.90	
21	UTILITY	WALL MOUNTED	3597	4512	1.06%	**1.24%**	83.13	
22	BEDROOM	CEILING SUSPENDED	4604	9445	2.13%	**1.07%**	84.20	
23	GARAGE	WALL MOUNTED	2174	2405	0.85%	**1.06%**	85.26	
24	DEN	TABLE LAMP	3061	3630	1.10%	**1.01%**	86.27	
25	BEDROOM	WALL MOUNTED	5194	7079	1.58%	**0.95%**	87.22	
26	KITCH/DINE	UNDER CABINET	4550	5607	0.90%	**0.89%**	88.11	
27	UTILITY	CEILING SUSPENDED	1061	2311	0.43%	**0.80%**	88.91	
28	BEDROOM	FLOOR LAMP	2747	3378	1.51%	**0.78%**	89.69	28 =90%
29	HALL-ENTRY	CEILING SUSPENDED	1537	4752	0.78%	**0.71%**	90.39	
30	YARD-PORCH	OTHER	1137	1768	0.38%	**0.70%**	91.10	
31	UTILITY	OTHER	450	763	0.19%	**0.67%**	91.76	
32	YARD-PORCH	GROUND	691	2138	0.26%	**0.64%**	92.40	
33	KITCH/DINE	WALL MOUNTED	1988	2268	0.45%	**0.63%**	93.03	
34	UTILITY	CEILING RECESSED	1528	2254	0.59%	**0.58%**	93.61	
35	LIVING ROOM	WALL MOUNTED	2157	2836	0.62%	**0.55%**	94.16	
36	KITCH/DINE	OTHER	2041	2541	0.51%	**0.48%**	94.64	
37	HALL-ENTRY	WALL MOUNTED	1771	2106	0.42%	**0.45%**	95.09	
38	BATHROOM	CEILING SUSPENDED	1352	2275	0.65%	**0.43%**	95.53	
39	DEN	FLOOR LAMP	840	1098	0.39%	**0.40%**	95.93	
40	DEN	CEILING SUSPENDED	899	2026	0.48%	**0.40%**	96.34	
41	DEN	CEILING SURFACE	1015	2096	0.46%	**0.35%**	96.69	
42	KITCH/DINE	TABLE LAMP	1075	1108	0.37%	**0.35%**	97.04	
43	YARD-PORCH	FLOOR LAMP	136	439	0.08%	**0.32%**	97.36	
44	GARAGE	CEILING RECESSED	557	1440	0.25%	**0.26%**	97.62	
45	DEN	WALL MOUNTED	963	1258	0.30%	**0.26%**	97.88	
46	BEDROOM	CEILING RECESSED	1401	1979	0.58%	**0.25%**	98.13	
47	DEN	CEILING RECESSED	902	1083	0.35%	**0.23%**	98.36	
48	UTILITY	TABLE LAMP	693	866	0.19%	**0.20%**	98.55	
49	LIVING ROOM	OTHER	810	1408	0.18%	**0.19%**	98.75	
50	GARAGE	TABLE LAMP	273	299	0.09%	**0.17%**	98.91	

Residential Lighting Applications, Ranked by kWh

kWh RANK	Room	Fixture	fixtures 1000s	sockets 1000s	Percent Total Watts	**Percent total kWh**	Cum % total kWh
51	LIVING ROOM	UNDER CABINET	999	1327	0.18%	**0.16%**	99.07
52	GARAGE	OTHER	651	798	0.22%	**0.16%**	99.24
53	KITCH/DINE	FLOOR LAMP	251	262	0.14%	**0.15%**	99.39
54	BATHROOM	OTHER	275	308	0.09%	**0.12%**	99.51
55	BEDROOM	OTHER	935	1098	0.19%	**0.11%**	99.62
56	YARD-PORCH	TABLE LAMP	166	166	0.05%	**0.07%**	99.69
57	GARAGE	UNDER CABINET	344	501	0.11%	**0.07%**	99.77
58	HALL-ENTRY	TABLE LAMP	250	307	0.06%	**0.07%**	99.84
59	BATHROOM	TABLE LAMP	370	414	0.11%	**0.05%**	99.89
60	BEDROOM	UNDER CABINET	709	904	0.13%	**0.03%**	99.92
61	HALL-ENTRY	OTHER	128	251	0.04%	**0.03%**	99.96
62	DEN	UNDER CABINET	286	365	0.06%	**0.03%**	99.98
63	HALL-ENTRY	UNDER CABINET	46	46	0.01%	**0.01%**	100.00
64	DEN	OTHER	90	191	0.02%	**0.01%**	100.00
		Totals	**243,438**	**391,666**		**1.00**	

Residential Lighting Applications, Sorted by Room Type

Residential Lighting Applications, Sorted by Room Type

State wide kWh RANK	Room	Fixture	# fixtures, 1000s	# sockets, 1000s	% of statewide Watts	**% of statewide kWh**	Cum % room kWh in model	% of room kWh modeled
12	UTILITY	CEILING SURFACE	7443	9126	2.56	**2.57**	2.57	
21	UTILITY	WALL MOUNTED	3597	4512	1.06	**1.24**	1.24	
27	UTILITY	CEILING SUSPENDED	1061	2311	0.43	**0.80**	0.80	
31	UTILITY	OTHER	450	763	0.19	**0.67**		
34	UTILITY	CEILING RECESSED	1528	2254	0.59	**0.58**		
48	UTILITY	TABLE LAMP	693	866	0.19	**0.20**		
	UTILITY Total		**14772**	**19831**	**5.03**	**6.04**	**4.60**	**76%**
5	BATHROOM	WALL MOUNTED	16147	40577	8.85	**7.29**	7.29	
10	BATHROOM	CEILING RECESSED	7512	11240	4.31	**2.97**	2.97	
19	BATHROOM	CEILING SURFACE	5994	7947	2.28	**1.65**	1.65	
38	BATHROOM	CEILING SUSPENDED	1352	2275	0.65	**0.44**		
54	BATHROOM	OTHER	275	308	0.09	**0.12**		
59	BATHROOM	TABLE LAMP	370	414	0.11	**0.05**		
	BATHROOM Total		**31649**	**62761**	**16.28**	**12.51**	**11.90**	**95%**
8	BEDROOM	TABLE LAMP	25631	28597	8.11	**4.03**	4.03	
13	BEDROOM	CEILING SURFACE	9941	17242	4.61	**2.55**	2.55	
22	BEDROOM	CEILING SUSPENDED	4604	9445	2.13	**1.07**	1.07	
25	BEDROOM	WALL MOUNTED	5194	7079	1.58	**0.95**	0.95	
28	BEDROOM	FLOOR LAMP	2747	3378	1.51	**0.78**	0.78	
46	BEDROOM	CEILING RECESSED	1401	1979	0.58	**0.25**		
55	BEDROOM	OTHER	935	1098	0.19	**0.11**		
60	BEDROOM	UNDER CABINET	709	904	0.13	**0.03**		
	BEDROOM Total		**51162**	**69722**	**18.83**	**9.78**	**9.39**	**96%**
24	DEN	TABLE LAMP	3061	3630	1.10	**1.01**	1.01	
39	DEN	FLOOR LAMP	840	1098	0.39	**0.40**		
40	DEN	CEILING SUSPENDED	899	2026	0.48	**0.40**		
41	DEN	CEILING SURFACE	1015	2096	0.46	**0.35**		
45	DEN	WALL MOUNTED	963	1258	0.30	**0.26**		
47	DEN	CEILING RECESSED	902	1083	0.35	**0.23**		
62	DEN	UNDER CABINET	286	365	0.06	**0.03**		
64	DEN	OTHER	90	191	0.02	**0.01**		
	DEN Total		**8056**	**11747**	**3.16**	**2.70**	**1.01**	**38%**
9	GARAGE	CEILING SURFACE	5273	8954	2.33	**3.00**	3.00	
20	GARAGE	CEILING SUSPENDED	4248	8540	1.71	**1.30**	1.30	
23	GARAGE	WALL MOUNTED	2174	2405	0.85	**1.06**	1.06	
44	GARAGE	CEILING RECESSED	557	1440	0.25	**0.26**		
50	GARAGE	TABLE LAMP	273	299	0.09	**0.17**		
52	GARAGE	OTHER	651	798	0.22	**0.16**		
57	GARAGE	UNDER CABINET	344	501	0.11	**0.07**		
	GARAGE Total		**13519**	**22937**	**5.56**	**6.02**	**5.36**	**89%**
11	HALL-ENTRY	CEILING SURFACE	9433	11792	2.91	**2.61**	2.61	
16	HALL-ENTRY	CEILING RECESSED	5417	6304	1.91	**1.70**	1.70	
29	HALL-ENTRY	CEILING SUSPENDED	1537	4752	0.78	**0.71**		
37	HALL-ENTRY	WALL MOUNTED	1771	2106	0.42	**0.45**		
58	HALL-ENTRY	TABLE LAMP	250	307	0.06	**0.07**		
61	HALL-ENTRY	OTHER	128	251	0.04	**0.03**		
63	HALL-ENTRY	UNDER CABINET	46	46	0.01	**0.01**		
	HALL-ENTRY Total		**18581**	**25558**	**6.14**	**5.58**	**4.31**	**77%**

Residential Lighting Applications, Sorted by Room Type

State wide kWh RANK	Room	Fixture	# fixtures, 1000s	# sockets, 1000s	% of statewide Watts	**% of statewide kWh**	Cum % room kWh in model	% of room kWh modeled
2	KITCH/DINE	CEILING SUSPENDED	9288	35248	6.65	**8.33**	8.33	
4	KITCH/DINE	CEILING RECESSED	10231	22102	5.02	**7.62**	7.62	
6	KITCH/DINE	CEILING SURFACE	10646	17449	4.30	**6.33**	6.33	
26	KITCH/DINE	UNDER CABINET	4550	5607	0.90	**0.89**	0.89	
33	KITCH/DINE	WALL MOUNTED	1988	2268	0.45	**0.63**		
36	KITCH/DINE	OTHER	2041	2541	0.51	**0.48**		
42	KITCH/DINE	TABLE LAMP	1075	1108	0.37	**0.35**		
53	KITCH/DINE	FLOOR LAMP	251	262	0.14	**0.15**		
	KITCH/DINE Total		**40070**	**86585**	**18.32**	**24.78**	**23.17**	**93%**
3	LIVING ROOM	TABLE LAMP	17322	20456	6.45	**8.06**	8.06	
7	LIVING ROOM	FLOOR LAMP	6118	8355	3.49	**4.10**	4.10	
14	LIVING ROOM	CEILING SUSPENDED	4039	11286	2.31	**1.96**	1.96	
17	LIVING ROOM	CEILING SURFACE	2237	4312	1.11	**1.67**	1.67	
18	LIVING ROOM	CEILING RECESSED	2321	3106	1.10	**1.65**	1.65	
35	LIVING ROOM	WALL MOUNTED	2157	2836	0.62	**0.55**		
49	LIVING ROOM	OTHER	810	1408	0.18	**0.19**		
51	LIVING ROOM	UNDER CABINET	999	1327	0.18	**0.16**		
	LIVING ROOM Total		**36003**	**53084**	**15.45**	**18.35**	**17.44**	**95%**
1	YARD-PORCH	WALL MOUNTED	22974	28433	8.98	**10.55**	10.55	
15	YARD-PORCH	CEILING YARD	4524	6499	1.48	**1.96**	1.96	
30	YARD-PORCH	OTHER	1137	1768	0.38	**0.70**		
32	YARD-PORCH	GROUND	691	2138	0.26	**0.64**		
43	YARD-PORCH	FLOOR LAMP	136	439	0.08	**0.32**		
56	YARD-PORCH	TABLE LAMP	166	166	0.05	**0.07**		
	YARD-PORCH Total		**29,626**	**39,442**	**11.23**	**14.24**	**12.51**	**88%**
	Grand Total		**243,438**	**391,666**	**100.00**	**100.00**	**89.69**	**90%**
	Note: grayed applications are specifically included in the California Lighting Model - residential							
	white applications are grouped into "other indoor" and "other outdoor" in the CLM							

Residential Lighting Applications, Sorted by Fixture Type

Residential Lighting Applications, Sorted by Fixture Type

State wide kWh RANK	Room	Fixture	fixtures 1000s	% of Fixtures	% of statewide Watts	**% of Statewide kWh**
4	KITCH/DINE	CEILING RECESSED	10231		5.11	**7.62**
10	BATHROOM	CEILING RECESSED	7512		4.38	**2.97**
16	HALL-ENTRY	CEILING RECESSED	5417		1.95	**1.70**
18	LIVING ROOM	CEILING RECESSED	2321		1.12	**1.65**
34	UTILITY	CEILING RECESSED	1528		0.60	**0.58**
44	GARAGE	CEILING RECESSED	557		0.25	**0.26**
46	BEDROOM	CEILING RECESSED	1401		0.59	**0.25**
47	DEN	CEILING RECESSED	902		0.36	**0.23**
	CEILING RECESSED Total		**29869**	**12.27%**	**14.36**	**15.25**
6	KITCH/DINE	CEILING SURFACE	10646		4.38	**6.33**
9	GARAGE	CEILING SURFACE	5273		2.38	**3.00**
11	HALL-ENTRY	CEILING SURFACE	9433		2.97	**2.61**
12	UTILITY	CEILING SURFACE	7443		2.61	**2.57**
13	BEDROOM	CEILING SURFACE	9941		4.70	**2.55**
17	LIVING ROOM	CEILING SURFACE	2237		1.13	**1.67**
19	BATHROOM	CEILING SURFACE	5994		2.32	**1.65**
41	DEN	CEILING SURFACE	1015		0.46	**0.35**
	CEILING SURFACE Total		**51982**	**21.35%**	**20.95**	**20.74**
2	KITCH/DINE	CEILING SUSPENDED	9288		6.77	**8.33**
14	LIVING ROOM	CEILING SUSPENDED	4039		2.35	**1.96**
20	GARAGE	CEILING SUSPENDED	4248		1.74	**1.30**
22	BEDROOM	CEILING SUSPENDED	4604		2.17	**1.07**
27	UTILITY	CEILING SUSPENDED	1061		0.44	**0.80**
29	HALL-ENTRY	CEILING SUSPENDED	1537		0.79	**0.71**
38	BATHROOM	CEILING SUSPENDED	1352		0.66	**0.44**
40	DEN	CEILING SUSPENDED	899		0.49	**0.40**
	CEILING SUSPENDED Total		**27028**	**11.10%**	**15.42**	**15.00**
15	YARD-PORCH	CEILING YARD	4524		1.51	**1.96**
	CEILING YARD Total		**4524**	**1.86%**	**1.51**	**1.96**
7	LIVING ROOM	FLOOR LAMP	6118		3.55	**4.10**
28	BEDROOM	FLOOR LAMP	2747		1.54	**0.78**
39	DEN	FLOOR LAMP	840		0.40	**0.40**
43	YARD-PORCH	FLOOR LAMP	136		0.08	**0.32**
53	KITCH/DINE	FLOOR LAMP	251		0.14	**0.15**
		FLOOR LAMP Total	**10092**	**4.15%**	**5.70**	**5.76**
32	YARD-PORCH	GROUND	691		0.27	**0.64**
	GROUND Total		**691**	**0.28%**	**0.27**	**0.64**
3	LIVING ROOM	TABLE LAMP	17322		6.57	**8.06**
8	BEDROOM	TABLE LAMP	25631		8.26	**4.03**
24	DEN	TABLE LAMP	3061		1.12	**1.01**
42	KITCH/DINE	TABLE LAMP	1075		0.38	**0.35**
48	UTILITY	TABLE LAMP	693		0.19	**0.20**
50	GARAGE	TABLE LAMP	273		0.09	**0.17**
56	YARD-PORCH	TABLE LAMP	166		0.05	**0.07**
58	HALL-ENTRY	TABLE LAMP	250		0.06	**0.07**
59	BATHROOM	TABLE LAMP	370		0.11	**0.05**
	TABLE LAMP Total		**48840**	**20.06%**	**16.83**	**14.01**

Residential Lighting Applications, Sorted by Fixture Type

State wide kWh RANK	Room	Fixture	fixtures 1000s	% of Fixtures	% of statewide Watts	**% of Statewide kWh**
26	KITCH/DINE	UNDER CABINET	4550		0.91	**0.89**
51	LIVING ROOM	UNDER CABINET	999		0.19	**0.16**
57	GARAGE	UNDER CABINET	344		0.11	**0.07**
60	BEDROOM	UNDER CABINET	709		0.13	**0.03**
62	DEN	UNDER CABINET	286		0.06	**0.03**
63	HALL-ENTRY	UNDER CABINET	46		0.01	**0.01**
	UNDER CABINET Total		**6933**	**2.85%**	**1.42**	**1.20**
1	YARD-PORCH	WALL MOUNTED	22974		9.14	**10.55**
5	BATHROOM	WALL MOUNTED	16147		9.02	**7.29**
21	UTILITY	WALL MOUNTED	3597		1.08	**1.24**
23	GARAGE	WALL MOUNTED	2174		0.87	**1.06**
25	BEDROOM	WALL MOUNTED	5194		1.61	**0.95**
33	KITCH/DINE	WALL MOUNTED	1988		0.46	**0.63**
35	LIVING ROOM	WALL MOUNTED	2157		0.63	**0.55**
37	HALL-ENTRY	WALL MOUNTED	1771		0.43	**0.45**
45	DEN	WALL MOUNTED	963		0.30	**0.26**
	WALL MOUNTED Total		**56,964**	**23.40%**	**23.54**	**22.97**
30	YARD-PORCH	OTHER	1137		0.39	**0.70**
31	UTILITY	OTHER	450		0.19	**0.67**
36	KITCH/DINE	OTHER	2041		0.52	**0.48**
49	LIVING ROOM	OTHER	810		0.19	**0.19**
52	GARAGE	OTHER	651		0.22	**0.16**
54	BATHROOM	OTHER	275		0.09	**0.12**
55	BEDROOM	OTHER	935		0.19	**0.11**
61	HALL-ENTRY	OTHER	128		0.04	**0.03**
64	DEN	OTHER	90		0.02	**0.01**
	OTHER Total		**6515**	**2.68%**	**1.84**	**2.48**
	Grand Total		**243,438**	**100%**	**100**	**100.00**
	Note: grayed applications are specifically included in the California Lighitng Model - residential					
	white applications are grouped into "other indoor" and "other outdoor" in the CLM					

Luminaire Types, Ranked by kWh

Luminaire Types, Ranked by kWh

kWh Rank	Fixture Type		Luminaire	% Watts	% kWh	Cum % kWh
1	TABLE	LAMP	LARGE	14.1	**12.1**	12.1
2	CEILING	SURFACE	TRACK	9.1	**10.4**	22.5
3	CEILING	SURFACE	DECORATIVE	10.2	**8.6**	31.1
4	OUTDOOR	WALL	LANTERN	6.7	**8.6**	39.7
5	CEILING	RECESSED	CANS	9.7	**8.4**	48.1
Top 5 luminaires = 50% of statewide energy use						
6	CEILING	SUSPENDED	CHANDELIER	8.0	**8.3**	56.4
7		OTHER	INDOOR	7.6	**7.6**	64.0
8		WALL	VANITY	8.8	**7.3**	71.3
9	CEILING	RECESSED	TROFFERS	4.1	**6.6**	77.9
10	CEILING	SUSPENDED	PENDANT	5.0	**4.7**	82.5
11	FLOOR	LAMP	TRADITIONAL	2.9	**2.8**	85.4
12	OUTDOOR	WALL	FLOOD	3.0	**2.6**	88.0
13		WALL	SCONCE	2.6	**2.2**	90.2
Top 13 luminaires = 90% of statewide energy use						
14	FLOOR	LAMP	TORCHIER	2.1	**2.1**	92.3
15		OUTDOOR	CEILING	1.5	**2.0**	94.2
16		OTHER	OUTDOOR	0.8	**1.7**	96.0
17	CEILING	SURFACE	KITCHEN	0.8	**1.3**	97.3
18	TABLE	LAMP	SMALL	1.5	**1.0**	98.4
19		UNDER	CABINET	0.9	**0.9**	99.2
20	OUTDOOR	WALL	BARN	0.1	**0.4**	99.7
21	FLOOR	LAMP	TASK	0.4	**0.3**	100.0

Notes: Many of these luminaires are specific to one or a few room types.
See luminaire definitions in Appendix B
Statewide averages, 1995

Energy Characteristics of Luminaires, Grouped by Fixture Types

Energy Characteristics of Luminaires, Grouped by Fixture Types

Fixture Type		Luminaire	% of all Fixtures	% of all Watts	Avg. Hrs per Day	% of all kWh
INDOOR FIXTURES*:						
CEILING	RECESSED	CANS	7.8%	9.7%	2.04	8.4%
CEILING	RECESSED	TROF/COVE	3.8%	4.1%	3.79	6.6%
	RECESSED Subtotal		11.5%	13.7%	2.56	15.0%
CEILING	SURFACE	DECOR/UTIL	10.7%	10.2%	1.97	8.6%
CEILING	SURFACE	KITCHEN	1.2%	0.8%	3.95	1.3%
CEILING	SURFACE	TRACK	9.3%	9.1%	2.69	10.4%
	SURFACE Subtotal		21.2%	20.1%	2.37	20.4%
CEILING	SUSPENDED	PENDANT	6.1%	5.0%	2.18	4.7%
CEILING	SUSPENDED	CHANDELIER	3.6%	8.0%	2.42	8.3%
	SUSPENDED Subtotal		9.6%	13.0%	2.33	13.0%
CEILING MOUNTED Total			**42.4%**	**46.9%**	**2.41**	**48.4%**
WALL	MOUNTED	SCONCE	3.6%	2.6%	1.94	2.2%
WALL	MOUNTED	VANITY	7.1%	8.8%	1.93	7.3%
WALL MOUNTED Total			**10.6%**	**11.5%**	**1.93**	**9.5%**
UNDER	CABINET	KITCHEN	1.8%	0.9%	2.32	0.9%
UNDERCABINET Total			**1.8%**	**0.9%**	**2.32**	**0.9%**
TABLE	LAMP	SMALL	3.7%	1.5%	1.61	1.0%
TABLE	LAMP	LARGE	15.2%	14.1%	1.99	12.1%
TABLE LAMP Total			**18.8%**	**15.6%**	**1.96**	**13.1%**
FLOOR	LAMP	TORCHIER	0.7%	2.1%	2.31	2.1%
FLOOR	LAMP	TRADITIONAL	2.8%	2.9%	2.30	2.8%
FLOOR	LAMP	TASK	0.5%	0.4%	2.18	0.3%
FLOOR LAMP Total			**4.0%**	**5.4%**	**2.30**	**5.3%**
OTHER	INDOOR		9.6%	7.6%	2.32	7.6%
ALL INDOOR Total			**87.2%**	**87.9%**	**2.25**	**84.7%**
OUTDOOR FIXTURES:						
OUTDOOR	CEILING		1.8%	1.5%	3.10	2.0%
OUTDOOR	WALL	FLOOD	1.3%	3.0%	2.06	2.6%
OUTDOOR	WALL	LANTERN	8.6%	6.7%	2.97	8.6%
OUTDOOR	WALL	BARN	0.1%	0.1%	10.55	0.4%
OTHER	OUTDOOR		1.0%	0.8%	5.16	1.7%
ALL OUTDOOR Total			**12.8%**	**12.1%**	**2.96**	**15.3%**
Grand Total			**100.0%**	**100.0%**	**2.33**	**100.0%**

Lamp Energy Characteristics, by Wattage Bin

Lamp Energy Characteristics, by Wattage Bin

Lamp Type	Wattage Bin	Avg. Watts per Lamp	Sockets per Fixture	% of total Watts	Average Hours per Day	% of Total kWh
Incandescent	**Overall Avg**	**62**	**1.6**	**86.8**	**2.22**	**82.6**
INCAN1	1-50	32	2.1	15.2	2.32	15.1
INCAN2	51-100	73	1.3	61.9	2.22	58.8
INCAN3	101-150	147	1.3	5.6	2.30	5.5
INCAN4	151+	217	1.2	4.1	1.82	3.2
Halogen	**Overall Avg**	**145**	**1.2**	**3.3**	**2.66**	**3.7**
HALOG1	1-50	43	1.6	0.3	2.54	0.3
HALOG2	51-150	99	1.3	0.6	2.81	0.7
HALOG3	151+	301	1.0	2.4	2.64	2.7
Fluorescent	**Overall Avg**	**37**	**1.9**	**9.6**	**3.10**	**12.7**
FLUOR1	1-19	15	1.3	0.3	3.28	0.4
FLUOR2	20-30	22	1.3	0.7	3.13	0.9
FLUOR3	31+	43	2.3	8.5	3.11	11.4
HID	**Overall Avg**	**72**	**1.8**	**0.2**	**8.81**	**0.7**
HID1	1-100	64	3.1	0.1	8.43	0.3
HID2	100+	182	1.3	0.1	9.22	0.3
Other	**Overall Avg**	**7**	**1.3**	**0.2**	**2.56**	**0.2**
OTHER1	1-100	54	1.2	0.2	2.86	0.2
OTHER2	101+	204	1.0	0.0	0.11	0.0
All Lamps	**Overall Avg**	**58**	**1.6**	**100%**	**2.33**	**100%**

Statewide Averages, 1995

Average Hours of Operation per Day for Fixtures with On-Off Switches, Ranked by Hours of Use

Average Hours of Operation per Day for Fixtures with On-Off Switches, Ranked by Hours of Use

Avg. Hr Rank	Average Hours/ Day	Room	Application
1	4.21	YARD	OTHER
2	3.69	KITCHEN-DINING	CEILING RECESSED
3	3.61	UTILITY	CEILING SUSPENDED
4	3.50	KITCHEN-DINING	CEILING SURFACE
5	3.03	YARD	CEILING
Applications with 3 or more hours per day			
6	2.98	KITCHEN-DINING	CEILING SUSPENDED
7	2.97	YARD	WALL
8	2.89	BEDROOM	WALL
9	2.83	INSIDE	OTHER
10	2.81	UTILITY	WALL
11	2.75	LIVING	TABLE
12	2.67	GARAGE	CEILING SURFACE
13	2.63	LIVING	CEILING SURFACE
14	2.56	LIVING	FLOOR
15	2.43	GARAGE	WALL
16	2.35	UTILITY	CEILING SURFACE
17	2.24	BATHROOM	WALL
18	2.20	HALL	CEILING SURFACE
19	2.19	KITCHEN-DINING	UNDER
Applications with 2 or more hours per day			
20	1.99	LIVING	CEILING RECESSED
21	1.88	LIVING	CEILING SUSPENDED
22	1.85	BATHROOM	CEILING SURFACE
23	1.80	DEN	TABLE
24	1.78	GARAGE	CEILING SUSPENDED
25	1.75	HALL	CEILING RECESSED
26	1.65	BATHROOM	CEILING RECESSED
27	1.22	BEDROOM	CEILING SURFACE
28	1.21	BEDROOM	TABLE
29	1.17	BEDROOM	FLOOR
30	1.03	BEDROOM	CEILING SUSPENDED

Statewide Averages, 1995

Average Hours of Operation per Day for Fixtures with On-Off Switches, Sorted by Room Type

Average Hours of Operation per Day for Fixtures with On-Off Switches, Sorted by Room Type

Average Hours/ Day	Room	Application	
1.65	BATHROOM	CEILING	RECESSED
1.85	BATHROOM	CEILING	SURFACE
2.24	BATHROOM	WALL	
1.03	BEDROOM	CEILING	SUSPENDED
1.17	BEDROOM	FLOOR	
1.21	BEDROOM	TABLE	
1.22	BEDROOM	CEILING	SURFACE
2.89	BEDROOM	WALL	
2.19	KITCHEN-DINING	UNDER	
2.98	KITCHEN-DINING	CEILING	SUSPENDED
3.50	KITCHEN-DINING	CEILING	SURFACE
3.69	KITCHEN-DINING	CEILING	RECESSED
1.88	LIVING	CEILING	SUSPENDED
1.99	LIVING	CEILING	RECESSED
2.56	LIVING	FLOOR	
2.63	LIVING	CEILING	SURFACE
2.75	LIVING	TABLE	
1.80	FAMILY	TABLE	
1.75	HALL	CEILING	RECESSED
2.20	HALL	CEILING	SURFACE
2.35	UTILITY	CEILING	SURFACE
2.81	UTILITY	WALL	
3.61	UTILITY	CEILING	SUSPENDED
2.83	INSIDE	OTHER	
1.78	GARAGE	CEILING	SUSPENDED
2.43	GARAGE	WALL	
2.67	GARAGE	CEILING	SURFACE
2.97	YARD	WALL	
3.03	YARD	CEILING	
4.21	YARD	OTHER	

Energy Correction Factor for Control Types

Energy Correction Factor for Control Types

	Control Type		% Watts	% Hours
1	DIMMER		80	0.92
2	MOTION	SINGLE	100	0.46
3	MOTION	MULTI	100	0.46
4	MOTION	YARD	100	1.14
5	PHOTO	OUTDOOR	100	3.94
6	PHOTO	OTHER	100	2.37
7	SIMPLE	ON/OFF	100	1.00
8	TIMER		100	1.10
9	SCHEDULER	YARD	100	0.84
10	SCHEDULER	INDOOR	100	2.61
11	3-WAY	LOW	80	0.57
12	3-WAY	HIGH	80	1.25

Sort by % Hours				
	Control Type		% Watts	% Hours
5	PHOTO	OUTDOOR	100	3.94
10	SCHEDULER	INDOOR	100	2.61
6	PHOTO	OTHER	100	2.37
12	3-WAY	HIGH	80	1.25
4	MOTION	YARD	100	1.14
8	TIMER		100	1.10
7	SIMPLE	ON/OFF	100	1.00
1	DIMMER		80	0.92
9	SCHEDULER	YARD	100	0.84
11	3-WAY	LOW	80	0.57
2	MOTION	SINGLE	100	0.46
3	MOTION	MULTI	100	0.46

Statewide averages, 1995

2.5 Title 24 Compliance

Compliance with Title 24's provisions for residential lighting is a contentious subject. It is commonly reported that builders hate the lighting provision of Title 24 because they believe home buyers don't like fluorescent lighting. It is also widely believed that building officials give the residential lighting requirements very low priority in their enforcement efforts. Thus, it is commonly assumed that these provisions of Title 24 are a "failure." This section looks at the available evidence and attempts to separate fact from perception.

Outside of California, it is unusual to have lighting restrictions in a residential energy code. For example, there are no lighting requirements in the Washington State or Hawaiian residential energy codes, nor in the national Model Energy Code for residential buildings (based on ASHRAE Std. 90.2). The Canadians, when developing their national residential energy code[11], considered residential lighting restrictions but decided they were too difficult to enforce. In fact, they cited California's experience as a reason not to regulate residential lighting.

Title-24 requires:

- Dedicated fluorescent luminaires must be installed in kitchens and bathrooms (specifically, the rooms containing a water closet).
- The switches to these fluorescent luminaires are to be "accessible" or at the entrance to the room.
- Kitchens and bathrooms may have decorative or secondary lighting provided by incandescent lamps.
- Incandescent fixtures recessed into insulated ceilings must have a UL rating for contact with insulation.

(Note: The requirement for kitchen and bathroom lighting does not explicitly require fluorescent lighting. Instead, it requires lighting having a luminous efficacy not less than 40 lumens per Watt. For all practical purposes, however, this means fluorescent lighting in these types of application.)

Studies of Title 24 compliance have surveyed residential lighting compliance. Two studies are cited here as illustrative of the findings.

[11] Canadian Commission on Building and Fire Codes, *National Energy Code for Houses 1995*, Public Review 1.0, Section 4.2.3.2. Interior Lighting Power in Dwelling Units commentary, February 24, 1994.

The 1994 CEC compliance monitoring study[12] did a careful review of 89 residences in 30 different jurisdictions. Of those, 9 houses (10%) failed to meet the lighting requirement for the kitchen, and 26 houses (29%) failed to meet the bathroom lighting requirement. This bathroom lighting violation was the fifth most common compliance problem in the houses that were inspected.

The 1994 CADMAC study[13] states in its Executive Summary that "BSG found significant non-compliance with the mandatory measures in only two areas. Hot water pipes and....High efficiency fluorescent lights are required by the standards in all kitchens and bathrooms, with its switch at the entrance of the room. This condition was found to be missing in almost half of the houses." This statement distinguishes mandatory measures, which must always be installed, from other measures which can be variable depending on compliance approach.

A closer look at the BSG data tells us that only 4% of the kitchens failed to comply with the fluorescent lamp requirement and only 7% failed to comply with both the lamp and the switching requirement. Compliance was generally found to be lower with bathrooms, with 42% of bathrooms failing to comply with both requirements. This observation is based only on the numbers of instances of a strict pass-fail approach to compliance vs. non-compliance. A more useful view of the data, however, is to look at the installed Watts and lumen outputs of the fixtures. From this perspective, the compliance problem does not appear as great.

Error! Reference source not found. shows the total Watts of both incandescent and fluorescent lamps for all kitchens and bathrooms in the BSG surveyed houses, and also the total lumen output of those lamps, assuming an average of14 lumens/Watt for incandescent and 65 lumens/Watt for fluorescent lamps. Here we see that over three-quarters of the lumens in kitchens are from fluorescent sources, and over one-third of all lumens in bathrooms are fluorescent. The incandescent watts still substantially outweigh the fluorescent watts, but it is clear that a substantial amount of the lighting in these rooms is being provided by the more efficient fluorescent lamps.

[12] Valley Energy Consultants, *Monitoring Final Report,* prepared for the California Energy Commission, Contract No. 400-91-032, June 1, 1994.

[13] Berkeley Solar Group, *Energy Characteristics, Code Compliance and Occupancy of California 1993 Title 24 Houses,* 1993 Residential Field Data Project, prepared for the California Energy Commission and the California DSM Measurement Advisory Committee (CADMAC), April 30, 1995.

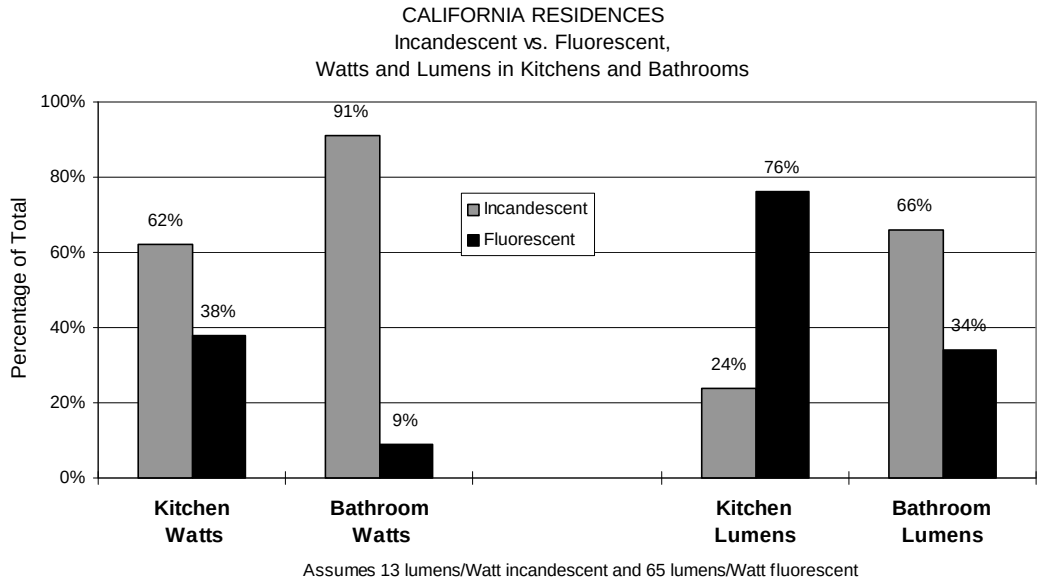


Figure 2-43 - Incandescent vs. Fluorescent, Watts and Lumens in Kitchens and Bathrooms, California

The TPU data graphed below in Figure 2-44 shows that in two states without the lighting provisions in the Title 24 code, one third less watts of fluorescent lighting was installed in kitchens, and two thirds less fluorescent lighting was installed in bathrooms.

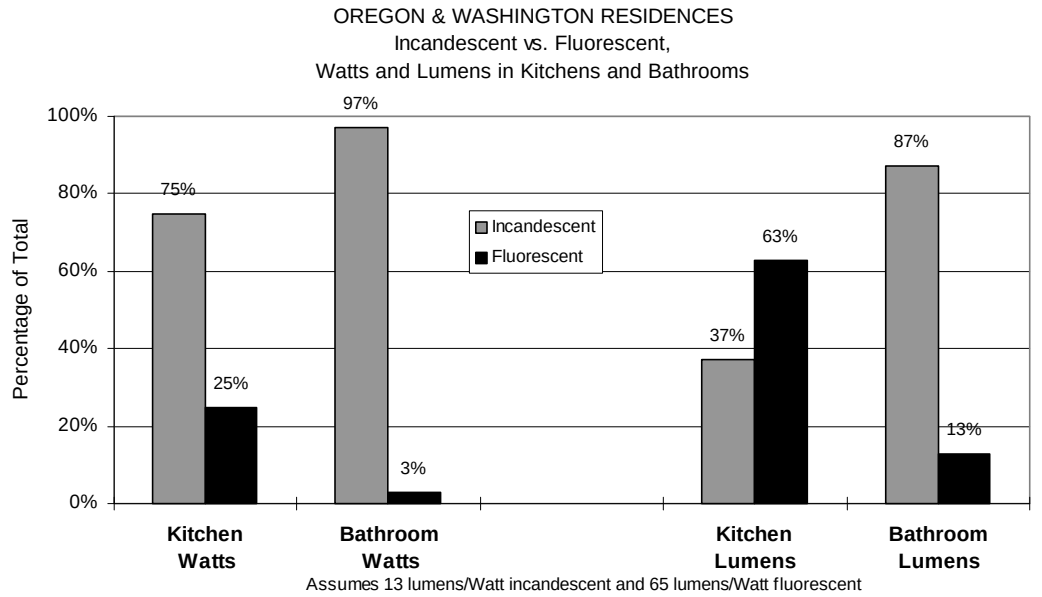


Figure 2-44 - Incandescent vs. Fluorescent, Watts and Lumens in Kitchens and Bathrooms, WA & OR.

2.6 Residential Data Analysis Methodology

The sources of the data were the same for both the residential baseline analysis presented in this report, and for the residential California Lighting Model discussed in Section 5.1. Two datasets from Southern California Edison datasets, the Edison Inventory, the Edison Monitored Data, and a third from Tacoma Public Utilities, the TPU Monitored Data, were analyzed and compared, as discussed below.

The analysis for both purposes is based on the same final data set using weighted data from the Edison Inventory, with some correction factors derived from the Tacoma Monitored Data. The analysis methodology, however, differs significantly between the two purposes.

The baseline information presented in this report is based on a summation of each individual record within the data set. Thus, to tabulate energy use in single family living rooms for the baseline analysis, the actual watts for a given fixture were multiplied times the hours of operation for that same fixture, and then all fixtures in all single family living rooms were added up.

The model analysis, on the other hand, is based on averages. For example, the average wattage for a given type of lamp is multiplied times the average number of lamps in a type of fixture, then multiplied times the market share of that fixture type within its application, times the average number of that application type in living rooms, etc.

The results are very similar, but not identical. The model analysis allows use of the relational database structure to create alternate scenarios. The baseline analysis presented in this report allows the most accurate discussion of lighting energy use by individual subject.

2.6.1 The Datasets

This section describes each of the datasets used in the analysis.

Scope of Edison's inventory

In the spring of 1993, Edison commissioned 700 homes to be surveyed for the residential lighting inventory. Of this sample, 683 surveys formed the final dataset. A trained auditor spent approximately one hour in each home, inventoried all of the light fixtures inside and outside of the home, and interviewed the occupants about the hours of use for each fixture, and their lamp purchasing habits.

The inventory consisted of visual inspection and documentation of every fixture and light bulb in the residence, totaling 16,275 fixtures. It included information

on building type, age, number and size of rooms, fixture types and room location, control types, lamp types, bulb wattage, and customer's estimate of average daily use.

The sampling plan stratified Edison residential customers by geographical location, terciles of annual electricity usage, and single family vs. multifamily building type. After the final sample was achieved, weighting factors were assigned so that the final sample would be representative of the overall Edison population.

Scope of Edison monitored data

Edison installed 477 time-of-use light meters, one fixture per household. Due to attrition, malfunctions, and missing data, the final usable sample was 359 meters. The meters ran for approximately 2 months each from the winter or spring to fall of 1993. This dataset is very useful in understanding time-of-use patterns, and diversity factors by room type, fixture type, and lamp type.

There are, however, some biases suggested in the data which we decided would make it not useful to gauge total hours of use. Analysis of the data showed consistently higher total hours of use than the self-reported Edison inventory data and also the metered TPU data. This is consistent with the biases that would be expected due to the selection and installation procedures.

Meters were located in a randomly selected sample of houses, and in a randomly selected room designated for each house. The fixture to be monitored was also supposed to be randomly selected, with one criterion that it be used for at least one hour per day on average. This would preclude the lowest usage fixtures. However, the surveyors manual also included the script: "I need to place a light meter in one of the fixtures you most frequently use," suggesting that choice of fixture to be metered was not at all random, but rather biased towards the highest usage fixtures. Finally, since lighting loggers were used, there was the potential for results to be contaminated from adjacent fixtures, or from ambient daylight. The study attempted to correct for contributions from ambient light, but could not conclusively show that all false readings had been avoided.

We attempted to correlate monitored hours-of-use data with self reported data for the same specific fixture, but were not able to do so in a majority of the cases. Low numbers of data points for some room types and some fixture types, also made it unreliable to compare monitored to self reported for room or fixture types.

The potential for the data to be biased upward, and the inability to draw conclusions for a self-reporting error by room or fixture categories, lead us to

decide to not use the Edison monitored data for analysis of kWh usage in this study. This data, however, is still quite valuable in understanding time-of-use patterns.

Scope of TPU monitored data

Tacoma Public Utilities (TPU) monitored 80% of the fixtures in 161 houses in Oregon and Washington, for 7 utilities, for a total of 2,641 monitored fixtures. Because TPU monitored almost all of the fixtures in a home, there was less selection bias for the fixtures than occurred in the Edison monitored data. The one systematic exclusion was of fixtures mounted over 12 feet above the floor. The fixtures were monitored from 4 to 12 months, over the course of two years, and checked monthly for proper performance by the surveyors.

TPU also used lighting loggers, but used 2” to 12" light pipes to shield the loggers from ambient influences. The light pipes were pointed directly at the lamp being monitored, and the loggers were checked for sensitivity to the fixture being monitored vs. outside influences. The light loggers monitored run time and number of periods on and off, but not time-of-use.

The houses were almost all single family houses, recruited by a variety of sometimes informal means from each participating utility, rather than a statistical sampling frame of the overall population. The sample is considered somewhat biased towards high end homes, and is not weighted to represent the general residential population.

On the one hand, the TPU monitored data is more robust than the Edison data in that it includes 7 times as many fixtures, for 2-6 times as much elapsed time, with less bias in fixture selection. Furthermore, there were far fewer missing fields in the data, and a broader distribution of data across room, fixture and control types. On the other hand, the TPU data is not statistically representative of the Puget Sound residential population, let alone that of California.

Given these considerations, we decided to use the TPU data only for limited purposes. We used it to check the reasonableness of our analysis. We used it to look for consistent patterns across the datasets. And we used it to create two correction factors for hours of operation, which will be described below in Section 2.6.2 under "Self Reporting Error Correction Factor" and "Control Type Multiplier for Hours of Operation."

2.6.2 Analysis of the Datasets

Self Reported vs. Monitored Hours of Operation

We compared the whole dataset of self-reported hours of use from the Edison inventory to the whole dataset of monitored hours of use from the TPU study. Thus, we were comparing 16,275 self reports to 2,641 monitored reports (a 6:1 ratio) and found a startlingly similar overall pattern of hours of use per day, as shown in Figure 2-45. Looking at both of the whole datasets, the two curves are remarkably close, suggesting that in aggregate, self-reported hours of operation have very similar results to monitored data.

The most noticeable differences are in the shortest hours of operation. More people thought a fixture was always off, whereas the monitored data captured very small hours of operation, showing more fixtures with one hour or less of operation per day. Compared to the monitored data, people over-reported the number of fixtures with zero hours of operation by 15% and under-reported 1,2, and 3 hours of operation by a total of 15%.

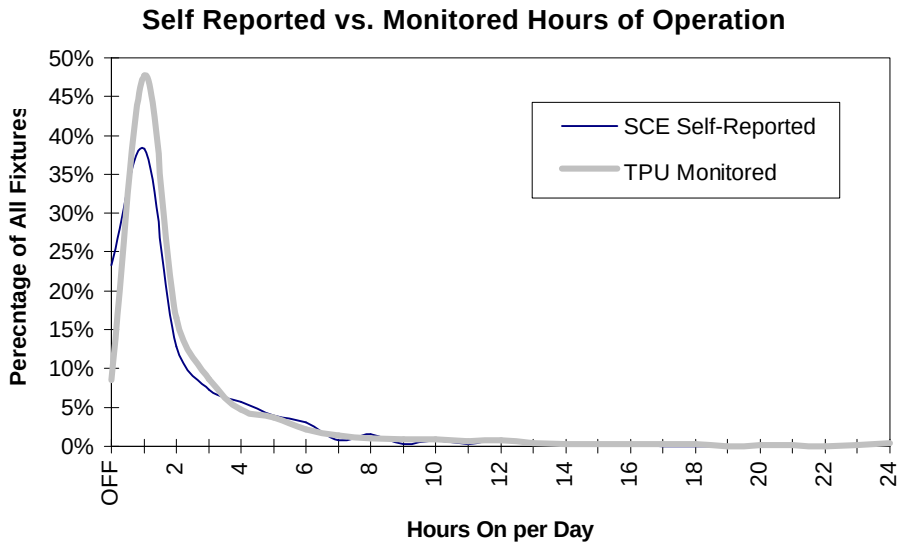


Figure 2-45 - Hours of Operation per Day for Self Reported and Monitored Data

A closer look at the fixtures with longer hours of operation, i.e. with 4 or more hours per day, in Figure 2-46 below, shows that there is a slight tendency to underestimate longer hours of operation. The proportion of fixtures reported to be operating for 12 or more hours per day increased from 2.1% in the self reported data to 3.2% in the monitored data. But most noticeably, people tend to report hours in even integers, (4, 8, 12 hours) whereas the monitored data is more continuous.

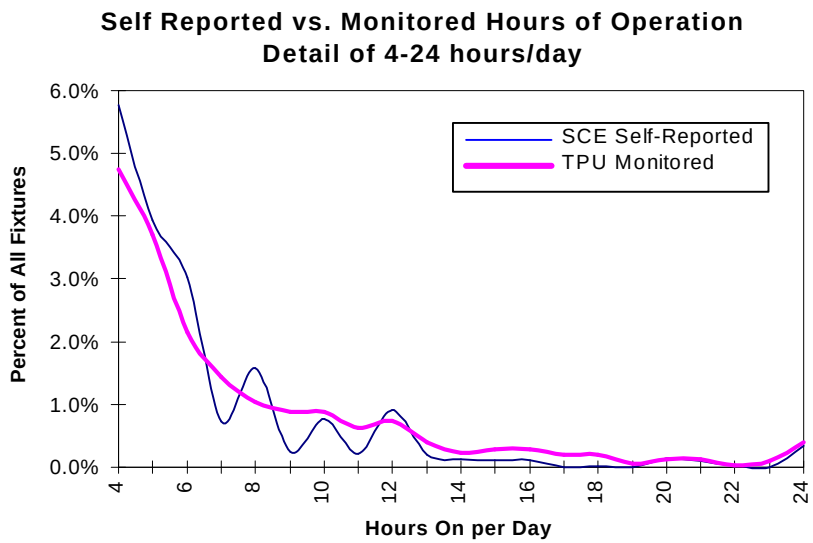


Figure 2-46 - Detail of Hours of Operation per Day

Overall, the average hours of operation per day for the raw Edison (SCE) self reported data is 2.10 hours per day, and for the raw monitored TPU data is 2.51 hours per day. This is almost completely explained by the differences between 0, 1, 2, and 3 hours per day discussed above. There is a much smaller effect due to a few more fixtures reported operating 12 or more hours per day in the monitored dataset. The self reported data show 2% of fixtures operating 12 or more hours, while the monitored data show 3% of all fixtures.

Self Reporting Error Correction Factor

Early in the analysis it was noted that there was a consistent pattern of variation between the average hours of operation by room type calculated from each dataset. This variation by room type is illustrated below in Figure 2-47, comparing the ratio of hours of operation between all three datasets. For example, the left most column has a value of 65%. This means that the TPU monitored hours for all fixtures in bedrooms were 65% of the self-reported hours from the Edison inventory for all fixtures in bedrooms. This graph was used to analyze which comparison might be the most reliable to establish a self reporting correction factor.

The comparison of TPU monitored (TPUm) to SCE self reported (SCEs) data was the most robust comparison in terms of the size and reliability of the datasets. We used the unweighted data for single family home for both TPU and Edison for this comparison, because both of these samples tended to biased

towards larger, or upper income single family homes, and so seemed to have reasonably well matched demographics.

The TPUm to SCEs also proved to be the most conservative assumption (i.e. closest to 100%, or the least correction factor--these are called out with arrows in the graph) in 4 out of 5 of the room types where sufficient data was available for all the datasets. The one exception of TPUm results with less conservative results, bedrooms, is corroborated by the Edison monitoring report which specifically stated that they found a 59% self-reporting error in bedrooms, very similar to the 65% error derived from our analysis.

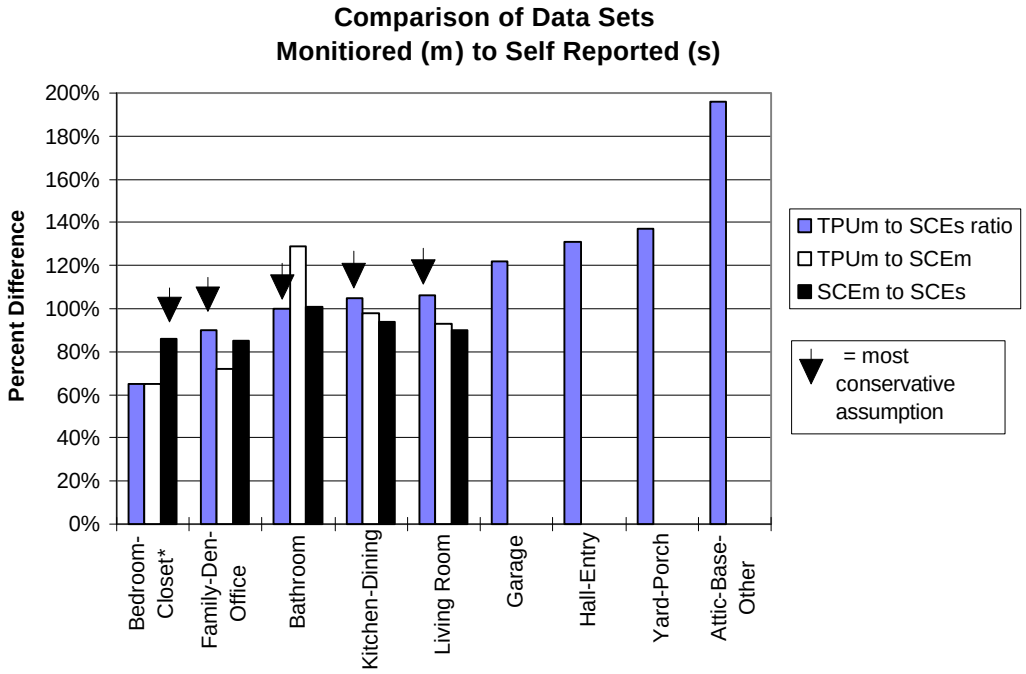


Figure 2-47 - Comparisons of Monitored vs. Self Reported Datasets by Room Type

This pattern of assumed over or under reporting seen in the comparison of the TPU monitored and SCE self reported data is also very consistent with another study that was done on self reporting error in office buildings for SDG&E.[14] In this study, room occupants and building managers were asked to estimate the hours of operation, and then the areas were monitored continuously for one month. Monitored hours were found to exceed self reported hours by 8.5%

[14] I. Owashi, D. Schiiffman and A. Sickels, *Lighting Hours of Operation: Building Types vs. Space Use Characteristics of the Commercial Sector.* Proceedings of ACEEE 1994 Summer Study on Energy Efficiency in Buildings, Vol. 8. p157

overall, however, there was considerable variation by space type. The results by room type are presented in Figure 2-48.

The SDG&E report concluded that "Areas which are constantly in use such as halls, lobbies and sales areas have hours of operation which are consistently greater than reported hours. On the other hand, areas which are used somewhat intermittently, such as private offices, storage rooms and conference rooms, have hours which tend to be less than reported hours." It could also be noted that areas that tend to be used by one or a few individuals tend to be over reported, while the most public areas tend to be under reported. For example, while private offices and open offices were reported to have essentially the same average hours of operation, the open offices were found to have 18% more hours, and private offices were found to have 26% fewer actual hours of operation than reported.

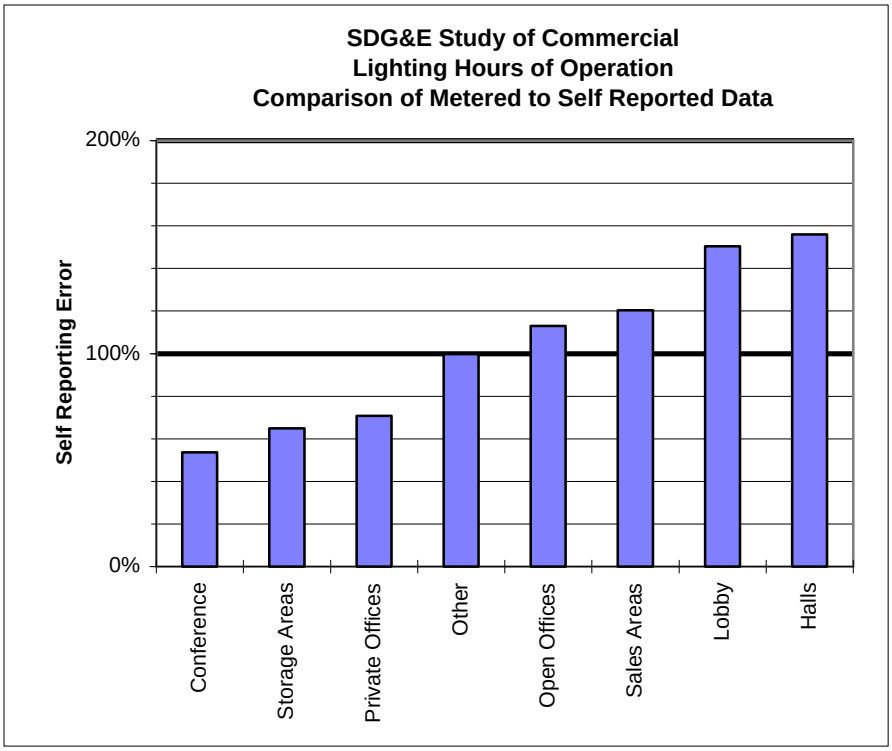


Figure 2-48 - SDG&E Study of Self Reporting Error for Hours of Operation by Room Type

Given the similarity to the SDG&E patterns, given that it generally was the most conservative assumption, and given that the largest multipliers (such as 196% for attic-basement-utility-other) tended to be for rooms with the smallest populations and installed wattages and would therefore have a comparatively small impact, we decided to adopt the TPUm to SCEs ratio as the most reasonable self reporting error.

There are, of course, many other possible explanations of the variations in these datasets besides a self reporting error. The variation could be a result of the difference in behavior between people who live in Southern California and people who live in Oregon and Washington state. The variation could be due to seasonal variations, since the Edison data were mostly reported in the spring, and the TPU data was monitored over 6 to 12 months. The variation could be due to differences in the demographics of the two samples. All of these influences are possible. However, we did not have sufficient information to consider these possibilities, or to try to isolate their effects. We decided to stay with the simplest assumption, and avoid more complex factors.

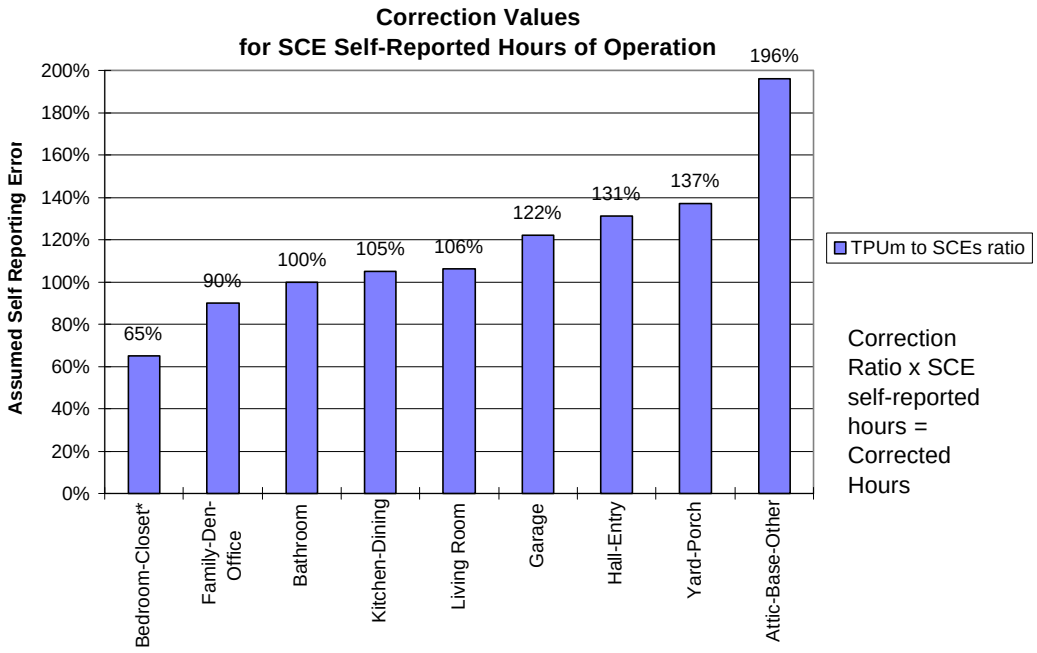


Figure 2-49 - Correction Values for Self Reported Hours of Operation.

The correction factors used in the analysis are presented above in Figure 2-49. These factors were constrained so that any resulting value could not be less than 0 hours of operation, nor more than 24 hours of operation per day.

Control Type Multiplier

On-off switches represent 88% of the Edison dataset and 85% of the TPU dataset, and therefore had the largest sample size, and the most reliable data, for all of the control types. Comparison of self-reported vs. monitored hours of operation for on-off switches by room types resulted in the self-reporting error correction factor by room type described above.

However, the self-reported hours of operation from the Edison inventory were not considered reliable enough to evaluate average hours of operation by other control types. This is because, while people might be expected to have some knowledge of how much they operate a fixture that they directly switch on and off, they are far less likely to be aware of how long a fixture which is under an automatic control is really operating. Thus, for the model, we wanted to directly use the monitored data to determine the hours of operation for the other control types.

Furthermore, since the total duration of use is likely to vary from California to the Northwest, we wanted to isolate the difference between hours of operation by control type, and then apply that correction to the Edison hours. Therefore, we calculated the impact of control types as a multiplier on the average hours of operation for on-off controls, rather than directly figuring the average hours of operation per control type. In the model, these control type multiplier values from the TPU monitored data, which are presented earlier in Figure 2-31, are multiplied times the average hours of operation for on-off switches determined from the Edison inventory for the applicable residential lighting application. This can be summarized as follows:

[Control avg $hrs_{TPU\ m}$ / On-off avg hrs_{TPUm}] X [On-Off avg hrs for Application $Type_{SCE\ s}$] = Avg hrs for Control Type in Application

Weighting factors

The Edison dataset was then weighted according to the HBRS sampling plan to bring it up to the general population. This included weights for geographic location and load terciles (a stand-in for economic status) based on the overall Edison population. Weights for single family and multifamily households were based on the general California population.

2.6.3 Calibrating the Results

The Baseline Energy Use Characteristics[15] prepared for the California Energy Commission by NEOS in 1994, estimated a total electricity usage of 6,074 kWh/yr. per household. (The estimate of energy usage by Edison customers of 6,191 kWh/yr. is closest of all California utilities to the statewide average, a reassurance that the values from the Edison inventory may not diverge too greatly from the overall state population.) Our average value of 1,704 kWh/yr. per household represents 28% of this total electricity use. Significantly, this value

[15] NEOS report

is less than the NEOS estimate of 38% going to miscellaneous plug loads including lighting, and thus is well within the range of expected values.

Our results also compare favorably with the recent findings by the Tacoma Public Utilities in their residential lighting baseline study, which found an average of 1,818 kWh per household per year for their sample of 161 single family homes in the northwest (compared to 2,076 kWh/yr. per household for single family homes from this study). The TPU value represents 9% of total electric usage in these northwest homes, in a region where electric space and hot water heaters and electric stoves are quite common.

The 1992 LBL "Yellow Book" estimated national residential unit energy consumption for lighting at 1,294 kWh/household-year, based primarily on the 1990 PG&E Residential Appliance Saturation Survey (RASS) and the 1987 U.S. DOE nationwide Residential Energy Consumption Survey (RECS). This older, national value represents 76% of our estimate of 1,704 kWh/yr. per household for California derived from the 1993 Edison Inventory data.

The TPU and the LBL values for residential lighting energy use described above are plotted along with the 90% confidence levels for our analysis in Figure 2-50. Ninety percent of all observations from our residential dataset are within the upper and lower values shown; the average is shown as the middle value at the cross bar. There are two factors to consider here. On the one hand, our average hours of operation are shorter than most previous assumptions. On the other hand, our total installed wattage (Figure 2-51) is higher than most previous assumptions. However, we also observed in our data that there are definite correlations between the type of lamp, its location, and its hours of operation. Therefore, simply multiplying average hours times average wattage will give a skewed result. In contrast, our values are a summation of each individual fixture's wattage and hours of operation.

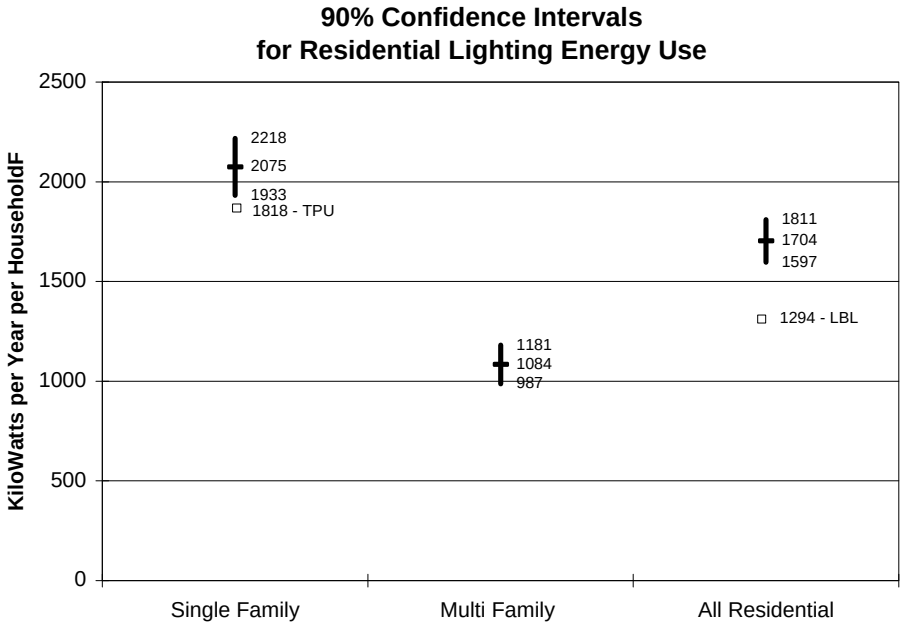


Figure 2-50 - Confidence for Residential Energy Use

The is a slightly smaller level of spread in the graph of 90% confidence for installed wattage in Figure 2-51 below, suggesting that there is a higher level of uniformity for installed wattage than for hours of operation.

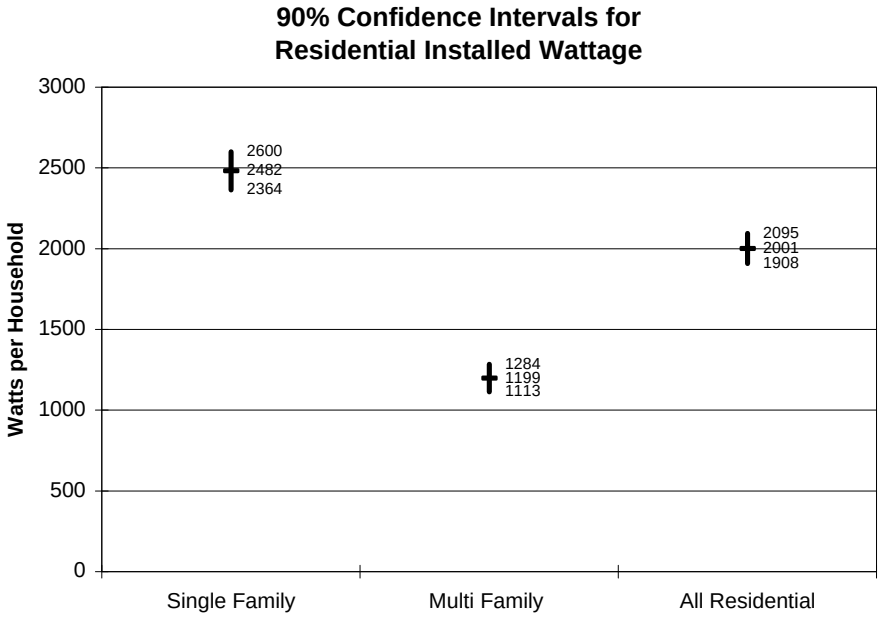


Figure 2-51 - Confidence Levels for Residential Installed Wattage

The statewide total residential lighting energy use predicted by the baseline analysis and the California Lighting Model - residential baseline scenario, described in Volume II, are very similar, within 1% of each other, as compared below:

Residential Lighting Energy Use	Baseline Analysis kWh/yr per Household	Model Analysis kWh/yr per Household	Ratio of Modeled to Calculated
Total Population:	1726	1704	101.3%

Given this close agreement, and the agreement with the CEC Baseline Energy Use Characteristics prediction of miscellaneous electric end uses for households in California, we feel that the California Lighting Model can be used with confidence.

3. COMMERCIAL LIGHTING BASELINE

A detailed sample of California commercial buildings, obtained from recent utility "Commercial End Use Survey" (CEUS) data, was analyzed to establish baseline energy use for commercial lighting. The sample was weighted to represent the population characteristics of buildings in the state, based on the sampling frames for each study, and the total statewide square footage for each building type. Figure 3-1 below shows the total statewide 1995 square footage of each building type included in the study, per the forecasting office of the California Energy Commission.

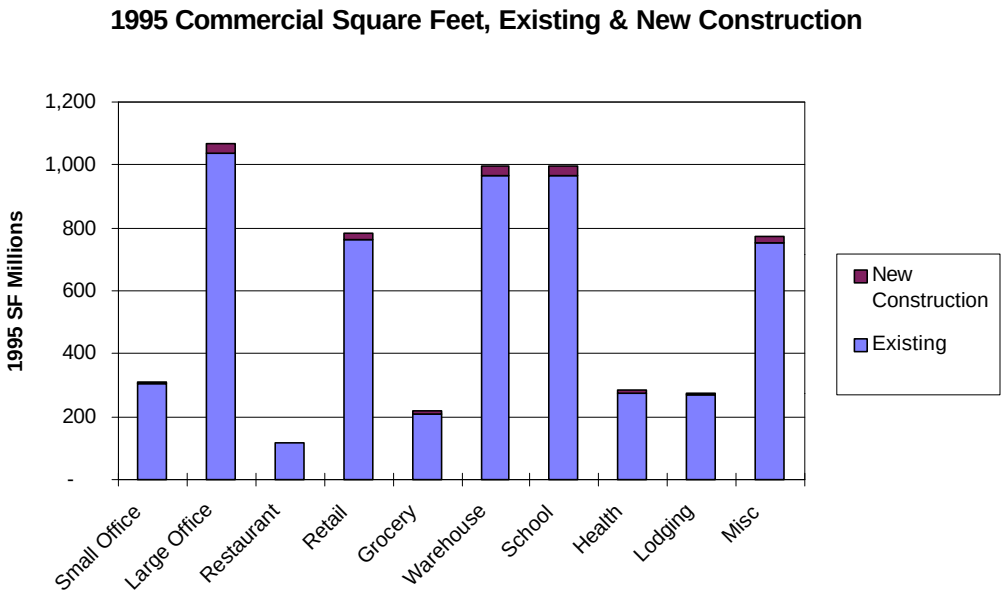


Figure 3-1 - 1995 Commercial Square Footage, by Building Type

Ten building types and 14 space types were identified for the analysis. Some building types and space types available within the CEUS datasets were combined in order to increase the sample size and the reliability of the analysis. The ten building types are shown in Figure 3-2. Most categories are self explanatory. The detailed composition of "Miscellaneous" is unknown as we did not have access to more specific information on building usage in the CEUS datasets.

	Building Type	Includes:
1.	Small Office	office buildings less than 50,000 SF
2.	Large Office	office buildings greater than 50,000 SF
3.	Restaurant	site down restaurants, fast food
4.	Retail	small retail, large retail
5.	Grocery	convenience stores
6.	Warehouse	refrigerated warehouses
7.	School	colleges
8.	Health	hospitals, out patient treatment
9.	Lodging	nursing homes
10.	Miscellaneous	non-buildings, church

Figure 3-2 - Building Types Definition

The fourteen space types are listed in Figure 3-3 below. Note that some space types and building types, such as office or lodging, have the same names. Please be careful to distinguish between an “office” building type, which can be composed of many space types, and an “office” space type, which can occur in any building type.

	Space Type	Room types included
1.	Office	Office, Conference, Library
2.	Hall	Hallway, Lobby, Stair
3.	Retail	Retail
4.	Dine	Dining Room
5.	Cook	Cooking
6.	Tech	Technical Area: Medical Care, Lab., Operating Room
7.	Class	Classroom
8.	Public	Public Assembly, Gymnasium
9.	Lodging	Lodging: Hotel Room, Patient Room,
10.	Stor-c	Storage, Conditioned
11.	Stor-u	Storage, Unconditioned
12.	Indust	Industrial Processing, Conditioned & Unconditioned
13.	Misc-c	Misc. Cond., Vacant Cond., Repair Cond., Refrig. Storage,
14.	Misc-u	Misc. Unconditioned, Vacant Unconditioned

Figure 3-3 - Space Types Definition

3.1 Data Sources

This CEUS data was collected between 1992 and 1994 by Southern California Edison, Los Angeles Department of Water and Power, and San Diego Gas and

Electric.[16] The combined datasets include over 1500 commercial buildings, representing over 50,000,000 square feet, or almost 10% of the commercial building stock in California. The combined sample is summarized in Figure 3-4 below.

Building Type	# Premises	Sq. Ft.
Small Office	344	5,035,228
Large Office	100	18,847,126
Resturant	198	828,692
Retail	339	10,316,293
Grocery	104	1,597,807
Warehouse	114	6,415,858
School	33	1,609,997
Health	102	2,993,956
Lodging	30	2,820,623
Misc.	219	3,922,858
Total	**1583**	**54,388,438**

Figure 3-4 - Combined Commercial Sample Size

Data available from the surveys came in two formats, high resolution and low resolution. High resolution surveys provided us with detailed inventories of lighting equipment and operation schedules by each room within a given building. Low resolution surveys provided the same information at the building level only. High resolution surveys provided about 75% of the data. A majority of the low resolution surveys were from single use buildings, where one space type represented more than 90% of the building, and one operating schedule for the whole building was appropriate.

Thus, the technology inventory, the lighting operating hours, and the resulting lighting energy use calculations are extremely detailed in this analysis. In most (90%) of cases they are based on room by room lighting specific operating schedules.

3.2 Commercial Lighting Energy Use

Figure 3-5 illustrates the relative importance of each building type in statewide lighting energy use, and the proportion of energy used by each major lighting technology. It is interesting to compare this graph to the relative importance of building type by square footage shown above in Figure 3-1. Retail and

[16] PG&E also collected CEUS data during these time periods, which are on file at the CEC, however, they were not made available for analysis during this study. The PG&E data did not include any high resolution surveys, and so their use in this study would have been limited to balancing statewide building population characteristics.

miscellaneous rise in relative importance, because of their long hours of operation and higher lighting densities. Schools and warehouses drop in significance because of their more efficient lighting systems (see below), while groceries increase in importance primarily because of their long hours of operation.

Fluorescent lighting represents the majority of commercial lighting energy use, although there is also significant use of incandescent and HID lighting in some building types.

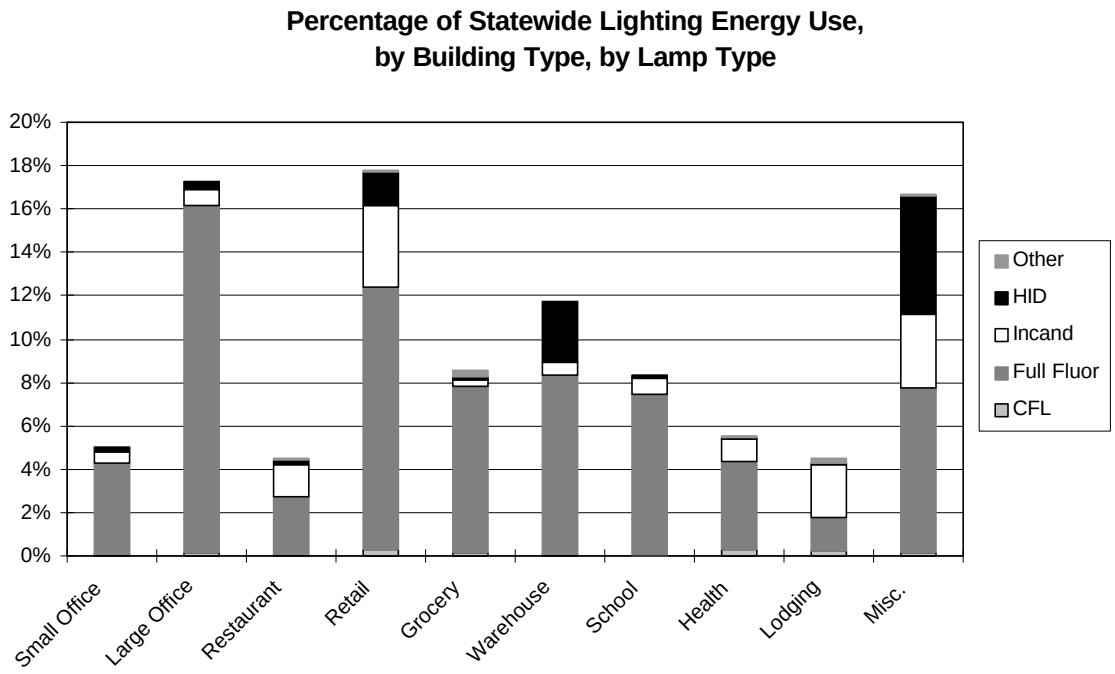


Figure 3-5 - Commercial Lighting Energy Use, by Building and Lamp Type

3.2.1 Hours of Operation

In our analysis a key parameter that we used was hours of operation by space type. These were then aggregated into building types, based on the proportion of square footage devoted to each space type within the building type.

Lighting hours of operation by building type are presented below in Figure 3-6, as Full Time Equivalent (FTE) hours per week. (For example, lighting circuits that have only half of their lamps on are at 50% FTE.) Schools have the shortest hours of operation and lodging the longest. As mentioned earlier, these building type averages were derived from information on room-by-room lighting schedules available for most of the survey data. Thus, these values are

considered more precise than the typical “business hours of operation” that are often used when actual lighting schedules are not available.

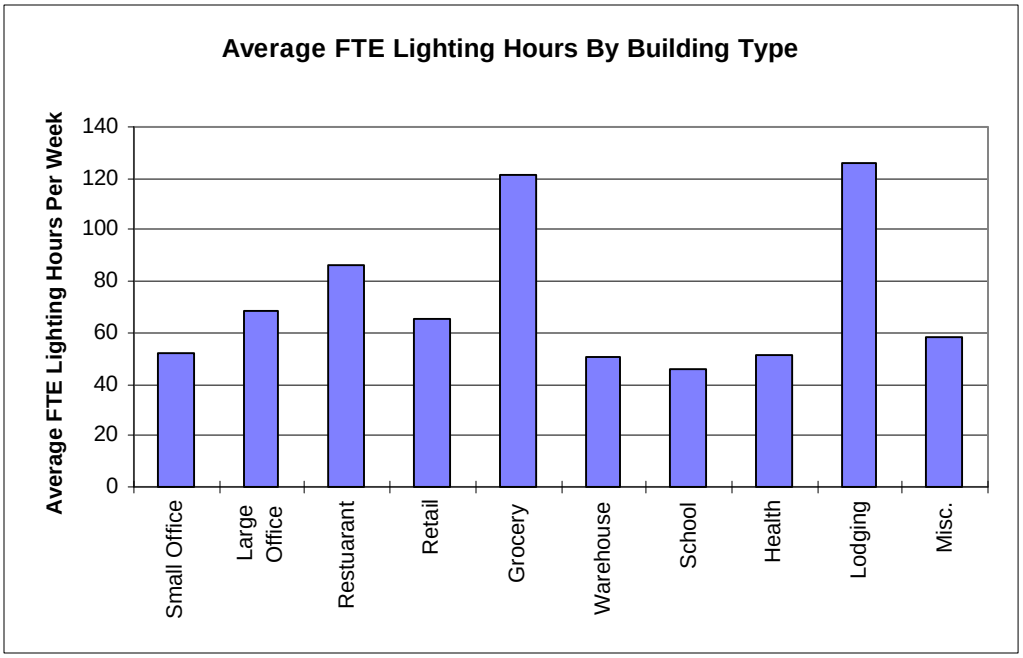


Figure 3-6 - Hours of Operation by Building Type

Hours of operation by space type are illustrated below in Figure 3-7. Here it can be seen that the lodging space type has the longest average hours of operation, and public spaces, such as movie theaters or exhibit halls, have the least.

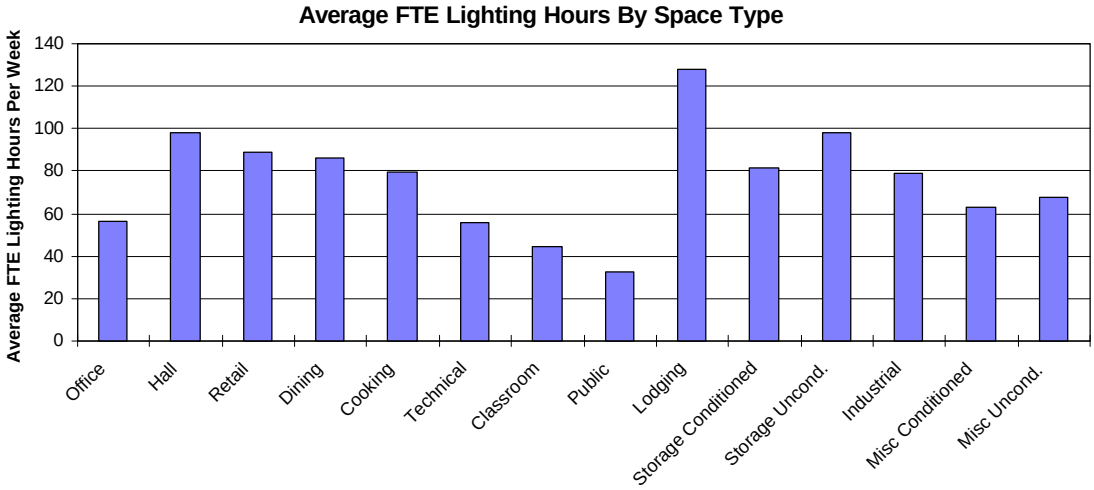


Figure 3-7 - Average FTE Lighting Hours by Space Type

3.2.2 Lighting Power Density

Figure 3-8 compares lighting power density (Watts/SF) to lumen density (lumens/SF) and lamp efficacy (lumens/Watts) for various building types. The overall average lighting power density for the commercial buildings in the state was 1.48 Watts/SF. Both schools and groceries have comparatively high lumen output. Lodging has the lowest light levels, and also the lowest overall efficacy. Restaurants have the highest lighting power density, and second lowest efficacy of sources.

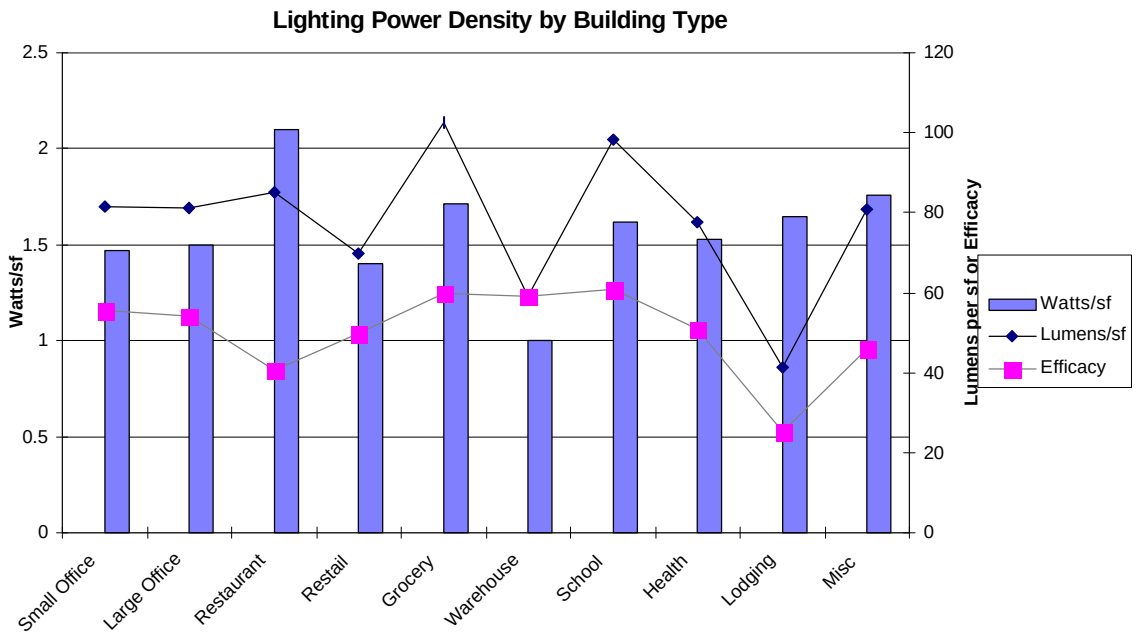


Figure 3-8 - Lighting Power Density by Building Type

3.2.3 Confidence Levels

The following two graphs plot the 90% confidence levels from our data analysis for the commercial lighting power densities and mean lumen output by building type. The confidence levels reflect the diversity of lighting conditions and secondarily, the size of the sample for each building type. Center values for each band are the average for that building type, while 90% of all values occur between the top and bottom numbers. Building types with high variation in conditions will show a big spread. A small sample may also result in a big spread. Building types with little variation in conditions will show a very tight

distribution. Very large samples may also contribute to a tighter distribution. Sample sizes are listed in Figure 3-4 above.

Figure 3-9 below plots the confidence bands for commercial lighting power densities. The band is largest for restaurants, which have widely divergent lighting conditions, and also a comparatively small square footage sample in the data set.

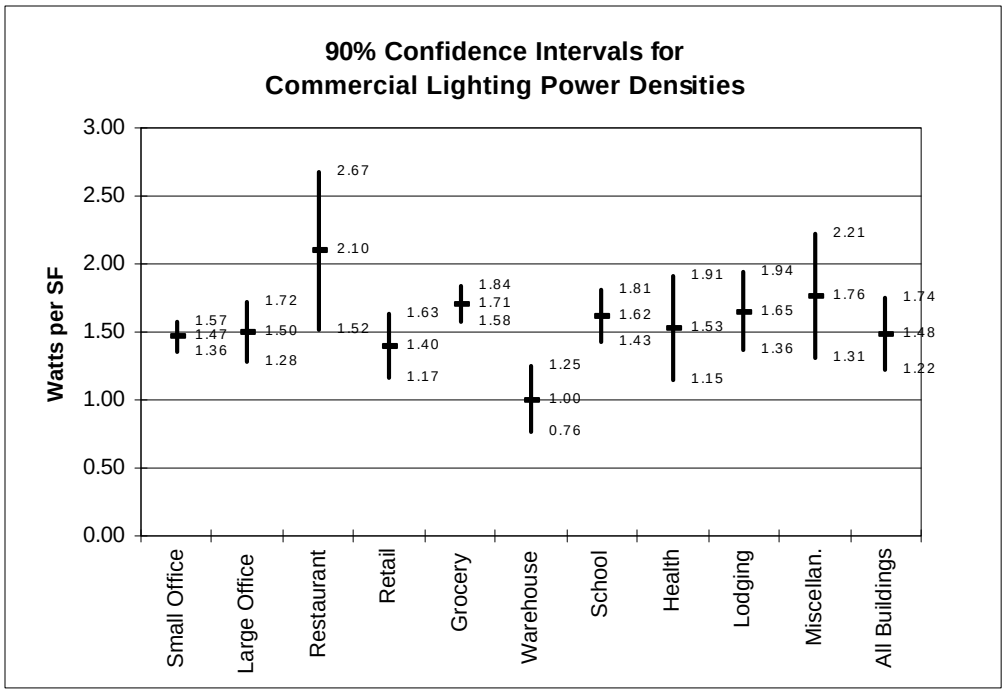


Figure 3-9 - LPD Confidence Levels

Figure 3-10 below plots the spread of lumen output levels found in the data. In addition to the variables discussed above, this plot also accounts for variations in lighting technology efficacy levels found within each building type.

The graph has a similar pattern of spreads in the 90% confidence levels for lighting output by building type. There are a few interesting exceptions. Warehouses have a much bigger spread for lumen output than LPDs, suggesting that there is a wide range of lighting conditions in the warehouse buildings, resulting in a greater range in lumen output, probably due to variations in room cavity ratios and reflectances found in warehouses. The other notable exception is the miscellaneous building type, where the spread of lumen output decreases substantially from the LPD spread. This implies that a wide range of technology types is used to produce a relatively smaller range of lumen output levels.

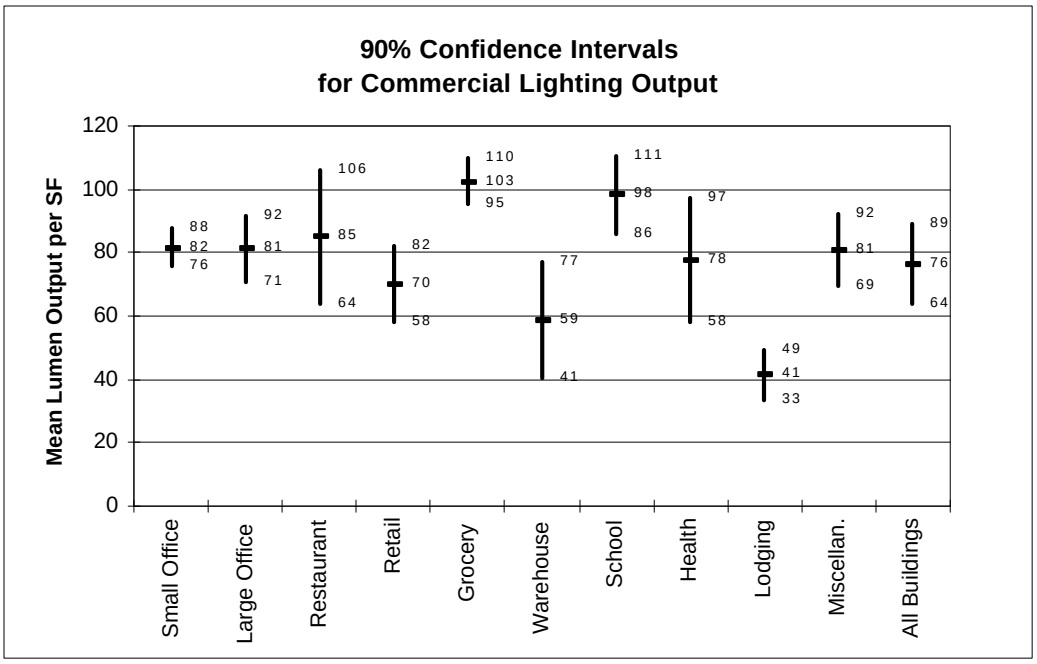


Figure 3-10 - Lumen Output Confidence Levels

3.2.4 Efficacy Levels

The following graph in Figure 3-11 summarizes the average lighting efficacy levels by building type. From this analysis, we learn that lodging, and then restaurants, have the least efficient lighting systems currently in California, while schools and groceries have the most efficient lighting systems. The high efficiency of school lighting is likely due to the success of utility and government programs which have supported lighting retrofits for schools. The high efficiency of groceries is probably also due to grocery store chains investing directly in lighting efficiency. Because of their long hours of operation, there is a quick payback for such an investment.

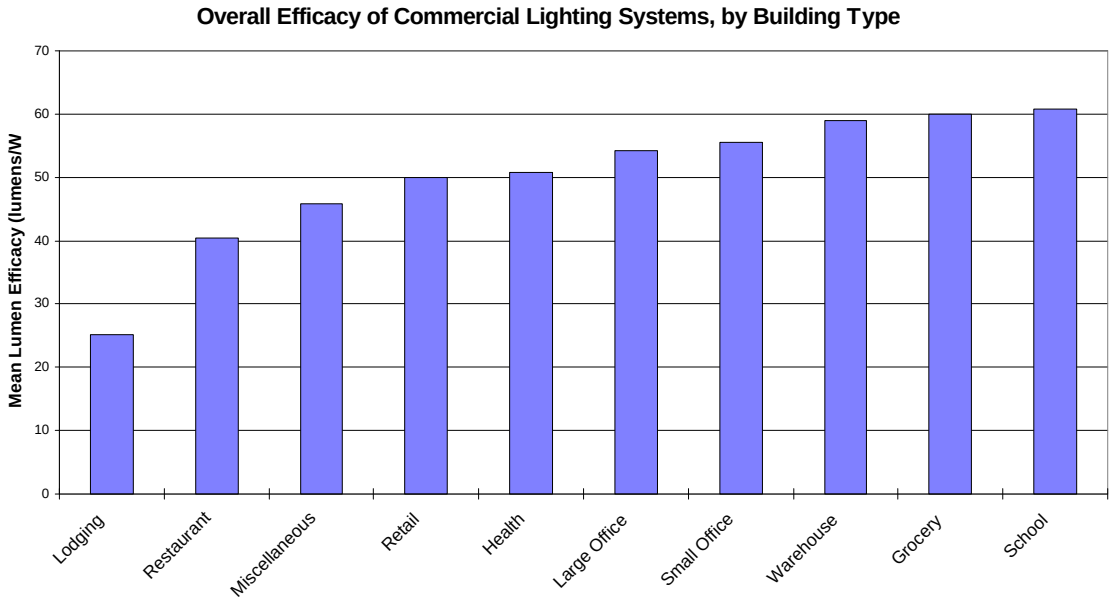


Figure 3-11 - Commercial Lighting System Efficacy, by Building Type

3.2.5 Load Profiles

Lighting load profiles for commercial buildings tend to very closely mirror occupancy, or hours of operation for a given building type, thus the pattern of lighting load profiles varies considerably with building type. Figure 3-12 shows the lighting load profile for two commercial building types (from ADM Associates, End-Use Metered Data for Commercial Buildings, for Southern California Edison, 1993). The office profile reflects the typical 8AM-6PM office day, with a slight dip at lunch time, and some lag in the evening from overtime workers and maintenance staff. The grocery profile, on the other hand, reflects a pattern of 7AM to 12PM business hours, with very little change during that time.

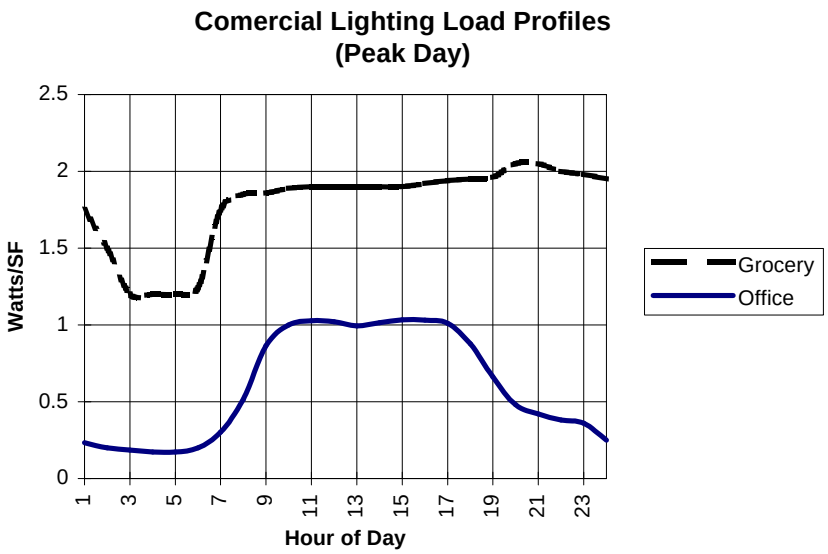


Figure 3-12 - Commercial Lighting Load Profiles (Peak Day)

Al though end use profiles aggregated across building type are difficult to come by, EPRI has published assumptions about commercial lighting loads, which have been used to generate the following chart, Figure 3-13. Based on the assumptions, the overall commercial sector lighting load is about 87% at a 3PM summer peak, and 78% at a 6PM peak.

Peak Lighting Demand	% load*		vacancy	% load * vacancy	
	3:00 PM	6:00 PM	rate	3:00 PM	6:00 PM
GROCERY	100	95	0.95	0.95	0.90
HEALTH	95	85	0.95	0.90	0.81
LARGEOFFICE	100	90	0.90	0.90	0.81
LODGING	100	98	0.95	0.95	0.93
MISCELLANEOUS	100	90	0.90	0.90	0.81
RESTAURANT	100	90	0.90	0.90	0.81
RETAIL	100	98	0.90	0.90	0.88
SCHOOL	100	75	0.70	0.70	0.53
SMALLOFFICE	100	90	0.90	0.90	0.81
WAREHOUSE	90	75	0.90	0.81	0.68
			average	0.88	0.80
			Kwh weighted average	0.87	0.78

Figure 3-13 - Peak Lighting Load Percent by Building Type[17]

Since most commercial buildings are occupied during periods of peak demand (generally summer afternoons and evenings), reducing installed lighting wattage for commercial buildings directly reduces peak building electrical demand in most

[17] EPRI, Lighting Handbook for Utilities pages 3-4, 3-5, April '86

cases. Just as interesting as the specific lighting load profile, is the interaction of this profile with other end uses of the building type, especially cooling. Reduction in lighting off-peak can significantly reduce the internal heat gains which contribute to the cooling peak later in the day. The resulting reduction in cooling load is a function of both local climate and building configuration. A method for estimating these impacts on a building by building basis has been published.[18] Many software programs are capable of making very good estimates for a given building. However, there are no estimates for the overall building stock more accurate than a rule of thumb 10-15% impact of lighting on cumulative cooling load.

3.3 Penetration of Technologies

A partial cause of high efficiency lighting in schools and groceries stores can be seen in the high proportion of electronic ballasts for those building types, as shown in Figure 3-14 below. From this graph it is clear that the current penetration of electronic ballasts varies considerably by building type. The penetration pattern of 4' lamp technologies was found to be very similar: T8s mirror that of electronic ballasts, F34 lamps that of efficient magnetic, and F40 lamps that of standard magnetic ballasts.

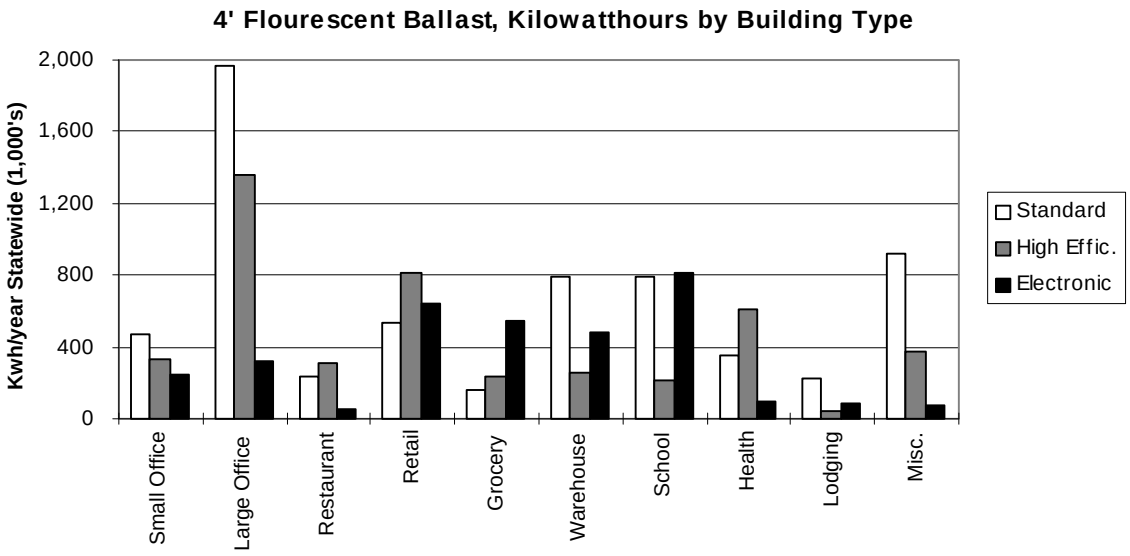


Figure 3-14 - 4' Fluorescent Ballast Types, kWh by Building Type

[18] Rundquist, R.A. et all, "Calculating lighting and HVAC interactions," ASHRAE Journal 35 (no. 11) pp 28-37.

Figure 3-15 below shows the penetration of various lighting control technologies by building type. It shows the percentage of lighting energy use for each building type which is controlled by a given control technology. Thus, almost 60% of retail lighting energy use is on a control, primarily EMS (energy management systems=43%). Schools have the greatest proportion of their lighting load (25%) controlled by occupancy sensors, while large office more commonly use time clocks, which control about 20% of their lighting energy use. Dimmers were found to be most common in miscellaneous buildings (6%), occur rarely in schools and restaurants (1.5%) and rarely in any other building types. Photosensors were found only in trace amounts, primarily in small offices and miscellaneous building types.

The survey data did not allow us to distinguish the energy impacts of these various control types, only their prevalence.

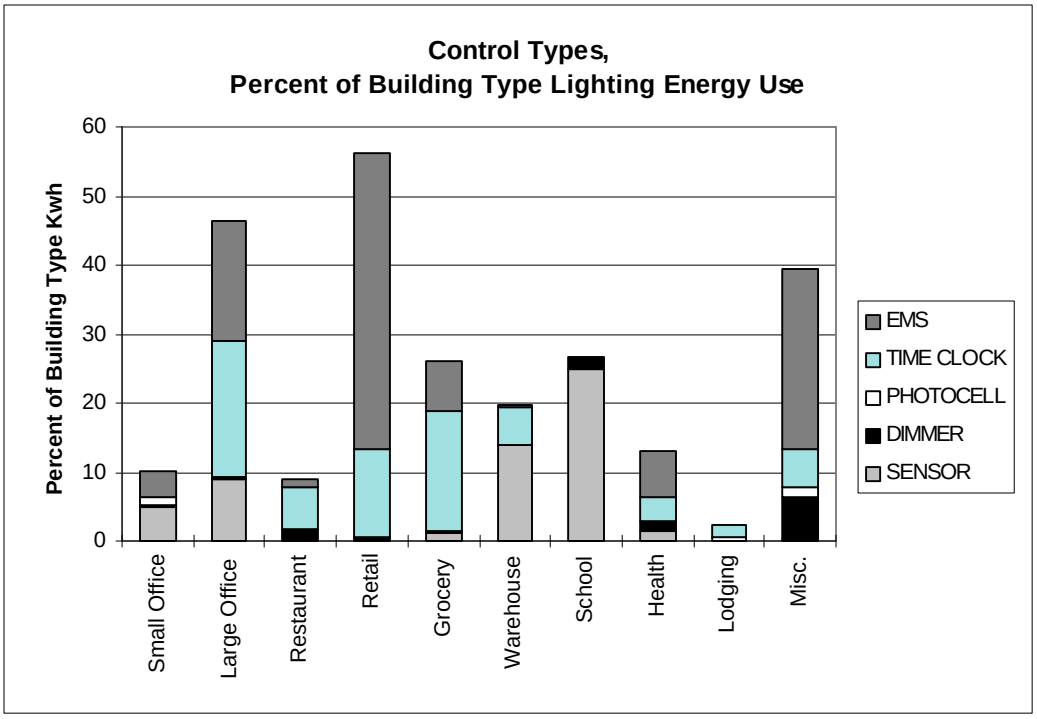


Figure 3-15 - Penetration of Control Technologies

3.4 Commercial Outdoor Lighting

This section discusses the available data on outdoor lighting for commercial buildings. The outdoor lighting discussed does not include street lighting or industrial lighting.

3.4.1 Data Sources

Information on outdoor lighting was available from two smaller subsamples of the datasets which were used to analyze commercial indoor lighting. The larger and more balanced of these subsamples, Sample A, reported only on the purpose of the outdoor lighting and its wattage by building type. The smaller of these subsamples, Sample B, reported on lamp types, control types, and wattage by building type, but only for the larger commercial utility customers, focusing on very large buildings or multiple small buildings under one owner. Thus, neither subsample is considered a reliable representative of California buildings. The data were collected in 1992 and 1993. Also, information on hours of operation for the outdoor lighting was not available for either of these datasets, thus, we can only describe installed wattage, not energy use.

Even though these datasets are limited, and may be unrepresentative, we felt it was important to present the data as a first cut at understanding outdoor commercial lighting. Better data is needed before any conclusions are drawn.

3.4.2 Outdoor Lighting by Business Type

The two subsamples were combined to look at total outdoor lighting wattage by building type. Figure 3-16 shows that the Miscellaneous and Retail building types combined have over 50% of the reported outdoor lighting wattage. A second graph from the combined subsamples, Figure 3-17, shows outdoor lighting watts per square foot (of indoor space) for those buildings which reported any outdoor lighting, and the percentage of square feet of each building type that did report any outdoor lighting. This second graph shows that Restaurants have the highest intensity of outdoor lighting installed per building size, and that Large Offices, followed by Warehouses, have the highest percent of square footage which has some outdoor lighting.

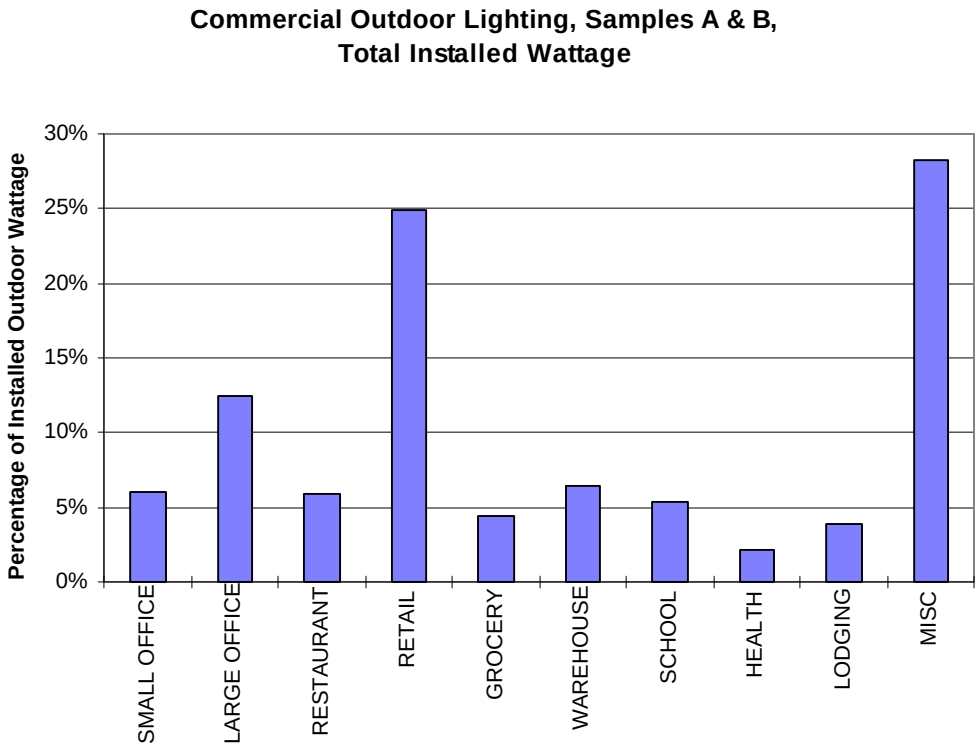


Figure 3-16 - Commercial Outdoor Lighting by Building Type

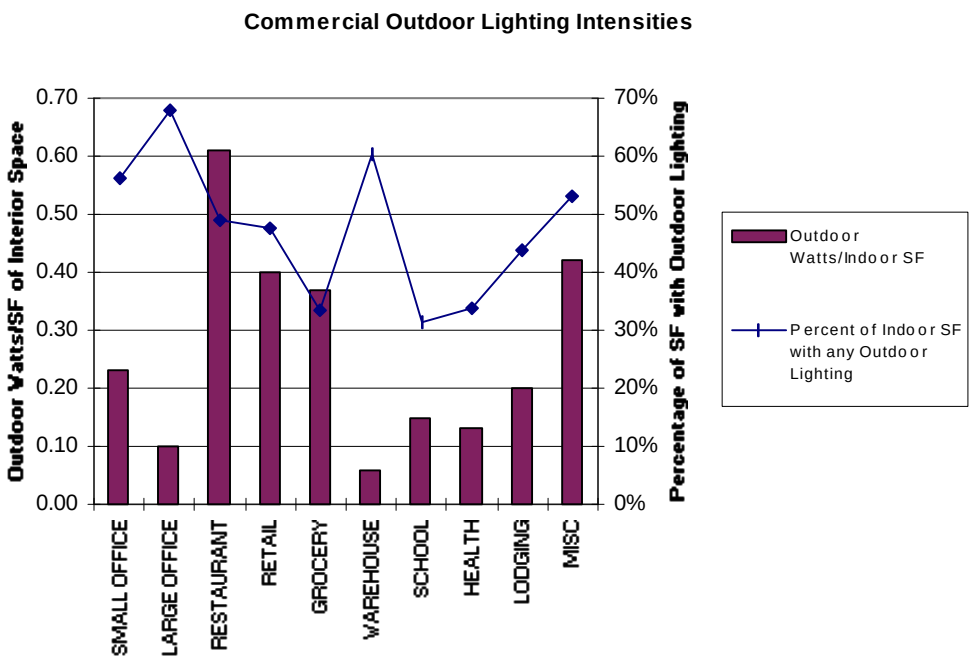


Figure 3-17 - Commercial Outdoor Lighting Intensities by Building Type

It is important to note that the watts/square foot value is “watts of installed outdoor lighting divided by square feet of interior space.” This is a measure of how much outdoor lighting is installed by the size of the building. We do not have any measures for the area covered by the outdoor lighting itself.

It is also important to note that the wattage of outdoor lighting reported is that which is connected to the main building electric meter. Any parking lights or general area lighting which are operated on a separate meter would not be included. Consequently, we do not know very much about parking lighting in shopping centers or other large complexes from this data.

From Figure 3-18, drawn from Sample A, it is seen that security lighting represents 47% of outdoor lighting wattage. Most of this is from Small Offices (13% of overall) and Miscellaneous (14%). Display lighting represents 38% of outdoor wattage, with the greatest proportion (28%) from Retail use.

Parking and storage together represent less than 10% of the total. However, they are the two outdoor lighting purposes which are most likely to be on a separate meter, and thus not included in these datasets.

Figure 3-19 presents the distribution of lighting purpose by building type.

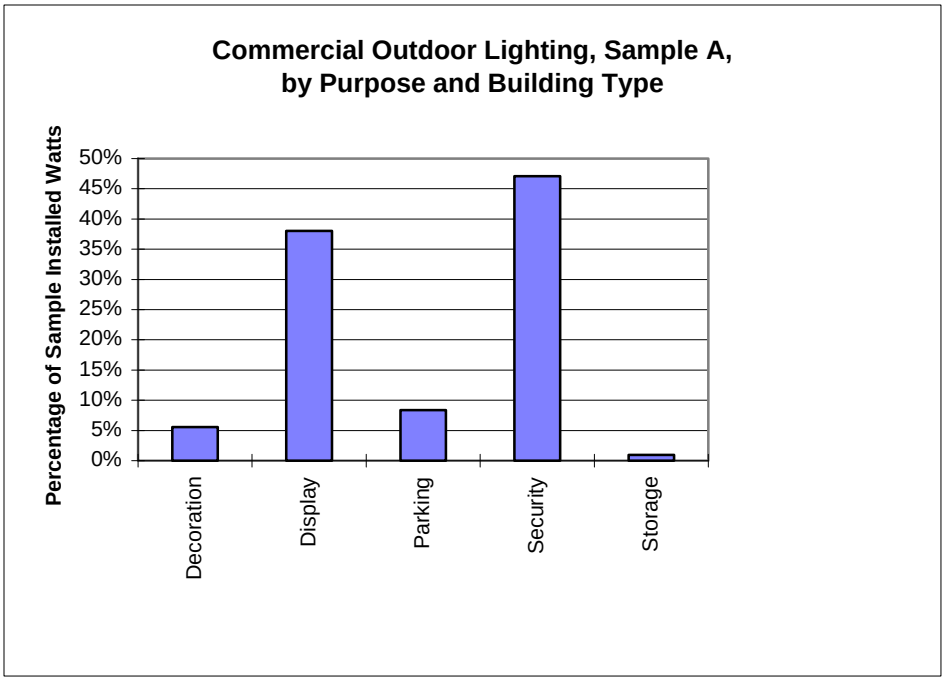


Figure 3-18 - Commercial Outdoor Lighting by Purpose

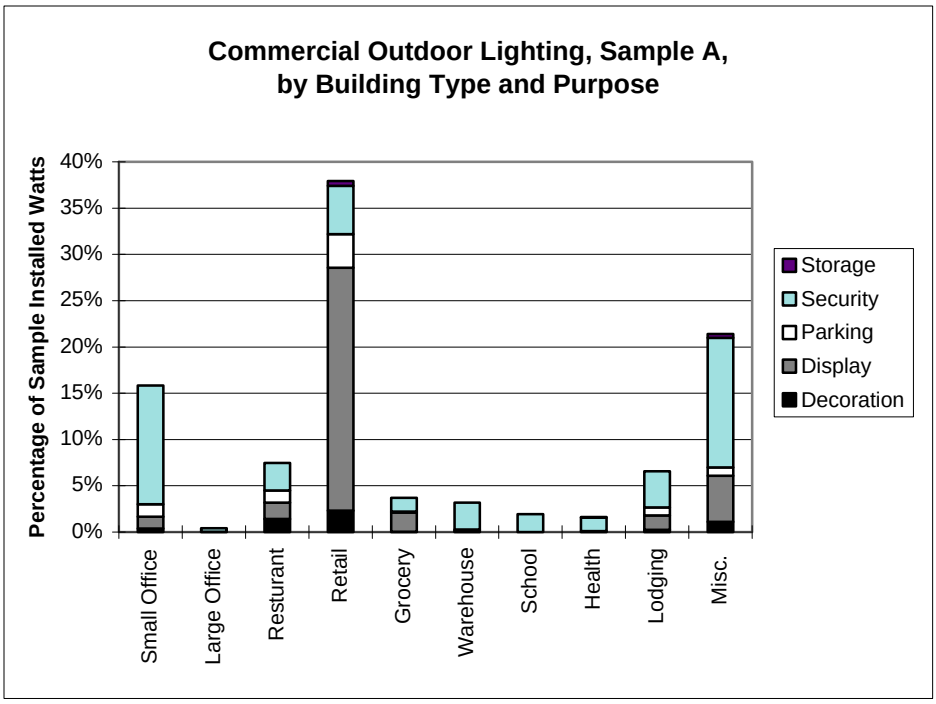


Figure 3-19 - Commercial Outdoor Lighting by Purpose and Building Type

3.4.3 Outdoor Lighting by Lamp Type

Figure 3-20 shows that High Intensity Discharge lamps (HPS, LPS, MV and MH) represent 52% of the installed wattage, and Fluorescent lamps (FFL and CFL) represent 31%. Of the Fluorescent wattage, 61% is from lamps greater than 40 watts, and 39% is from lamps 40 watts or less.

Of the HID lamps, High Pressure Sodium is the most common, representing 20% of all outdoor lighting, then Metal Halide at 17%, Mercury Vapor at 10% and Low Pressure Sodium at 6%. Standard Incandescent lamps represent 15% of the wattage, and Quartz-Halogen only 1%. Compact Fluorescent lamps show only a trace presence, at ¼ of 1%.

Figure 3-21 presents the distribution of outdoor lighting lamp types by building type.

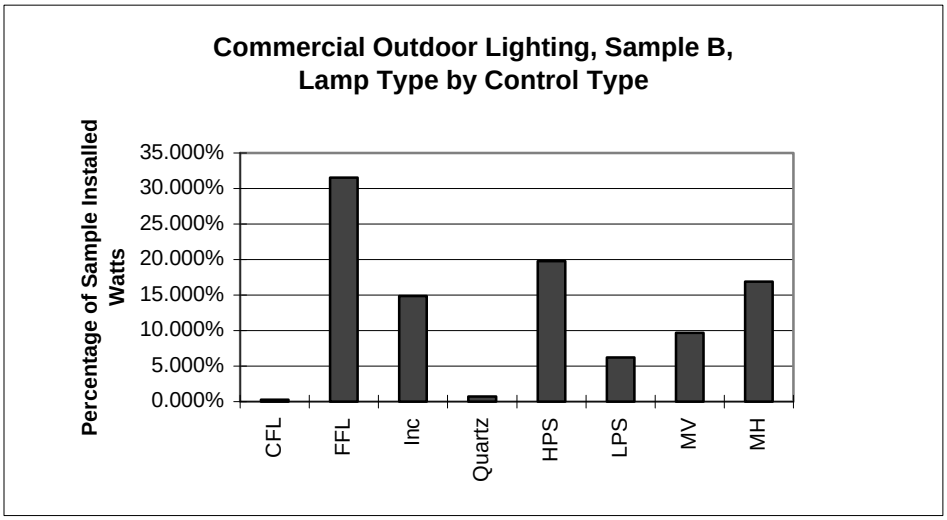


Figure 3-20 - Commercial Outdoor Lighting by Lamp Type

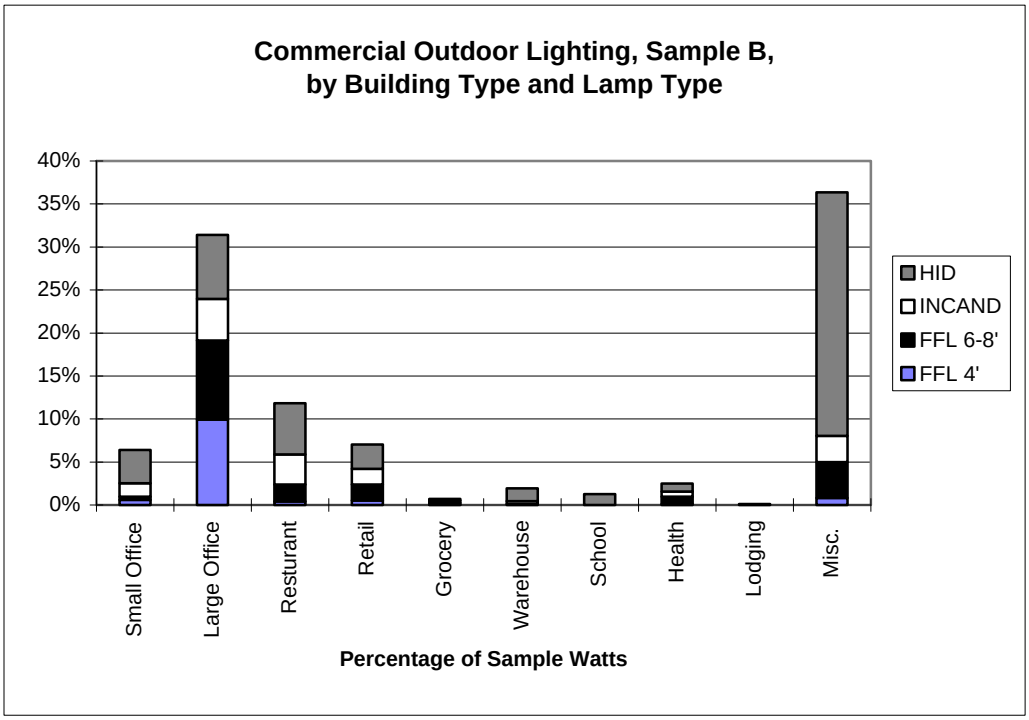


Figure 3-21 - Commercial Outdoor Lighting by Lamp Type and Building Type

3.4.4 Outdoor Lighting Controls

Figure 3-22 shows that most outdoor lighting, 64% of all installed wattage, is on time clock controls. On-off controls are the next most common at 28%. All other control types represent only 8% of the wattage. This distribution remains fairly consistent across building types, with only schools showing a large majority of on-off switches, and restaurants showing 45% of wattage with on-off switches.

HID lamps are the most likely to be on time clock controls, at 71% of all HID wattage. Half of Fluorescent wattage is on time clocks, as is 60% of Incandescent wattage.

Figure 3-23 presents the distribution of the four most common outdoor lighting controls by building type.

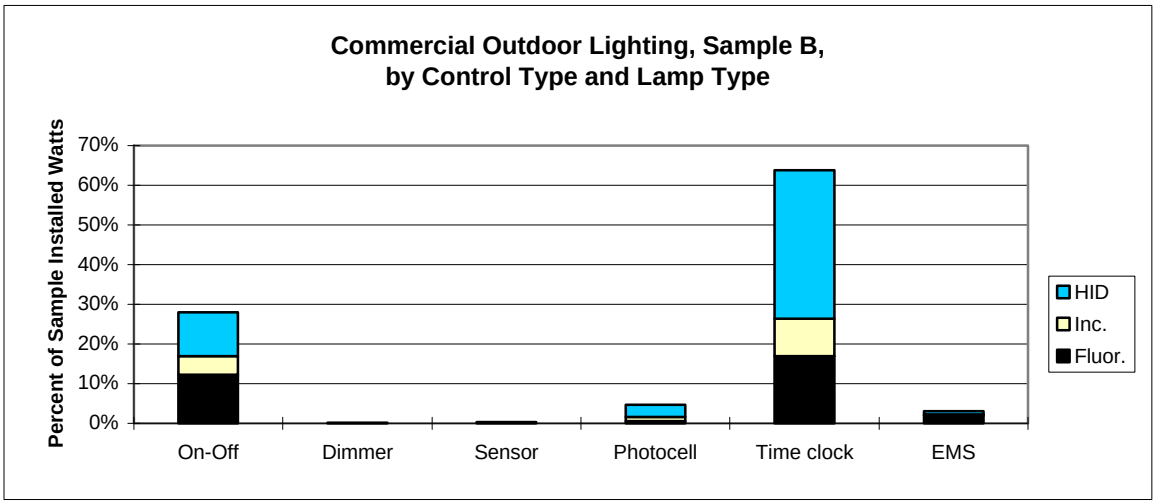


Figure 3-22 - Commercial Outdoor Lighting by Control Type and Lamp Type

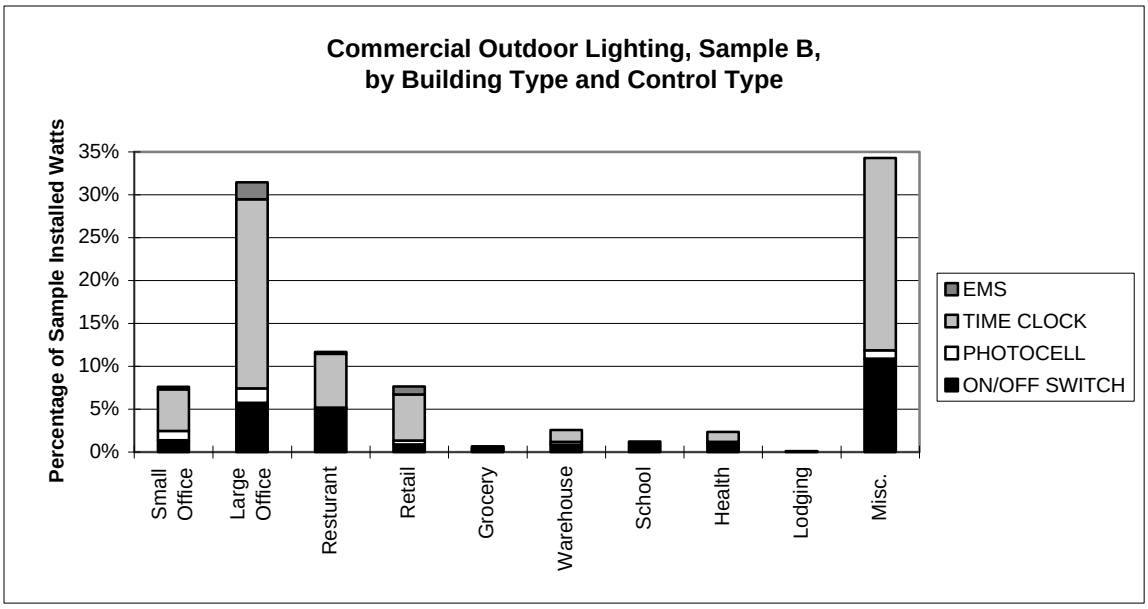


Figure 3-23 - Commercial Outdoor Lighting by Control Type and Building Type

4. LITERATURE SEARCH

Current literature on lighting energy use, lighting efficiency programs, user attitudes, and forecasts for changes in the lighting industry were assembled as part of the initial research of this project. Some of the more interesting materials are described below.

4.1 Published Reports

A survey of recent literature concerning residential lighting energy use resulted in reviewing the following significant studies:

Residential Lighting: The Data to Date

This paper, prepared by Lawrence Berkeley National Laboratory for delivery at national conferences in 1996 analyzes data from a number of utility studies which inventoried and/or monitored residential lighting energy use. It compares findings on installed wattage and unit energy consumption by room type, fixture type, and lamp type. It analyzes market segment information from the Rising Sun report described below, and U.S. Census to target those areas of the residential lighting market which have greatest potential for energy savings with improved technologies.

(California) Baseline Energy Use Characteristics

Published by the California Energy Commission (CEC) in 1994, this study prepared by NEOS Corporation uses data from recent utility studies to estimate the baseline residential Unit Energy Consumption (UEC) and commercial Energy Utilization Intensity (EUI), and average load shapes by building type, vintage, and climate regions. This is a comprehensive study, used as a standard reference by the CEC for forecasting and analysis.

Of greatest interest to this report, the Baseline Energy Use Characteristics estimate total residential electric energy usage, by region, by utility territory, and by single family and multifamily housing types. It also estimates a "Miscellaneous End Use" category which includes lights, plug loads, and everything else not included in specific end use categories. Using different methods and sources, our study further details the lighting component of this Miscellaneous End Use.

Energy Efficient Residential Luminaires: Technologies and Strategies for Market Transformation

Prepared for the U.S. EPA by the Natural Resources Defense Council in 1996, this report analyzes the U.S. residential luminaire market, and makes 6 recommendations for strategies to encourage the development and marketing of more efficient luminaires. The recommendations focus on developing a specification for efficient residential luminaires, and use of a labeling program to promote market penetration of those fixtures. Appendices include reviews of other programs.

Most interestingly, the report suggests that there is a potential market for high end table or floor lamps that include a compact fluorescent bulb with the sale. These lamps could be safer, brighter, longer lasting and more efficient than the equivalent incandescent lamp, and if they were also considered a decorative fixture, they could compete on style rather than price.

U.S. Residential Lighting Fixture Marketplace - Accelerating the Penetration of Dedicated Energy Efficient Light Fixtures

Prepared for Lawrence Berkeley National Laboratories by Rising Sun Enterprises in 1995, this study describes the residential fixture market in the United States based on U.S. Census data and information from Economic Industry Reports, Inc. It looks at the proportion of units and value of imported vs. domestic product, the proportion of dedicated fluorescent to incandescent fixtures, and the specific types of fixtures manufactured. It assesses key players and decision makers in the market, and estimates the technical potential for more efficient technologies.

Energy Characteristics, Code Compliance and Occupancy of California 1993 Title 24 Houses

This report, prepared in 1995 for The California Energy Commission and the California DSM Measurement Advisory Committee (CADMAC) by the Berkeley Solar Group, analyzes in detail the code compliance level of 95 homes built in 1993 in California which did not participate in utility DSM programs. This sample is used to establish a baseline level of compliance with California's residential energy code.

In addition to all other aspects of the code, the report also considers compliance with the lighting provisions of the residential code. General assessment of compliance was based on the "percentage of homes which complied with <u>all</u> provisions of the code," leading to a rather unfavorable assessment, since any

individual home's failure to comply with any one of a myriad of code provisions was considered to be complete failure.

The report very usefully tabulates the total incandescent and fluorescent lighting watts in kitchens and bathrooms for these homes. These values can be compared to other studies, and converted into approximate lumens delivered by technology type. The results of this study are discussed further in Section 2.5.

Analysis of Federal Policy Options for Improving U.S. Lighting Energy Efficiency: Commercial and Residential Buildings

Produced by Lawrence Berkeley National Labs in 1992, this study estimates national baseline energy use for commercial and residential sectors, and then projects the savings potential of various scenarios promoting energy efficiency over a 40 year period. The analysis uses the COMMEND computer model to project the scenarios, and compares the results to other recent studies.

Most attention in the report is devoted to the analysis of the commercial sector, however, some residential data is detailed. Residential unit energy consumption is estimated and penetration rates for lamp technologies by scenario are detailed.

EPRI Reports

EPRI published a series of reports on residential lighting and compact fluorescent lamps in 1992-93. These include:

- *Survey and Forecast of Marketplace Supply and Demand for Energy Efficient Lighting Products*, prepared by the Lighting Research Institute in 1992
- *Residential High-Efficiency Lighting, An Assessment of Utility Programs*, prepared by Aspen Systems Corporation in 1992.
- *Advances in Residential Lighting Technologies* Prepared by Energy International, Inc. in 1992
- *Market Infrastructure and Compact Fluorescent Lamps*, prepared by Macro Consulting in 1993

In general, these reports are now somewhat dated, and thus not immediately useful for our study. The Energy International report, however, does provide an interesting comparison between the structure of and recent changes in the U.S. residential lighting market and that of Japan. It attempts to explain the much greater penetration of fluorescent lighting into the residential market in Japan.

The report suggests that the vertically integrated and highly standardized lighting industry in Japan has been more supportive of innovation and change than the segmented industry which exists in the U.S. The U.S. residential lighting industry tends to be dominated by the limited competition among the three major lamp

companies, with a myriad of fixture, ballast and control businesses trying to compete on cost rather than performance. Japanese lighting equipment firms, on the other hand, tend to be subsidiaries of large conglomerates that develop many electronic products. Innovations can be passed from one section of the company to another, and new lamp technologies introduced simultaneously with compatible new fixtures.

Utility Residential DSM Program Reports

California utilities which have conducted residential lighting DSM programs have filed reports on their programs at the CEC. All reports from PG&E, SCE, and SDG&E for 1990-1995 were reviewed. All of these programs focused on installation of compact fluorescent lamps (CFLs) in residences. They provide some useful information on consumer preferences and behavior, installation rates and locations.

Perhaps the most useful report on consumer attitudes was by SDG&E "Appliance Efficiency Incentives: Residential Compact Fluorescents 1992 Lighting Focus Groups and Follow-up Interviews." Participants in four focus groups were asked about their attitudes to CFLs, and then given a CFL bulb to take home and evaluate. This study distinguished between the income level and renter/owner status of participants and evaluated awareness and perceptions of CFL technology, barriers to marketing and consumer acceptance.

The PG&E evaluation submitted in 1993 includes average number of CFL purchases per participant, reported average wattage savings and estimated net energy savings per year per bulb type.

Conference Papers

Results from the most recent research on lighting programs or lighting technology performance is often presented at national conferences. One of the most useful forums for this information is the ACEEE bi-annual conference. At the most recent ACEEE conference in August of 1996, four papers on field studies of lighting control performance are especially useful. These papers present measured energy savings results from daylight control and occupancy sensor control systems.

Marketing research and market transformation studies also present useful information on consumer acceptance, market barriers, and market penetration of lighting technologies, most commonly, compact fluorescent lamps. The most useful sources are listed in the bibliography.

Lighting Pattern Book for Homes

The Lighting Pattern Book for Homes was published by The Lighting Research Center at Rensselaer Polytechnic Institute in 1993. The book is aimed primarily at designers and residential building managers, to provide guidance in their selection of more energy efficient lighting options. It provides typical room lighting plans, a 3D sketch of lighting conditions, and analysis of annual operating costs for the various lighting options. It also provides background information on lighting and current technologies, performance data for various lighting technologies, general advice on installation and operation, a glossary, and additional references.

The study found that the simplest energy efficient option, "replace lamps," saved an average of 26% in annual operating costs. "Replace controls" saved an average of 45% and "replace luminaires" or "remodel" saved an average of 57% of annual operating costs. These figures are calculated on a per room basis, and cannot be projected to larger populations. Careful attention was paid to assuring that efficiency levels of various options were accurate and that lighting conditions between options were comparable to or improved over the more efficient option. The cost of conversion, however is not addressed. Also the hours of operation, a key element in any economic analysis, is based on a simple set of assumptions, which are reasonably conservative but not based on any referenced source.

4.2 Bibliography

1. *ADM Associates, Inc., End Use Metered Data for Commercial Buildings: Annual Report 1992-1993, Southern California Edison Company, December 1993.*
2. *ADM Associates, Inc., Non Residential New Construction Impact Evaluation Study, Pacific Gas and Electric Company, October 1993.*
3. *ADM Associates, Inc., Residential Pilot Lighting Program Baseline Survey Results, Hawaiian Electric Company, Inc., January 1994.*
4. *Appliance Efficiency Incentives: Residential Compact Fluorescents 1992 Lighting Focus Groups and Follow-up Interviews Report, San Diego Gas and Electric, MIAP 92-P09-S01-R241, March 1993.*
5. *Aspen Systems Corporation, Residential High-Efficiency Lighting: An Assessment of Utility Programs, Electric Power Research Institute, TR-101221, December 1992.*
6. *Atkinson, Barbara A., Analysis of Federal Policy Options for Improving U.S. Lighting Energy Efficiency: Commercial and Residential Buildings, Lawrence Berkeley Laboratory, LBL-31469, December 1992.*
7. *Berkeley Solar Group, Energy Characteristics, Code Compliance and Occupancy of California 1993 Title 24 Houses, California Energy Commission and California DSM Measurement Advisory Committee, April 1995.*
8. *Calwell, Chris; Granda, Chris; Stephens, Charlie, Energy Efficient Residential Luminaires: Technologies and Strategies for Market Transformation Final Report, U.S. Environmental Protection Agency, Grant #CX824685, May 1996.*
9. *Commercial Building Lighting Standards Needs Assessment, Minnesota Building Research Center.*
10. *Conway, Kathryn M., Leslie, Russell P., The Lighting Pattern Book for Homes, Lighting Research Center, Rensselaer Polytechnic Institute, 1993, Troy, New York.*
11. *Draft Report on Potential Impact of Possible Energy Efficiency Levels for Fluorescent Lamp Ballasts, Lawrence Berkeley National Laboratory, February 1996.*
12. *Energy International, Inc., Advances in Residential Lighting Technologies, Electric Power Research Institute, EPRI TR-100868, July 1992.*

13. *Haddad, Brent M., Why Compact Fluorescent Lamps are not Ubiquitous: Industrial Organization, Incentives and Social Convention, presentation at ACEEE Conference, 1994.*

14. *Hanford, J.W., et. al., Baseline Data for the Residential Sector and Development of a Residential Forecasting Database, Lawrence Berkeley Laboratory, DOE Contract DE-AC03-76SF00098, May 1994.*

15. *HBRS, Inc., Residential Lighting Study: Time of Use Metering Results, Southern California Edison Company, November 1993.*

16. *HBRS, Inc., 1992 Residential Compact Fluorescent Lighting Program Evaluation Survey Results, Pacific Gas and Electric Company, September 1993.*

17. *HBRS, Inc., Final Report: Residential Lighting Study (Inventory Results), Southern California Edison Company, July 1993.*

18. *Jennings, Judith, Residential Compact Fluorescent Fixtures: The Next Generation, Lawrence Berkeley Laboratory and California Compact, January 10-11, 1995.*

19. *Jennings, Judith, et. al., Residential Lighting: The Data to Date, Lighting Research Group, IESNA Conference Proceedings 1996.*

20. *Koomey, Jonathan G., Sanstad, Alan H., Shown, Leslie J., Magnetic Fluorescent Ballasts: Market Data, Market Imperfections, and Policy Success, Lawrence Berkeley National Laboratory #LBL 37702 UC 1600, December 1995.*

21. *Lighting Research Institute, Survey and Forecast of Marketplace Supply and Demand for Energy-Efficiency Lighting Products, California Institute for Energy Efficiency, December 1992.*

22. *Lightsaver Program Bulletin, Bonneville Power Administration, Vol. 2, No. 4, p. 3, July 1996.*

23. *MACRO Consulting, Market Infrastructure and Compact Fluorescent Lamps, Electric Power Research Institute, EPRI TR-102120, March 1993.*

24. *Mathematica Policy Research, Inc., Southern California Edison Company 1990 Residential Appliance Saturation Survey, Southern California Edison Company, November 1990.*

25. *NEOS Corporation, Effective Measure Life Estimation for Commercial Lighting Measures, presented at 1995 Energy Program Evaluation Conference, August 1995.*

26. *NEOS Corporation, Technology Energy Savings Volume I: Baseline Energy Use Characteristics, California Energy Commission, P300-94-006, May 1994.*

27. *Owashi, Leslie D., Shiffman, Dean A., Sickels, Andrew D.,, Lighting Hours of Operation: Building Type versus Space Use Characteristics for the Commercial Sector, presented at ACEEE 1994 Summer Study on Energy Efficiency in Buildings San Diego Gas and Electric Company,.*

28. *Quantum Consulting, Inc., 1993 Impact Evaluation of the Residential New Construction Program, Pacific Gas and Electric Company, P651-052, September 1994.*

29. *Residential and Small Commercial Lighting Initiative Program Description, Consortium for Energy Efficiency, December 1994.*

30. *Residential Appliance Efficiency Incentives: Compact Fluorescents 1993 Retail Sales Study, San Diego Gas and Electric Company, MIAP-93-P09-S01-R329, CEC No. 26, September 1993.*

31. *Rising Sun Enterprises, U.S. Residential Lighting Fixture Marketplace: Accelerating the Penetration of Dedicated Energy Efficient Light Fixtures, Lawrence Berkeley Laboratory, June 1995.*

32. *Sales, Jack E., California at Night: A Massive Waste of Energy and Light, presentation to the California Energy Commission, June 1996.*

33. *Tacoma Public Utilities, Baseline Residential Lighting Energy Use Study, presented at ACEEE 1996 Summer Study on Energy Efficiency Buildings, 1996.*

34. *Wiggins, Don, Boutwell, Bob, Residential Lighting Program Customer Evaluation, San Diego Gas and Electric Company, MIAP-010-91, September 1991.*

35. *Xenergy, Inc., 1995 Residential Compact Fluorescent Lamp Peak Day Survey, San Diego Gas and Electric Company, February 1996*

36. *Xenergy, Inc., Measuring Spillover and Market Transformation Effects of Residential Lighting Programs, presented at ACEEE 1996 Summer Study on Energy Efficiency Buildings, 1996.*

37. *Xenergy, Inc., Residential Appliance Efficiency Incentives: Compact Fluorescents Gross Impact Study, 1994 Residential CFL Program, San Diego Gas and Electric Company, February 1996.*

38. *Xenergy, Inc., Residential Appliance Efficiency Incentives Program: Fluorescent Lighting (CFL) 1994 First Year Statewide Load Impact Study, San Diego Gas and Electric Company and Southern California Edison Company, February 1996.*