U.S. Lighting Market Characterization

Volume I: National Lighting Inventory and Energy Consumption Estimate

Final Report

Prepared by
Navigant Consulting, Inc.

for
U.S. Department of Energy

Office of Energy Efficiency and Renewable Energy
Building Technologies Program

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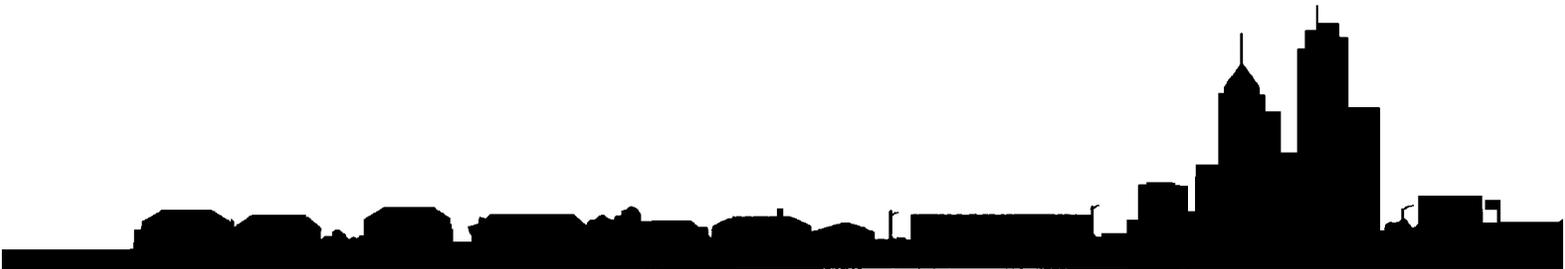
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Comments

The Department is interested in receiving input on the material presented in this report. If you have suggestions of better data sources and/or comments on the findings presented in this report, please submit your feedback to Jim Brodrick by September 30, 2003 at the following address:

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List of Acronyms and Abbreviations

ACEEE	American Council for an Energy Efficiency Economy
AHS	American Housing Survey
BT	DOE Building Technologies Program
CBECS	Commercial Building Energy Consumption Survey
CFL	Compact Fluorescent Lamp
CRI	Color Rendering Index
CU	Coefficient of Utilization
DOE	United States Department of Energy
EIA	Energy Information Administration
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
HID	High Intensity Discharge
HPS	High Pressure Sodium
IESNA	Illuminating Engineering Society of North America (also "IES")
LBNL	Lawrence Berkeley National Laboratory
LED	Light Emitting Diode
LPS	Low Pressure Sodium
LR&D	Lighting Research and Development
MECS	Manufacturing Energy Consumption Survey
NAICS	North American Industrial Classification System
NEEP	Northeast Energy Efficiency Partnerships
NWEEA	Northwest Energy Efficiency Alliance
PNNL	Pacific Northwest National Laboratory
RECS	Residential Energy Consumption Survey
SIC	Standard Industrial Classification
TPU	Tacoma Public Utilities

h	Hour
kWh	Kilowatt-hour
lm	Lumen
quad	Quadrillion (10^{15}) British Thermal Units
TWh	Terawatt-hour
W	Watt
yr	Year

Useful Conversions

1 TWh = 1 billion (10^9) kWh
1000 TWh electricity = 3.412 quads delivered electricity
1 quad delivered electricity = 3.211 quads primary energy

Executive Summary

The *Lighting Market Characterization* study is a multiyear program to evaluate light sources in the United States, and identify opportunities for saving energy. Sponsored by the United States Department of Energy's (DOE's) Building Technologies Program (BT), the *Lighting Market Characterization* consists of two phases. This report, Phase I, provides an estimated inventory of installed lighting technologies for 2001 and their associated energy consumption. Phase II will evaluate this inventory and research lighting technologies to identify energy saving opportunities.

The objective of Phase I is to collect and present in one document the fundamental energy consumption information that DOE needs to plan an effective lighting research and development (LR&D) program. This report answers three main questions:

- How much energy is consumed by light sources in the United States?
- How many lighting technologies are installed, where are they installed, and what area do they illuminate?
- What are the performance attributes of the installed stock of lighting technologies?

This report attempts to answer these questions at the right level of aggregation and as uniformly as possible across end-use sectors. This study draws data from existing sources such as the Commercial Building Energy Consumption Survey (CBECS) and the Manufacturing Energy Consumption Survey (MECS), as well as previously untapped data sources such as end-use metering studies and building audits. Two important features that distinguish this study from prior efforts are its use of new data sources, and its analysis by applications that cut across building sectors.

One of the new sources of data on lighting use in buildings was the XenCAP™ energy auditing system. XenCAP™ is based on a database of nearly twenty-five thousand detailed audits of commercial and industrial facilities conducted throughout the U.S. in the 1990's. A statistical correction was applied to these audits to establish 2001 as the inventory estimate year. The report was circulated to more than 35 reviewers from government, industry, and academia. This final report incorporates their valuable input and additional insights.

End-use lighting installations in the U.S. were classified into four general sectors made up of three building categories (residential, commercial and industrial) and one category called 'outdoor stationary' which incorporates lighting installations such as street lighting, airport runway systems, traffic signals, and billboard lighting. The term 'stationary' is used in the category to differentiate it from automobile and other mobile lights that are beyond the scope of this study. To evaluate the available data on installed lighting technologies, these general sectors were broken down into further sub-groups (e.g., office, education, retail, etc.), which correspond to those used by the Energy Information Administration in CBECS and MECS. In total, more than fifty separate building types across the sectors were evaluated in this analysis.

Light sources in this study were grouped into four broad categories: incandescent, fluorescent, high intensity discharge and solid state. Within each of these, the market analysis evaluated subgroups of commonly available lighting products (e.g., reflector lamps, T8 fluorescent tubes, metal halide lamps). In total, thirty-one lamp subgroups were carried through the analysis, extracting information like average wattage and number of sockets from the data set. A complete list of the light source subgroups can be found in Table 2-3 of the main report.

Table ES-1 summarizes the lighting energy consumption estimate for the four general lighting market sectors in terms of both delivered (end-use site energy) and primary (source) energy. Primary energy refers to the total energy required to generate and supply electricity to the customer site.[1]

Table ES-1 U.S. National Energy Use for Lighting Disaggregated by Sector

Sector	Electricity Use per Building (kWh/yr)	Number of Buildings	Site Energy (TWh/yr)	Primary Energy (quads)	Percent of Total
Residential	1,946	106,989,000	208	2.2	27%
Commercial	83,933	4,657,000	391	4.2	51%
Industrial	475,063	227,000	108	1.2	14%
Outdoor stationary	n/a	n/a	58	0.6	8%
Totals			765	8.2	100%

Table ES-1 shows the estimate of total lighting electricity consumption as 765 Terawatt-hours (TWh) at the building site, or 8.2 quadrillion british thermal units (quads) of primary energy. Putting this level of consumption into a broader context, the United States used approximately 98.3 quads in 2001, more than a third of which, about 37 quads, to generate electricity (EIA, 2002a). Thus, lighting was approximately 8.3% of national primary energy consumption, or about 22% of the total electricity generated in the U.S.

From a buildings perspective, the percentages are even higher. Nationally, total energy use in commercial and residential buildings was approximately 36.4 quads, of which electricity use in buildings was approximately 21.3 quads (BTS, 2002). Summing together the energy use for lighting from Table ES-1, the residential and commercial sectors consume approximately 6.4 quads. Thus, in these two building types, lighting constituted approximately 17.6% of total building energy consumption, or approximately 30.3% of toal building electricity use.

Looking across the sectors shown in Table ES-1, commercial buildings were found to use the largest share of lighting energy use (51 percent), followed by residential (27 percent), industrial (14 percent) and outdoor stationary (8 percent). The estimates presented in this table for lighting energy use are compared with other studies on lighting energy consumption in Table 7-1 of this report.

Providing further breakdown of the study findings, Figure ES-1 shows the total lighting energy consumption for each of these four general sectors, and illustrates the amounts of energy used by the various light source technologies. The numerical values presented in this figure appear in Table 5-22 of this report.

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[1] The factor used to convert the site-use electrical energy to primary energy consumed at the generating power plant is 10,768 BTU/kWh (DOE, 2002) for the year 2000. This conversion factor incorporates generation, transmission and distribution losses on an average basis for the U.S. Note that the conversion efficiency varies from year to year, depending on the mix of electrical generating power plants used in a given year.
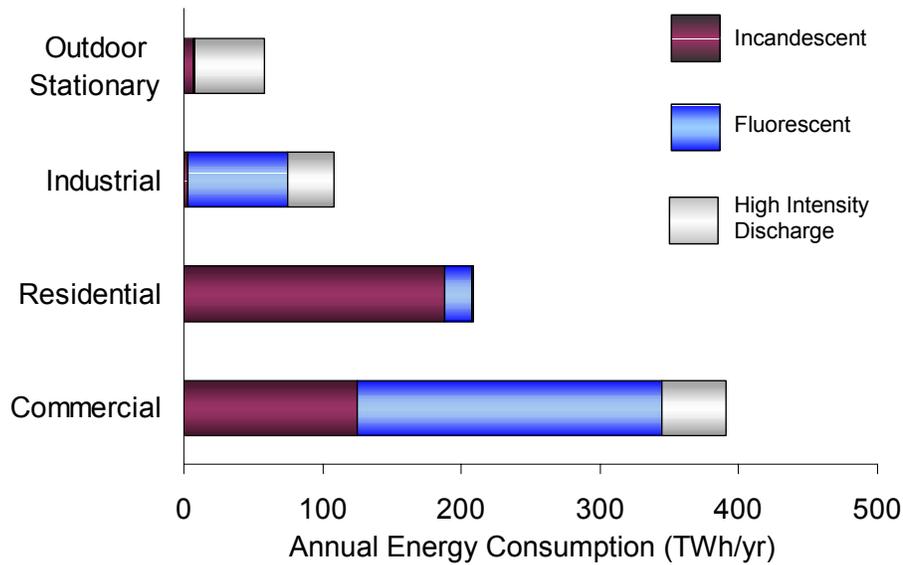
Figure ES-1 Shares of Sectoral Energy Use by Lighting Technology

Figure ES-1 shows that the outdoor stationary energy consumption is primarily HID sources, which account for 87% of the outdoor stationary's 56 TWh/year electricity use. The industrial sector has sizable energy shares of both fluorescent and HID sources, 67% and 31%, respectively, of this sector's 108 TWh/year consumption. The commercial sector is the largest energy user overall, having large quantities of energy used by all three light sources. Fluorescent and incandescent are the two largest commercial lighting energy users, accounting for 56% and 32% of its annual 391 TWh/year of electricity use. In the residential sector, energy use is primarily driven by incandescent technologies, where 90% of the energy is consumed by this light source.

It is helpful to have an estimate of the lighting energy budget in the United States, by sectors and light sources. Additionally, it is also helpful to understand the technologies and sectors where the estimated energy consumption levels are found. Electricity is a means to provide a service – visible light – in our workspaces, homes and other installations. Using manufacturer catalogues, lamp efficacies[2] were gathered for all 31-lamp types, differing by general building sector and average wattage.[3] Figure ES-2 provides an estimate of the resulting calculated source lumen[4] production in the United States. The numerical values shown in this figure appear in Table 5-8 of this report.

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[2] Efficacy is a lighting measure of efficiency, based on number of lumens of light produced per watt of energy consumed (lm/W). It is a metric similar to miles per gallon (MPG) in an automobile. MPG tells you how far you can travel on a gallon of gas, while efficacy tells you how much light you will get per watt of energy.

[3] A table of efficacies used can be found in Appendix D, E and F of this report.

[4] A lumen is a measure of light production, specifically it is the SI unit of luminous flux, defined as the quantity of light emitted in a unit solid angle (1 steradian) by a point source with uniform intensity of 1 candela. A lumen-hour (lm-hr), the metric used in Figure ES-2, is a measure of lighting service over a period of time (one hour). Tera is a unit modifier referring to a trillion units, or 10^12.
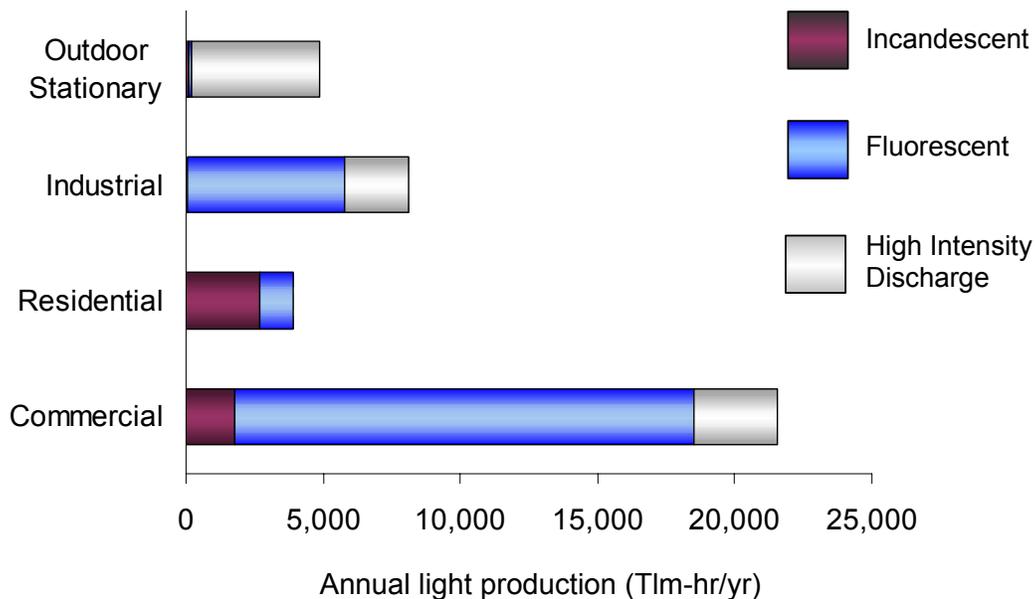
Figure ES-2 Estimated Source Light Production by Sector and Lamp Type, 2001

According to Figure ES-2, the greatest source lumen production in the United States is for the commercial sector. This sector, comprising retail establishments, office buildings, and many other commercial space-types, is generally lit throughout the day and into the evening hours – contributing to the large demand for lighting services. The high prevalence of fluorescent lighting in this sector (see Table ES-2), the high occupancy rates of many commercial space-types and fluorescent's relatively high efficacy all contribute to this considerable source lumen output.

When compared with Figure ES-1, Figure ES-2 shows the relative efficiencies – or lamp efficacies – associated with each of the light sources. For example, within the commercial sector, 32% of its energy use was for incandescent lighting – but only 8% of the commercial lumens were generated by this source. Conversely, 56% of energy use in the commercial sector was for fluorescent sources, which provide 78% of its lumen output.

Looking across all four sectors in Figure ES-2, it becomes clear that fluorescent is the most important light source in the U.S. in terms of lighting service. On a national basis, 62% of the source lumens are produced by this source. HID sources are the second most important, generating 26% of the lumens in 2001, followed by incandescent which delivered 12%. Figure ES-1 reports the energy consumed by each of these sources. Contrasting with their lumen output, incandescent is the highest energy user, accounting for 42% of the nation's electricity use for lighting. This is followed by fluorescent with 41% and HID with 17%. Thus, incandescent lighting, the light source developed more than 100 years ago and still in use today, consumes the most energy and provides the least amount of light nationally.

Table ES-2 provides a summary estimate of the number of lamps installed for a typical building in the United States. Further detail on this table can be found in Table 5-2 of the main report. A estimate of the total installed lamps by technology category is also provided in Table ES-2. Note that this column includes the lamps from the outdoor stationary sector, however outdoor stationary is not shown in the table because they cannot be presented on a per-building basis.

Table ES-2. Average Number of Lamps per Building and Total Lamps, 2001

Technologies	Residential	Commercial	Industrial	Total Lamps in US	Percent of Lamps
Incandescent	39	91	33	4,397,000,000	63%
Fluorescent	6	324	1,340	2,473,000,000	35%
HID	0.04	7	67	105,357,000	2%
Solid State	-	0.4	0.3	1,840,000	0.03%
Total	45	422	1,440	6,977,197,000	100%
Number of Buildings	106,989,000	4,657,000	227,000	n/a	n/a

Note the dominance of incandescent lighting in the residential sector, and fluorescent in the commercial and industrial sectors. Of the 7 billion lamps in the United States, incandescent constitutes the most common light source (63%) by sheer number of installations, however as was shown in Figure ES-2, incandescent contributes the least amount of light to the national annual lumen demand.

Table ES-3 presents an estimate of the daily operating hours by light source. Although incandescent outnumber other lamp types (particularly in the residential sector), the majority of them generally operate for less than three hours per day – contrasting with fluorescent and HID, that operate three times as long.

Table ES-3. Average Operating Hours per Day by Light Source, 2001

Lamp Type	Residential (hours/day)	Commercial (hours/day)	Industrial (hours/day)	Outdoor (hours/day)	National Avg. (hours/day)
Incandescent	1.9	10.2	16.7	7.9	2.8
Fluorescent	2.2	9.7	13.4	10.8	8.2
HID	2.8	10.1	13.9	11.3	11.0
Solid State	-	23.0	23.4	7.0	22.2
Total	2.0	9.9	13.5	10.5	4.8

In addition to this type of summary information on the installed base of lighting (both number and type of lamps) and the typical use profile, more detailed information is provided in the body of the main report where lamp type subgroups and other disaggregated information is presented. For example, the following observations about light sources can be made from information presented in Chapter 5:

- General service lamps account for 73% of the electricity consumed by incandescent sources across all building sectors. The second highest incandescent energy user is the standard-reflector lamp, estimated at 17% of the electricity consumed by incandescent sources.

- Four-foot linear lamps account for 61% (T-8 and T-12 together) of electricity for fluorescent

sources in all sectors. The second highest energy consumer in the fluorescent category includes the greater than four foot tubes, accounting for 23%. Of these, most are used in industrial building installations.

- For high intensity discharge lamps, metal halide is the primary consumer, constituting 49% of energy consumed by HID sources in all sectors. This is followed by high pressure sodium at 32% and mercury vapor at 17%. HID sources, while both used in commercial and industrial applications, consume 87% of the energy for the Outdoor stationary sources, and deliver 96% of the lumens for that sector.

In addition to the results presented in Chapter 5, the Appendices to this report contain the tables of data used to calculate and generate this 2001 US Lighting Market Inventory. Providing this level of transparency is intended to provide researchers and interested parties with a useful resource.

Observations such as these about the installed base of lighting technologies in the United States give the DOE a baseline from which to make decisions on the allocation of lighting research and development. This study helps to identify areas where new technologies could be developed, where incremental improvements in existing technologies may be targeted and the magnitude of energy savings that would result.

1. Introduction

Lighting Market Characterization is sponsored by the United States Department of Energy's (DOE's) Building Technologies Program (BT). The study's objective is to collect and present in one document the fundamental consumption information that DOE needs to plan an effective program in lighting research and development (LR&D) projects. These key elements include:

- Quantity, type, application, and energy use of stationary lighting in the U.S.
- Performance characteristics of lighting technologies
- Trends, drivers, and barriers to improved efficiency in the lighting market
- Opportunities for energy savings through advances in lighting technology and adoption of best practices
- Overview of ongoing lighting research in the public and private sectors

Transparency and conciseness are important aspects of this study. They allow planners and reviewers to easily compare the study's assumptions with their own data or intuitions and to verify the accuracy of the calculations. The result is increased confidence and familiarity with the results. Also, the simplicity of the calculation procedures and presentation allows planners to make quick estimates of energy use and savings potential while evaluating LR&D opportunities and designing programs.

Along with the study's convenience should come improved accuracy in some energy use estimates.

Lighting Market Characterization consists of two phases. Phase I, the Inventory Phase, is limited to the description of the lighting market as it exists today. Phase II, the Opportunities Phase, looks forward, describing potential energy savings due to improvements in lighting efficiency. This report details the background, methodology, results, and conclusions from Phase I only.

1.1. U.S. Department of Energy's Lighting Research and Development Program

The DOE Lighting LR&D Program's mission statement: to increase end-use efficiency in buildings by aggressively researching new and evolving lighting technologies, in close collaboration with partners, to develop viable methodologies that have the technical potential to conserve 50% of electric lighting consumption by 2010. The program's activities are focused in three areas: (1) advanced light sources; (2) lighting fixtures, controls and distribution systems; and (3) the impact of lighting on vision.

Such an ambitious goal requires DOE to focus its research efforts on new technologies that can make a significant impact on energy conservation. DOE also strives to coordinate its LR&D efforts with other public and private efforts at the local, state, and national levels to avoid duplication and leverage the relative strengths and funds of all the participants. Recognizing the importance of lighting to society and energy use, DOE seeks input from and coordination with the lighting industry in formulating its LR&D agenda. The lighting technology roadmap, *Vision 2020*, is one example of an activity that assists the DOE in this respect.

1.2. Existing Sources of Information on the Lighting Market

One of the hurdles DOE faces in planning its research agenda is the lack of a single, definitive, and publicly available source of information on the lighting market in a form that is sufficiently detailed for LR&D planning. Some studies exist that provide information on the lighting market, such as the

California Statewide Residential Lighting and Appliance Saturation Study (RLW Analytics, 2000); Energy and Housing in Wisconsin: A Study of Single Family Owner-Occupied Homes (WEC, 2000); Baseline Study of the Northeastern Residential Lighting Market (NEEP, 1998), Commercial Lighting Market Effects Study (PG&E and SDG&E, 1998); Commercial and Industrial Lighting Study (NWEEA, 2000).

Several of the lighting studies based on Energy Information Agency (EIA) data have been performed by DOE laboratories. Each available source is intended for a specific purpose—establish minimum efficiency standards, forecast national energy use, transform markets—but none is an ideal reference tool for general federal LR&D planning. In most cases the studies aggregate at a higher level or in a different manner than DOE's Lighting Program can utilize effectively. For example, the studies have too narrow a focus (e.g. electronic ballasts in commercial buildings), too broad an aggregation (e.g. "non-incandescent" lamps), too fine an aggregation (e.g. 32 W, 2-pin, T-12 fluorescent, with high-efficiency magnetic ballasts), or some missing information (e.g. energy use estimates but no technology descriptions).

There are also differences in the amount of lighting information available across sectors. The residential sector has been studied more often and in more detail than have the commercial and industrial sectors, while other stationary installations such as billboards and roadway lighting have received relatively little attention. For the commercial and residential sectors, the emphasis of several of the studies is typically on the distribution of lamp technologies within a residential or commercial building, and on the distribution of lamp technologies by application (e.g. indoor, outdoor).

Studies also conflict. For instance, Vorsatz (1997) points out that a prior Lawrence Berkeley National Laboratory (LBNL) estimate of lighting-related electricity consumption in the commercial sector was fully one-third below the EIA (1996) estimate. There is also a wide range in the estimates of residential lighting energy use (900 kWh/yr to 2500 kWh/yr per household, see Table 7-1).

1.3. Role of the Lighting Market Characterization — Inventory Phase

Phase I of the *Lighting Market Characterization* (the Inventory Phase) answers three main questions:

- How much energy is consumed by light sources in the United States?
- How many lighting technologies are installed, where are they installed, and what area do they illuminate?
- What are the performance attributes of the installed stock of lighting technologies?

It attempts to answer these questions at the right level of aggregation and as uniformly as possible across sectors (2001 is the base year). We rely upon existing data sources whenever possible. Even so, there are two important features that distinguish this study from prior efforts: the use of new data sources, and analysis by applications that cut across building sectors.

1.3.1. New Data Sources

Some sectors and lighting applications have received relatively little attention in existing studies. To investigate those overlooked areas, the Inventory Phase draws on data sources that have not previously been utilized for national energy consumption studies. These include:

- American Housing Survey (residential)

- Federal Highway Administration (traffic signals, street lights)
- Outdoor Advertising Association of America (billboards)
- Federal Aviation Administration (airport lighting)
- International Parking Institute (parking)

In addition, XENERGY's XenCAP™ database provided the bulk of data for our commercial and industrial sector and parking estimates. XenCAP™ data have been used as part of the Department of Energy's analysis of fluorescent lamp ballasts and for some California lighting energy studies, but until this study, have not yet been applied to evaluate lighting use on a national basis.

It is recognized that the use of data from a few concentrated areas to develop national estimates introduces uncertainties into the findings and estimates of this report. These uncertainties are discussed in chapter 7 of this report.

1.3.2. Results by Lighting Application

Existing studies provide little insight into the types of technologies that fit the same requirements across building sectors. For example, the living room of a single family home and the office of a commercial high-rise both require a light source capable of producing high Color Rendering Index (CRI). Several lighting technologies can satisfy the technical requirements of the application, but there is no convenient reference available that indicates the amount of national floorspace dedicated to that application and the amount of electricity it consumes. Both are key pieces of information for LR&D planning, since energy-saving lighting advances then can be better leveraged across applications and sectors.

Taking guidance from the Illuminating Engineering Society of America's (IESNA) *Lighting Handbook* (IESNA, 1999), the Inventory examines the technologies and energy used to satisfy lighting applications to pave the way for the identification of crosscutting energy conservation and efficiency opportunities in the next phase. The Inventory also shows results by end-use sector and building type to facilitate comparison with the results of other studies.

2. Classification Nomenclature

2.1. Building Classification

Sectors are made up of three building categories that correspond to EIA designations (residential, commercial, and industrial buildings) and one category that contains major stationary lighting applications, like roadway lighting, that are not related to buildings (outdoor stationary).

Each sector is subdivided into several *Subsectors* to align it with the available data, common conventions, and EIA designations. Residential and commercial buildings are divided into *Building Types* corresponding to EIA classifications. Industrial buildings are divided into Standard Industrial Classification (SIC) codes.[5] They include SICs 20-39. Office buildings within these SIC codes are included in the Commercial sector. The outdoor stationary sector is divided into various lighting *Installations*. Table 2-1 lists the sectors and subsectors.

Table 2-1: Sector and Subsector Classification

Residential	Commercial	Industrial	Outdoor Stationary
Manufactured Single Family – attached Single Family – detached Multifamily – less than 4 units Multifamily – 4 or more units	Vacant Office/Professional Laboratory Warehouse (non-refrigerated.) Food sales Public order/safety Health care (outpatient) Warehouse (refrigerated) Religious worship Public assembly Education Food service Health care (inpatient) Skilled nursing Hotel/Motel/Dorm Strip shopping Enclosed shopping center/mall Retail (excluding mall) Service (excluding food) Other	Food and Kindred Products Tobacco Products Textile Mill Products Apparel and other Textile Products Lumber and Wood Products Furniture and Fixtures Paper and Allied Products Printing and Publishing Chemicals and Allied Products Petroleum and Coal Products Rubber and Miscellaneous Plastics Products Leather and Leather Products Stone, Clay, and Glass Products Primary Metal Industries Fabricated Metal Products Industrial Machinery and Equipment Electronic and Other Electric Equipment Transportation Equipment Instruments and Related Products Miscellaneous Manufacturing Industries	Traffic Signals Roadway Parking Billboards Aviation

Within each subsector are *space functions* that describe the function of particular illuminated areas. Space functions represent the finest level of floorspace disaggregation present in the dataset. Commercial and industrial buildings share similar space function classifications since they both are based on descriptions in the XenCAP™ data. Table 2-2 lists the space function definitions.

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[5] The United States is replacing the SIC system with the North American Industrial Classification System (NAICS). The data serving as the basis for this study and the prior EIA surveys used to create our subsectors are all in terms of the SIC. Guidance for converting between SIC and NAICS is available at http://www.census.gov/epcd/www/naicstab.htm.

Table 2-2: Space Functions in XenCAP database

Architectural	*Exterior architectural features*
Assembly	*Gathering places*
Bathroom	*Lavatories*
Classroom	*Educational meeting rooms, lecture halls*
Dining	*Eating areas*
Exit sign	*Exit signs*
Food preparation	*Kitchens*
Hallway	*Connecting corridors*
Healthcare	*Examination and operating rooms*
Landscape	*Exterior landscaping features*
Lodging	*Sleeping and living areas*
Merchandise display	*Retail display areas*
Office	*General offices*
Parking	*Parking spaces and areas*
Roadway	*Streets and highways*
Shipping/receiving	*Loading docks and staging areas*
Shop	*Manufacturing, assembly areas*
Signage	*Luminous and illuminated signs*
Signal	*Traffic and unspecified signals*
Sports and Recreation	*Gymnasiums, racquet sports courts, ball fields*
Storage	*Warehouses, closets, storage facilities*
Task	*Individual task lighting*
Unknown	*Data records with insufficient description*
Utility	*Mechanical or electrical rooms, building services*

2.2. Light Sources

This study focuses on light source technologies. We also present limited information on the ballast population, with ballasts for fluorescent lamps segmented into seven types (e.g., Magnetic – standard, high efficiency and T8; Hybrid, and Electronic – standard, T8 Full Output, T8 Reduced Output). The results are shown in Appendix A, Table A-2. Because of the limited number of samples and the wide variety of fixtures and control systems, the data could not support a rigorous analysis of the prevalence of lighting fixtures and controls. Fixture information is of particular interest to lighting market participants and is an important factor in near-term energy saving possibilities due to lamp/ballast retrofits.

We define several light sources that are not currently applied on a widespread basis such as electroluminescent and xenon. We insert them now in preparation for Phase II, which will examine the potential of these emerging technologies to alter national energy use.

Table 2-3 presents our classification system for light sources.

Table 2-3: Lamp and Ballast Classification

Fluorescent	Incandescent
T5	Standard – general service
T8 – less than 4'	Standard – integral reflector
T8 – 4'	Halogen – general service
T8 – greater than 4'	Quartz Halogen
T8 – U-bent	Halogen – integral reflector – low voltage
T12 – less than 4'	Low wattage (less than 25W)
T12 – 4'	Miscellaneous incandescent[2]
T12 – greater than 4'	**High Intensity Discharge**
T12 – U-bent	Mercury vapor
Compact – Pin-base	Metal halide
Compact – Screw base	High pressure sodium
Compact – Pin-base – integral reflector	Low pressure sodium[1]
Compact – Screw base – integral reflector	Xenon[1]
Circline	Electrodeless (e.g. mercury) [1]
Induction discharge	**Solid State**
Miscellaneous fluorescent[2]	LED
	Electroluminescent

[1] Low pressure sodium, xenon, and electrodeless lamps are discharge lamps, but are not high intensity. They are included in this category for convenience of presentation. Electrodeless lamps consist primarily of mercury vapor lamps excited by radio frequencies, but this category also includes the sulfur lamp.
[2] "Miscellaneous" means that the light source cannot be categorized elsewhere either because it is of a different type (e.g. T4 fluorescent) or because it is undesignated in the database.

3. Data Sources

In searching for data sources that could provide credible insights into lighting use with the appropriate amount of technical detail, we preferred monitoring studies and building audits. Both are based on direct observations of lighting fixtures and their operation. They provide convincing and detailed information about each fixture that is not accessible by other methods such as surveys, conditional demand analysis, or shipment-based models. For example, a monitoring study can identify the number, location, and wattage of each incandescent fixture in a particular home and record the amount of time that fixture is on over a given period. Furthermore, there is little uncertainty that the fixtures are present and did perform as recorded during the observation period. When aggregated over a large number of homes, these detailed insights can help DOE planners more confidently focus on improvements in specific technologies or opportunities in certain applications. Conditional demand analysis and shipment-based models provide less insight into how particular types of fixtures are used.

Where monitored studies were not available or left gaps, we relied on other sources of objective data and estimates from the individuals and organizations who are most familiar with the areas of interest. Billboard lighting is an example. Since no monitored study exists for billboard lighting, we relied on estimates and technical literature provided by the Outdoor Advertising Association of America, a trade organization representing the billboard and outdoor sign industry.

The next section describes the data sources listed in Table 3-1, with the exception of outdoor stationary lighting sources. These sources are explained in Section 4.2 because of the different methodology applied in conducting the inventory.

Table 3-1: Data Sources used in Preparing the Inventory.

Residential	Tacoma Public Utilities
	Energy Information Administration – Residential Energy Consumption Survey (2001)
	American Housing Survey (1999)
Commercial	XenCAP™
	Energy Information Administration – Commercial Buildings Energy Consumption Survey (1999)
Industrial	XenCAP™
	Energy Information Administration – Manufacturing Energy Consumption Survey (1998)
Outdoor Stationary	Federal Aviation Administration
	Federal Highway Administration
	Outdoor Advertising Association of America
	International Parking Institute
	Lawrence Berkeley National Laboratory
	Energy Information Administration
	Airport Lighting Systems

3.1. EIA Surveys

Periodically, EIA interviews building owners and occupants across a statistically representative sample of United States buildings regarding their energy use. We relied on EIA data to provide the national population of buildings in each of the building segments (residential, commercial, and industrial). For residential buildings, the population is the number of single and multifamily households. For commercial and industrial buildings, the population is both the number of buildings and their total floorspace. Table 3-2 lists some important characteristics of the EIA surveys.

Table 3-2: Characteristics of EIA Building Energy Use Surveys

Survey	Year	Number of Completed Surveys	Number of Buildings	National Floorspace (million sq. ft.)
Residential Energy Consumption Survey (RECS)	2001	4,822	106,989,000	223,309[1]
Commercial Building Energy Consumption Survey (CBECS)	1999	5,430	4,657,000	67,300
Manufacturing Energy Consumption Survey (MECS)	1998	17,877	227,000	12,836

[1] The RECS floor space estimate is from RECS 1997, as the estimate for RECS 2001 was not available when this report went to print.

The EIA number of buildings and floorspace estimates shown in Table 3-2 are based on sample data from statistically-designed subsets of the U.S. residential, commercial and industrial building populations. Consequently, there is uncertainty in the point estimates shown in this table, and the actual population values may differ from the point values that were used in this analysis.

3.1.1. Residential Energy Consumption Survey (RECS)

The 2001 RECS provided the number of single and multifamily housing units in the nation.

The RECS is a national statistical survey that collects energy-related data for occupied primary housing units. RECS includes multifamily and single family homes, including manufactured homes. RECS captures physical characteristics of the housing units, the appliances utilized including space heating and cooling equipment, demographic characteristics of the household, the types of fuels used, and other information that relates to energy use. The RECS also provides energy consumption and expenditures data for natural gas, electricity, fuel oil, liquefied petroleum gas (LPG), and kerosene.

3.1.2. Commercial Building Energy Consumption Survey (CBECS)

The data obtained from the 1999 CBECS for this study include number of facilities and total floorspace by building activity.

The CBECS is a national sample survey that collects energy-related building characteristics, energy

consumption and expenditure data for commercial buildings in the United States. The target population for the 1999 CBECS consisted of all commercial buildings in the US with more than 1,000 square feet of floorspace. A commercial building is defined in CBECS as an enclosed structure with more than 50 percent of its floorspace devoted to activities that are neither residential, industrial, nor agricultural.

3.1.3. Manufacturing Energy Consumption Survey (MECS)

The data obtained from MECS for this study include number of facilities and total floorspace by NAICS code.

The MECS is a national sample survey that collects energy consumption data about the manufacturing sector of the US economy. In 1998, of the approximately 226,000 manufacturing establishments in the US, the MECS sample represented about 17,800 of the largest establishments. These companies represent about 98 percent of the US economic output from the manufacturing sector and a similar proportion of manufacturing energy use.

Previously, the MECS (1994) had been based on SIC code, the same industrial codes used in the XenCAP™ database. However, in 1998, the reporting of the MECS was changed to report using the new NAICS system. In order to use the most recent MECS database (1998), and yet be compatible with the XenCAP™ database, establishments in the MECS 1998 were mapped back to the old SIC codes to be matched with XenCAP™ building audits. The categories of primary interest in this analysis are the 20 major industrial manufacturing groups (SIC 20 through 39).

3.2. XenCAP™

XenCAP™ is a computerized energy auditing system developed by XENERGY, Inc. that analyzes building equipment inventory data, energy use and energy conservation measure information to produce a customized audit report. These reports are available for commercial, industrial and multi-family facilities of all sizes and degrees of complexity. The main purpose of the audit report is to characterize how all energy is consumed in the facility and to identify opportunities for saving energy in the building. The energy allocation process used in XenCAP™ reconciles all end-use results to the actual fuel bills of the facility. Over 150 energy savings measures are available, ranging from basic building shell measures to complex HVAC applications.

In the course of an audit, the auditor collects very detailed end-use data about the equipment in a facility. For example, when collecting information about lighting, the auditor attempts to note the type, hours of use, and wattage of every group of related lighting fixtures in use by the facility. All of these detailed end-use data are used in the energy savings calculations and are entered into a computerized database. The data of primary interest for this study is the lighting information contained in these databases.

The XenCAP™ data used for this study were collected over the past twelve years in several regions throughout the country, although the majority of samples occur in the New York City metropolitan area. The data were collected either as the result of an audit program sponsored by a utility to promote energy conservation or as a research project to gather customer data. Regardless of the motivation for the audit, the data collected are the same. The major difference is that audits collected during a research project are sampled to represent the population while the audits from a conservation program are not and hence may be biased. The regions and the amount of data available for this study are shown in Table 3-3.

Table 3-3: XenCAP^{TM} Databases

Utility Name	States	Data Collected	No. of Audits	Motivation
Georgia Power Company	Georgia	1993-94	167	Program
Anaheim Public Utilities Dept.	California	1993-94	22	Program
Kansas City Power and Light	Missouri	1991-93	461	Program
Northern States Power	Minnesota	1987-89	1,016	Research
Orange and Rockland Utilities	New York, New Jersey	1986, 1989-93	1,813	Both
Ohio Edison	Ohio	1993-96	208	Program
Omaha Public Power District	Nebraska	1992-95	402	Program
Missouri Public Service	Missouri	1992	43	Research
Pasadena Water & Power Dept.	California	1991-95	51	Program
Central Maine Power	Maine	1992-93	171	Program
Public Service Electric and Gas	New Jersey	1990-94	251	Both
Long Island Lighting Co.	New York	1986-98	13,637	Program
Cincinnati Gas & Electric	Ohio	1991-96	998	Program
Central Illinois Lighting Co.	Illinois	1983-96	213	Program
Central States Power Co.	Ohio	1994, 96	109	Program
Ohio Power	Ohio	1994-96	126	Program
Consolidated Edison	New York	-	5,078	Both
Rockland Electric	New York	-	54	Program
ABCS			26	Program

The data extracted from XenCAP™ consisted of three tables of information. Examples of these three tables from the XenCAP™ database appear in Appendix C.

- *Facility Table* - This contains information about the site including size (sq. ft.), location, facility type, SIC code, and date of the audit.
- *Lighting Group Table* - This table contains information about each group of related lighting fixtures within the facility, grouped together based on location and operation. The table contains a description of the group and the operating hours. There are usually multiple entries for each facility.
- *Lighting Technology Table* - This table contains information about the specific lighting equipment within each lighting group. The lighting data includes fixture type, number of fixtures, number of lamps, and ballast type. There may be several entries for each lighting group.

In addition to the data extracted from the audits, other XenCAP™ system data were extracted for the study. These include lookup tables of the facility type code and lighting equipment type code. The lighting lookup table contains wattage and lumen information based on the fixture type, ballast and number of lamps.

To identify the building type of the audit, XenCAP™ contains three pieces of information: a facility type code, a building description, and an SIC code field. The facility type codes are the primary means of identifying the facility. The building description is a free form field and was used in case the building category field was missing. The SIC code field was used to classify manufacturing (industrial) facilities and to distinguish them from commercial facilities.

Table 3-4 shows the number of buildings in the XenCAP™ database compared to the national population of commercial buildings as estimated by CBECS. This table shows that the majority of commercial building records in the XenCAP™ database are office buildings.

Table 3-4: Relationship between XenCAP™ and the Population of Commercial Buildings

XenCAP™ Code	XenCAP™ Description	XenCAP™ Samples	Samples per 10,000 Population (approx.)
1	Office building	5,232	64
2	Retail	3,658	52
3	Food Store	1,510	110
4	Service	1,438	25
5	Restaurant	2,116	74
6	Lodging	1,018	80
7	Warehouse	1,999	34
8	Religious	1,432	24
9	Education	2,161	70
10	Hospital	320	145
11	Nursing Home	409	132
	Total:	21,293	47

The XenCAP™ database contains 15 commercial facility types, while the CBECS database contains 26 separate building types, many of which are very similar to XenCAP™. To link these two databases, the output of the model for the XenCAP™ building types were weighted for selected building types in CBECS according to the mapping percentages given in Table 3-5, and then applied to the CBECS floor space.

Table 3-5: Mapping of CBECS Floorspace to XenCAP™ Building Types

CBECS		XenCAP™	
Code	**Description**	**Code**	**Description**
1	Vacant	1	Office (33%)
		2	Retail (27%)
		3	Food Sales (1%)
		4	Service (16%)
		6	Lodging (13%)
		9	Education (4%)
		10	Hospital (2%)
		11	Nursing Home (2%)
2	Office/Professional	1	Office (100%)
4	Laboratory	1	Office (89%)
		2	Retail (1%)
		4	Service (1%)
		7	Warehouse (4%)
		9	Education (5%)
5	Warehouse (nonrefrig.)	10	Warehouse (100%)
6	Food sales	3	Food Store (100%)
7	Public order/safety	1	Office (40%)
		6	Lodging (42%)
		9	Education (18%)
8	Health care (outpatient)	1	Office (100%)
11	Warehouse (refrig.)	7	Warehouse (100%)
12	Religious worship	8	Religious (100%)
13	Public assembly	1	Office (32%)
		2	Retail (8%)
		3	Food sales (6%)
		4	Service (24%)
		6	Lodging (1%)
		8	Religious (3%)
		9	Education (25%)
14	Education	9	Education (100%)
15	Food service	6	Restaurant (100%)
16	Health care (inpatient)	10	Hospital (100%)
17	Skilled nursing	11	Nursing Home (100%)
18	Hotel/Motel/Dorm	7	Lodging (100%)
23	Strip shopping	2	Retail Store (100%)
24	Enclosed shopping ctr/mall	2	Retail Store (100%)
25	Retail (excl mall)	2	Retail Store (100%)
26	Service (excl food)	4	Service
91	Other	1	Office (77%)
		2	Retail (7%)
		3	Food sales (6%)
		4	Service (2%)
		6	Lodging (3%)
		9	Education (3%)
		10	Hospital (2%)

Note: Mapping factors may not sum to 100% due to rounding.

Industrial facilities are identified in XenCAP™ with a unique facility type code. The MECS data covers industrial manufacturing facilities with 2 digit SIC codes of 20 through 39. The XenCAP™ data contains a field for the SIC code. However, since the SIC code field is optional for many of the audits, not all of the data contained this information. Of the 3128 industrial facility audits, 1791 do not have valid data in the SIC code field. For the SIC codes that do exist, not all fall within the range 20-39 which defines manufacturing facilities. This leaves two problems that were dealt with in the analysis: 1) filling in missing SIC codes, and 2) reassigning the non-manufacturing SIC codes.

For facilities without SIC data, we used a two part method to fill in SICs for as many facilities as possible. Beginning with the largest facilities in terms of floorspace, we looked up the facility name and location in a Dun & Bradstreet *iMarket* database, which contains SIC codes. If the facility was found, the SIC code was manually filled in to the XenCAP™ database. Next, the list of facilities was sorted by name to match observations with similar names and addresses. Reasonable judgments were made to decide whether separate entries appeared to be part of the same complex. In these instances, missing SIC codes could be filled in based on the SIC of an entry that is part of the same complex. This exercise resulted in obtaining the SIC code for an additional 763 facilities.

Of the industrial facility types with SIC codes, 250 were non-manufacturing. Since these SICs are not covered by the MECS data, most of these facilities were assigned to commercial building types. The SIC codes and corresponding building types for the basis of this assignment process are shown in Table 3-6. The facilities where no SIC was identified were classified into the miscellaneous industrial group.

Table 3-6: Mapping XenCAP^{TM} Industrial Buildings to CBECS based on SIC

CBECS Building Type	SIC Codes
Office/Professional	60-67, 81, 83, 87, 91, 93-96
Retail (excluding mall)	52, 53, 56, 57, 59
Warehouse (non-refrigerated)	50, 51
Service (excluding food)	43, 55, 72-76
Food sales	54
Food service	58
Health care (inpatient)	80
Hotel/Motel/Dorm	70
Education	82
Other	40-42, 44-49, 78, 79, 84-86, 89, 92, 97

The representation of XenCAP™ industrial facilities compared to the national population is contained in Table 3-7.

Table 3-7: Relationship between XenCAP™ and the Population of Industrial Buildings

SIC code	Description	Number of XenCAP™ Samples	Samples per 10,000 Population
20	Food and Kindred Products	73	44
21	Tobacco Products	1	83
22	Textile Mill Products	22	23
23	Apparel and Other Textile Products	24	13
24	Lumber and Wood Products	38	12
25	Furniture and Fixtures	29	27
26	Paper and Allied Products	90	102
27	Printing and Publishing	150	30
28	Chemicals and Allied Products	77	49
29	Petroleum and Coal Products	8	25
30	Rubber and Miscellaneous Plastics Products	109	62
31	Leather and Leather Products	3	15
32	Stone, Clay, and Glass Products	38	27
33	Primary Metal Industries	59	73
34	Fabricated Metal Products	175	53
35	Industrial Machinery and Equipment	130	24
36	Electronic and Other Electric Equipment	174	99
37	Transportation Equipment	76	57
38	Instruments and Related Products	61	37
39	Miscellaneous Manufacturing Industries	45	28
	Total	**1382**	**38**

The XenCAP™ data described above contain the weekly operating hours for each lamp group and the number of fixtures of each particular type. The wattage for each fixture type is needed to calculate the energy consumption. The wattage comes from a XenCAP™ table organized by fixture code that contains wattage, lumens, and fixture cost. The wattage for ballasted lamps depends both upon the number of lamps per fixture and upon the type of ballast.

The second table of the XenCAP™ lighting data contains details about the number and characteristics of the specific lighting fixtures and lamps within each of the lamp groups. The lighting technologies are indicated by a letter code for the lighting source and a numeric code that represents either the wattage or the specific type of fixture. More than 200 separate types of fixtures are covered by these codes, which are summarized in Table 3-8. In addition to the fixture types, the data also contain the number of lamps per fixture and the type of ballast, where applicable.

Table 3-8: XenCAP^{TM} Lamp Types

Lighting Source	Number of Fixture Types
Mercury Vapor	10
Low Pressure Sodium	7
High Pressure Sodium	12
Metal Halide	12
Quartz Halogen	13
Incandescent	22
Incandescent, Elliptical Reflector	6
Incandescent, Spotlight	16
Other, (Capsylite, Miniature)	16
High pressure Sodium, color Improved	5
Fluorescent (including compact)	104

3.3. Tacoma Public Utilities, Baseline Residential Lighting Energy Use Study

Tacoma Public Utilities (TPU) led a study for the Bonneville Power Administration on residential lighting energy use (Tribwell, 1996). A total of seven utilities participated in this study, which used lighting loggers to monitor the energy use of fixtures in single family homes throughout Oregon and Washington. TPU monitored approximately 82 percent of the 6100 fixtures counted in the 161 monitored homes for a total of 4,884 monitored fixtures. The fixtures were monitored from 4 to 12 months over the course of a two-year period. The data loggers recorded elapsed and total operating time but not time-of-use.

Each record contains information on a single fixture:

- Monitoring Period
- Customer ID
- Building Type (6 types)
- Building Size (4 bins)
- Building Age (7 bins)
- Owner Occupied (yes or no)
- Number of Occupants
- Space Heated (heated, unheated buffered)

- Hours Logged
- Days Installed
- Fixture Detail Location
- Fixture Type (16 types)
- Switch Type (7 types)
- Number of Lamps
- Lamp Type (14 types)
- Fixture Wattage

The raw TPU data contains multiple records for some fixtures. This usually occurred when the same fixture was monitored for two separate time periods, thus resulting in two separate records. The TPU data were reduced to one observation per unique fixture, including annual hours of operation, using all available data for that fixture. For fixtures with more than one record, the annual hours of use were calculated using the portion of the year represented by each observation. Observations with zero

observed time (if it was an observation with a logger and a true read and not a missing value) were not omitted from the analysis. Likewise fixtures without loggers were also included in the analysis to indicate proportion of the technology in a particular space type.

The TPU data also contain some anomalous records, such as high pressure sodium lamps in interior rooms. Also, the database does not provide information on the type of fluorescent lamps installed. We examined those records and placed them in other categories based on our judgment.

The TPU study data, because it is isolated to one small region of the country and covers a period of only several months, poses an even more serious limitation when extrapolating to the rest of the country than does the XenCAP™ database. However, as discussed at the start of this section, the TPU dataset was selected because the combination of sample size, technical detail, and methodology were considered most appropriate for our purposes.

3.4. American Housing Survey (AHS)

The AHS provided the floorspace (square footage) and occurrence of some rooms in a typical U.S. residential housing unit.

The American Housing Survey (AHS) collects data on the nation's housing, including apartments, single-family homes, mobile homes, vacant housing units, household characteristics, income, housing and neighborhood quality, housing costs, equipment and fuels, size of housing unit, and recent movers. National data are collected every other year, and data for each of 46 selected Metropolitan Areas are collected about every four years, with an average of 12 Metropolitan Areas included each year. The national sample covers on average 55,000 homes. Each metropolitan area sample covers at least 4,800 homes. The survey is conducted by the Bureau of the Census for the Department of Housing and Urban Development (U.S. Census Bureau, 2000).

4. Energy Use Estimate Methodology

Generally, the national lighting inventory was generated by merging two databases: 1) building inventories and square footage provided by RECS, CBECS and MECS with 2) end-use audit or metering data to determine the number and type of lamp, and its operating hours. More specifically, Figure 4-1 illustrates the building blocks used to estimate the lighting energy consumption for each sector. Each block represents a two-dimensional matrix of aggregated data. For calculations other than energy use such as operating hours per day by type of light source, we combined selected matrices and intermediate results. The next two sections describe the methodology in more detail.

Figure 4-1 Electricity Consumption Calculation Methodology

Residential	Commercial	Industrial	Outdoor Stationary
Number of Units (RECS)	Floorspace per Building (CBECS)	Floorspace per Building (MECS)	Number of Installations (Various)
Lamps per Room (TPU); Rooms per Unit (AHS)	Space Function Floorspace per Building (XenCAP)	Space Function Floorspace per Building (XenCAP)	Operating Hours per Installation (Various)
Operating Hours per Room (TPU)	Operating Hours per Space Function per Building (XenCAP)	Operating Hours per Space Function per Building (XenCAP)	Lamps per Installation (Various)
Wattage per Lamp (TPU)	Lamps per sq ft per Space Function (XenCAP)	Lamps per sq ft per Space Function (XenCAP)	Wattage per Lamp (Various)
	Wattage per Lamp (XenCAP)	Wattage per Lamp (XenCAP)	
	Number of Buildings (CBECS)	Number of Buildings (MECS)	

National Lighting Electricity Consumed per Sector

4.1. Building Sectors

4.1.1.   Introduction

The estimation of the characteristics of the lighting market covers commercial, industrial, and residential buildings. The methodology used a combination of building audit data and national data to characterize the specific technologies in use in the buildings. The audit data for commercial and industrial buildings (XenCAP™ data) were collected over several years through various building auditing programs around the U.S., although as discussed in Section 3.2, concentrated in a few areas. The audit data for residential buildings (Tacoma data) are from a residential energy lighting use study conducted over a three-year period in the Pacific Northwest (Tribwell and Lerman 1996). CBECS, MECS, and RECS provide the national data for commercial buildings, industrial buildings, and residential buildings respectively.

The detailed audit data were used to develop a model that estimates the probability of a technology being employed in a space type given the characteristics of the space. The modeling was done separately for commercial, industrial, and residential buildings, and within each sector separately by each of several space types (e.g., hallways, offices, etc.). These models were then applied to the national data to generate national results.

The remainder of this section describes the revised allocation of floorspace, the details of the model estimation, the application of the estimated models to the national data, and the national results provided. Results of this analysis appear in section 5 of this report, however the matrices used to calculate these results appear in the Appendices. The set of numbers for the residential sector appears in Appendix D, the commercial sector is shown in Appendix E, and the industrial sector appears in Appendix F. By accessing the tables of data reported in the Appendices, the reader will secure a greater understanding of the underlying inputs and assumptions that contributed to the inventory estimate.

4.1.2.   Allocating Floorspace To Space Types

The method to allocate a building's floorspace to the space types within the building is based on the illumination requirements of each space. The steps involved in this calculation are:

1. Calculate lumens for each technology,
2. Determine the illuminance level appropriate for each space type,
3. Estimate space type floorspace given the illuminance level, and
4. Adjust estimated floorspace to known total building floorspace.

The lumens for each technology are calculated from the technology information in the audit data. The audit data contains the fixture code, the number of fixtures, and the number of lamps per fixture within each space type. The lumens for each fixture comes from a lookup table by fixture code.

In the first round of the analysis, space types were allocated within each building type based on the lighting wattage in each space type. A shortcoming of this method is that for a given building, all space types will have the same lighting density in terms of watts per square foot. However, we know that the lighting requirements varies depending on the space type and function. To reflect these differences, the allocation method was revised under the assumption that no matter the lighting source used in the space, the lumen requirement should be the same. The starting point for this type of allocation was assigning each space type an Illuminating Engineering Society of North America (IESNA) illuminance category, as

listed in Table 4-1.

Table 4-1: Illuminance Levels Assigned to Each Space Type

Space Type	IES Illuminance Category	Footcandles (lumens / sq. ft.)
assembly	B-C	7.5
athletic	F	100
bathroom	B	5
boarding	C	10
class	E	50
dining	C	10
display	E	50
food prep	E	50
hall	B	5
healthcare	E	50
office	D-E	40
ship/rec	D	30
shop	E	50
storage	C	10
task	E	50
unknown	D-E	40
utility	B	5

4.1.3. Estimating The Models

Separately for commercial, industrial, and residential buildings, and for each of several space types listed in Table 4-1, detailed audit data were used to develop a model that estimates the probability a technology is employed in a space type given the characteristics of the space. The econometric model employed and appropriate for this type of analysis is a multinomial logit model.

In the cases of commercial buildings and industrial buildings, a set of 22 models was developed employing the relevant data from XenCAP, one model for each space type. For residential buildings, a set of 10 models was developed employing the relevant Tacoma data. Three of the 10 residential models applied to 2 space types.

4.1.3.1. Dependent Variable

The dependent variable in each of the 54 space type models is a set of technologies. For a technology to be included in a space type's dependent variable set, it must be employed in the space type and must be a truly distinct choice from the other technologies within the same set. The latter criterion caused some relatively disaggregate initial technologies to be combined into a single technology in a space type's dependent variable set of technologies. Also, when we had a problem fitting a model, combining

technologies with relatively few observations with other technologies often solved problems of model fit.

Most of the "technologies" are combined across varying lamp sizes within the same core lighting technology. For example, in most of the space types the different sized T12 fluorescent lamps are generally grouped into a single technology of T12 fluorescent. Fluorescent T8 lamps are grouped in a similar manner. The aggregation of the technologies in general is done based on the relative frequency of the technologies within each space type. Certain technologies are more prevalent in particular space types than in others and represent a distinct choice. Differences in aggregation among the space types are the result of maintaining these choices.

In the cases of commercial and industrial buildings, the software package employed to estimate the space type models (LIMDEP[6]) also imposed a limit on the number of technologies that could be included in a set. However, given the necessity of combining some of the initial 28 technologies for the aforementioned reasons, we do not think the limit imposed by LIMDEP was very restrictive. Further information relative to the statistical update can be found in Appendices H, I and J which provide data on the residential, commercial and industrial sectors respectively. Note that due to their length, these three appendices are published in a separate report, U.S. Lighting Market CharacterizationVolume I — National Lighting Inventory and Energy Consumption Estimate, Appendices H, I and J.

4.1.3.2.   Independent Variables

Commercial and Industrial Buildings
In the cases of commercial and industrial buildings, the probability a technology is employed in a space type was modeled as a function of:

- Square footage of the space,
- Square footage of the entire building in which the space type is located,
- Square footage of the space as a fraction of the square footage of the entire building,
- Number of hours the lights are on in the space, and
- Year.

In addition, for commercial buildings, the list of independent variables also included building type. We tried to use geographic region as an independent variable for the commercial and industrial analysis, but the data were not rich enough for us to get a meaningful result that varied across geographic regions. As a result we had to eliminate it as an independent variable.

In the commercial and industrial building analyses, an observation on a technology in a space type is a unique combination of a premise and the number of hours the lights are on.

The parameters for the commercial models are contained in Appendix I and the parameters for the industrial models are contained in Appendix J.

Residential Buildings
For residential buildings, the probability a technology is employed in a space type was modeled as a function of:

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[6] LIMDEP is a statistical software program which provides parameter estimation of nonlinear models such as those for qualitative and limited dependent models. The name is derived from LIMited DEPendent models.

- Number of bathrooms in the home,
- Number of bedrooms in the home, and
- Number of hours a fixture is on in the space type.

The residential data, coming from just one area of the country, prevented us from distinguishing by geographic region.

In the residential building analysis, an observation on a technology in a space type is a unique fixture. Data and results concerning the residential model are contained in Appendix H.

4.1.3.3. Results

For each space type, the results of the multinomial logit model are a set of parameter estimates for all but one of the technologies included as a dependent variable. In the cases of each technology for which there is a set of parameter estimates, the parameter estimates may be employed to estimate the probability the technology is employed in the space type. The probability of the remaining technology being employed in the space type is one minus the sum of the probabilities that each of the other technologies is employed in the space type.

Although the aforementioned data sources represent various years, a statistical correction based on more recent data was conducted by Xenergy, and therefore the model results are considered a lighting inventory estimate for 2001.

4.1.4. Applying The Models

The estimated models were applied to national data to generate national results. The models estimated using commercial buildings in the XenCAP™ data were applied to the individual commercial buildings in the CBECS public use data set. The models estimated using the industrial buildings in the XenCAP™ data were applied to the single observation on each two-digit SIC code in MECS. The models estimated employing the residential buildings in the Tacoma data were applied to the individual residential buildings in the RECS data set.

In our analysis we used the most recent EIA data available. These surveys are done only every 3-4 years, and there's a time lag between the survey year and publication of data. We used the most recent published data. The survey dates of the data we used are: RECS 2001, CBECS 1999, and MECS 1998. In order to apply the estimated models to a building in the national data set, the national data must include values for each of the independent variables included in the model. An observation on a building in the commercial and industrial national data includes square footage of the entire building and building type (i.e., SIC code). (From the MECS data, for each two-digit SIC code, we employ the average square footage of an entire building.) An observation on a building in the residential national data includes number of bathrooms and number of bedrooms. The values of the remaining independent variables and other necessary data for a building in the national data were estimated as follows.

4.1.4.1. Commercial and Industrial Buildings

<u>Square Footage of the Space</u>
The square footage of a building in the commercial and industrial national data was allocated across 17

interior space types based on the distribution of building square footage across these space types in the XenCAP data. In the case of commercial buildings, this distribution was determined separately for building type and size (square footage) combinations. In the case of industrial buildings, the distribution of building square footage across the interior space types in the XenCAP data was determined separately for each building type.

Based on the distribution of building square footage across the interior space types in the XenCAP data, each interior space type was assigned a fraction, where the sum of these fractions equals one. For example, in the cases of commercial buildings, by building type b and size category z, the fraction assigned to interior space type f is

$$p_{bzf} = \frac{\sum_j S_{bzfj}}{\sum_j S_{bzj}}$$

where

p_{bzf} = fraction of building type b and size z square footage in interior space type f,

j = building with building type b and of size z,

S_{bzfj} = square footage of XenCAP building j in interior space type f, and

S_{bzj} = square footage of XenCAP building j.

The appropriate set of fractions was then applied to the square footage of a building in the national data to estimate the building's square footage in the 17 interior space types.

A building's square footage in 5 additional space types, 4 exterior space types and exits, was set equal to the building's total square footage. Exterior lighting and exit signs do not illuminate interior space and, therefore, a building's square footage in these space types was not allocated as a fraction of building square footage. Rather, a building's quantity of exterior lighting and exit signs is better measured as proportion to the building's total square footage.

Number of Hours Lights are On in the Space
The estimated models were applied to a building in the commercial and industrial national data three times, employing three different estimates of the number of hours lights are on in the space: low, medium, and high numbers of hours. At the same level square footage is allocated across the 22 space types, values for low, medium, and high numbers of hours were calculated employing the XenCAP data. The low, medium, and high numbers of hours (weekly) categories were defined as less than 40 hours, between 40 and 84, and more than 84. At the appropriate level (commercial: building type and size combinations, industrial: building type), for each space type, values for low, medium, and high numbers of hours lights are on in a space were calculated as a weighted average of the number of hours in the low, medium, and high hours categories, respectively, with a building's square footage in the space type as the weight.

4.1.4.2. Residential Buildings
Number of Hours a Fixture is On in the Space Type
Values for the number of hours were obtained for the residential national data similar to how they were

obtained for the commercial and industrial national data. The estimated models were applied to a building in the residential national data three times, employing three different estimates of the number of hours a fixture is on in a space type: low, medium, and high numbers of hours. A building in the residential national data was assigned values for low, medium, and high numbers of hours a fixture is on in a space type based on the number of bathrooms and the number of bedrooms in the home. For each space type, separately for each of 5 categories of home size (based on the number of bathrooms and the number of bedrooms in a home), values for low, medium, and high numbers of hours were calculated employing the Tacoma data. The low, medium, and high numbers of hours (weekly) categories were defined as less than 2 hours, between 2 and 14, and more than 14. For each space type, separately for each of the 5 categories of home size, values for low, medium, and high numbers of hours a fixture is on in a space type were calculated as the average of the number of hours in the low, medium, and high hours categories, respectively.

4.1.5.   National Results Provided

After applying the estimated models to the buildings in the national data, several steps were taken to produce the national results provided:

- Prepare the results for each building in the national data:
  1. Combine a building's three results for each of a space type's dependent variable technologies (the results for each of the three hours categories) into a single probability the building employs the technology in the space type;

  2. Multiply the probability a commercial or industrial building employs a technology in a space type by the building's square footage in the space type to obtain the building's square footage lit by the technology in the space type;

     Multiply the probability a residential building employs a technology in a space type by the building's number of fixtures in the space type to obtain the building's number of fixtures in the space type that employ the technology;

  3. Allocate a commercial or industrial building's square footage results for a space type's set of dependent variable technologies across the desired, relatively more disaggregated initial 28 technologies;

     Allocate a residential building's number of fixtures results for a space type's set of dependent variable technologies across the desired, relatively more disaggregated 9 technologies;

- For each building in the national data, calculate kW and kWh for each of the disaggregated technologies employed in a space type;

- Employing the weight associated with each building in the national data, aggregate over buildings to generate the national results for each of the disaggregated technologies employed in a space type by building type; and

- Place the national results into a series of spreadsheet matrices.

Some of these steps are discussed in greater detail below.

4.1.5.1. Prepare the Results for Each Building

Combine Results for the Three Hours Categories
Applying the estimated models to a building in the national data employing low, medium, and high numbers of hours, results in three estimates of the probability the building employs a technology in a space type. For each building in the national data, a single estimate was obtained from these three estimates by taking a weighted average.

For a building in the commercial and industrial national data, the weights equal the fraction of a space type's square footage in each of the hours categories. These fractions were calculated at the same level square footage is allocated across the interior space types, by building type and size in the cases of commercial buildings and by building type in the cases of industrial buildings. For a building in the residential national data, the weights equal the fraction of a space type's fixtures in each of the hours categories. For each space type, these fractions were calculated separately for each of the 5 categories of home size.

Residential Building: Number of Fixtures in a Space Type
The number of fixtures in a building space type in the residential national data (which is multiplied by the probability the building employs a technology in the space type) was obtained by multiplying the average number of fixtures in a room of that space type by the building's number of rooms of that space type. For each space type, the average number of fixtures in such a room was calculated employing the Tacoma data. A building's number of rooms of each space type was either obtained from the national data or estimated employing the Tacoma data.

The number of bathrooms and the number of bedrooms in a building are included in the residential national data. A building in the residential national data was assigned the average number of rooms of each of the remaining 11 space types based on the number of bathrooms and the number of bedrooms in the home. For each of the remaining 11 space types, separately for each of the 5 categories of home size, the average number of rooms of that space type in a home was calculated employing the Tacoma data.

Results for the Disaggregated Technologies
Commercial and Industrial Buildings: Square Footage Lit by Each of the 28 Initial Technologies in a Space Type

If a technology included in a commercial or industrial space type's set of dependent technologies consists of more than one of the initial 28 technologies, a building's square footage lit by this technology in the space type was allocated across the technology's component initial technologies. This allocation was based on the distribution of building square footage lit by the technology's component initial technologies in the space type found in the XenCAP™ data.

Residential Buildings: Number of Fixtures Employing Each of the 9 Disaggregate Technologies in a Space Type

If a technology included in a residential space type's set of dependent technologies consists of more than one of the disaggregated 9 technologies, a building's number of fixtures in the space type that employ the technology was allocated across the technology's component disaggregate technologies. This allocation was based on the distribution of fixtures across the technology's component disaggregate technologies in the space type found in the Tacoma data.

4.1.5.2. Calculate kW and kWh

Commercial and Industrial Buildings
For each building in the commercial and industrial national data, to calculate kW and kWh for each of the disaggregated initial 28 technologies employed in a space type (see Appendix Table E-5), the following additional data are used:

1. kW per square foot associated with each disaggregated technology in the space type and
2. the number of hours lights are operating in the space type.

The product of a building's square footage lit by a disaggregated technology employed in a space type and the kW per square foot associated with the disaggregated technology in the space type, produces for the building the kW for this technology employed in this space type. The product of this kW and the number of hours the lights are on in the space type, produces for the building the kWh for the given disaggregated technology employed in the given space type.

The kW per square foot associated with a disaggregated technology employed in a space type was calculated using the XenCAP data. The number of hours lights are on in a space type was also calculated using the XenCAP data.

The hours data were calculated at the same level square footage is allocated across the interior space types (by building type and size in the cases of commercial buildings and by building type in the cases of industrial buildings). At this level, the number of hours lights are on in a space type was calculated as a weighted average, with a building's square footage in the space type as the weight. For example, in the cases of commercial buildings, by building type b and size category z, the number of hours lights are on in space type f H_{bzf} is

$$H_{bzf} = \frac{\sum_j S_{bzjf} H_{bzjf}}{\sum_j S_{bzjf}}$$

where

j = building with building type b and of size z,

S_{bzjf} = square footage of XenCAP building j in space type f, and

H_{bzjf} = number of hours building j has lights on in space type f.

Residential Buildings
For each building in residential national data, to calculate kW and kWh for each of the disaggregated 9 technologies employed in a space type (see Appendix Table D-7), the following additional data are used:

1. kW per fixture associated with each disaggregated technology in the space type and
2. the number of hours a fixture is on in the space type.

The product of a building's number of fixtures in a space type that employ a disaggregate technology and the kW per fixture associated with the disaggregated technology in the space type, produces for the building the kW for this technology employed in this space type. The product of this kW and the number

of hours a fixture is on in the space type, produces for the building the kWh for the given disaggregated technology employed in the given space type.

The kW per fixture associated with a disaggregated technology employed in a space type was calculated using the Tacoma data. A building in the national data was assigned a number of hours a fixture is on in a space type based on the number of bathrooms and number of bedrooms in the home. For each space type, separately for each of the 5 categories of home size, the average number of hours a fixture is on in a space type was calculated using the Tacoma data.

4.1.5.3. National Results

Each building in CBECS and RECS has a sample weight associated with it that can be employed to produce national results for commercial buildings and residential buildings respectively. In the cases of industrial buildings, we associated with the single observation on each two-digit SIC code in MECS, the number of industrial buildings in the SIC code in order to produce national results. Employing these weights, we summed over buildings in the national data to generate the national square footage (commercial and industrial buildings) or number of fixtures (residential buildings), kW, and kWh for each of the disaggregated technologies employed in a space type by building type.

Residential Buildings: Adjustment to the Number of Rooms of a Space Type
The residential space type models were estimated using the Tacoma data, which consist almost exclusively of single-family detached homes (only two homes in the Tacoma data are not single-family detached homes). These estimated models were applied to single-family detached homes as well as mobile homes, single-family attached homes, multi-family units in a complex consisting of between 2 and 4 units, and multi-family units in a complex consisting of more than 4 units. If the Tacoma data had contained homes other than single-family detached homes, we would have considered estimating separate space type models for other types of homes. However, it is not unreasonable to apply the estimated models based on single-family attached homes to any type home. Two of the three values for the independent variables, the number of bathrooms and the number of bedrooms in a home, come directly from a home's observation in RECS.

Also, a building in the residential national data was assigned a number of fixtures in a space type that was at least in part based on the Tacoma data. The average number of fixtures in a room of each space type was calculated employing the Tacoma data and a building's number of rooms of each space type was either obtained from the national data or estimated employing the Tacoma data. The product of these data results in a building's number of fixtures in a space type.

Although we have no basis for adjusting the average number of fixtures in a room of a given space type, we do have a basis for adjusting a building's number of rooms of some space types. The American Housing Survey (AHS) for the U.S. 1999 Table 7-2 provides an estimate of the fraction of each type home in the population that has a:

- dining room,
- family room (fraction of homes with two or more living rooms or recreation rooms, etc.),
- garage,
- complete kitchen,
- utility room (fraction of homes with a washing machine).

Employing the weights in the RECS data, we calculated the national number of rooms in a space type by

building type and then the fraction of each building type that has each of the space types listed above. We then adjusted the national results for each building type and space type combination by the building type-space type AHS fraction divided by the RECS/Tacoma data fraction. All the national results, the number of fixtures, kW, and kWh, were adjusted by this fraction because each result reflects the initial assignment of a number of rooms of each space type to buildings in the residential national data.

4.1.5.4. Spreadsheet Matrices

The analysis result is a database that populates a series of spreadsheet matrices, disaggregating national building data, down to the lighting technologies. The matrices provided for the commercial and industrial results are listed below;
- Floorspace by Building Type,
- Space Type by Building Type,
- Operating Hours by Space Type,
- Technology by Space Type, and
- Wattage by Lamp Type.

The result matrices provided for the residential sector are:
- Number of Households by House Type,
- Number of Fixtures by House type and Space Type,
- Hours by House Type and Space Type,
- Fixture Type by Space Type, and
- Wattage by Fixture Type.

4.2. Outdoor Stationary Lighting Sector

The outdoor stationary lighting sector, comprised largely of lighting technologies similar to those used in buildings, required similar calculations to those used in the building sectors. In general, outdoor stationary lighting required the definition of a representative installation and the number of installations in the nation.

For each of the applications examined, we gathered or derived estimates of:

- Number of installations,
- Operating hours,
- Number of lamps per installation,
- Distribution of lamp technologies, and
- Typical wattage per technology.

Once the five parameters above are estimated, calculating the implied annual lighting energy consumption estimate is a straightforward procedure. First, the number of installations of a particular type of stationary application is multiplied by its typical operating hours and apportioned among the lamp types that comprise the application. The typical lamp wattage for each lamp type in the application is then multiplied by the operating hours to derive a national energy consumption estimate.

Results of this analysis appear in section 5 of this report, however the matrices used to calculate these results appear in the Appendices. The set of numbers for the outdoor stationary sector appears in

Appendix G, providing the reader with a greater understanding of the underlying inputs and assumptions that arrived at the inventory estimate reported.

4.2.1. Billboard Lighting

The Outdoor Advertising Association of America (OAAA) maintains relevant information on the billboard industry. They track three types of illuminated billboards: 1) 8 sheet poster panels (72 sq. ft.), 2) 32 sheet poster panels (300 sq. ft.), and 3) bulletins (672 sq. ft.). Literature from OAAA provided the number of each type currently installed in the US (OAAA, 1999). A second OAAA publication contained information and suggestions on billboard lighting (OAAA, 1998). The literature provided estimates for operating hours, the number of lamps per billboard type, and typical lamp wattage. However, the guidelines only contain information on lighting with metal halide lamps. We assumed 80% of billboards were lit with metal halide for the purposes of our estimates. The remaining 20% was assigned to mercury vapor and fluorescent sources (OAAA, 2002).

4.2.2. Traffic Signals

There are a few sources of information on traffic signals, largely associated with the recent interest in the installation and retrofitting of traditional incandescent traffic signal lamps with light emitting diode (LED) light sources.

ACEEE provided estimates for installations (signalized intersections), lamps per installation, typical lamp wattage, and the distribution of lamp technologies (ACEEE, 1998). We adjusted these estimates based on information from the Federal Highway Administration (FHWA, 2000). We adopted an estimate of 300,000 signalized intersections in the U.S. FHWA also advised on the estimate of operating hours. In the absence of an estimate of LED signals in operation (red, yellow or green), we assumed that 1% of all signals used LED technology and 99% used incandescent reflector lamps.

We estimated operating hours based on a signal with three "ball" lamps and eight such signals per intersection. We assumed that the each signal is in a "flashing" mode for four hours during the night. During this mode, one of the three lights is flashing and is presumed to be on half of the time. This results in an average utilization of 16 percent for all the lamps in the signal. During the other 20 hours of a day, one of the lamps is on at all times. This represents a per lamp utilization of 33 percent. The weighted average utilization per lamp is 30.6 percent.

In addition to the ball lamp signals, we assumed that each signalized intersection has two "signal arrows" with a lamp utilization approximately one-third that of a ball lamp signal. This utilization would approximate a signal with one green turn arrow, on for the first or last third of the green light phase. Considering the flashing period mentioned before, the weighted utilization of the "turn arrow" is 9.3 percent.

Finally, the behavior of pedestrian signals was modeled with each of the "walk" and "don't walk" signals off half of the time, on one-quarter, and flashing for one-quarter. This results in a pedestrian signal utilization of 31.3 percent. We assumed that there are three pedestrian signals for every four traffic ball lamp signals.

4.2.3. Roadway Lighting

The roadway lighting estimate was derived by reviewing data from three sources, Lawrence Berkeley

National Laboratory (LBNL), the National Electrical Manufacturers Association (NEMA) and the Federal Highway Administration (FHWA).

LBNL provided estimates of the wattage of each light source-ballast combination used for roadway lighting, the number of installations by technology, and the overall operating hours (LBNL, 2002).

NEMA provided HID shipment data for the last decade, disaggregated by source – i.e., high pressure sodium, metal halide and mercury vapor. NEMA provided annual U.S. sales for these sources were provided for the period 1990 to 2001. By applying the LBNL operating hours and typical lamp lives from manufacturer catalogues, an estimated installed base of each technology was derived from this historical shipment data. However, the installed base includes more than simply outdoor stationary installations, thus the estimated installe base was compared to HID lamp operation across all four sectors.

The FHWA confirmed that no national inventory of street lights exists, however through an industry contact, they secured an estimate of 60 million "cobra-head" street light fixtures in operation in the U.S. Working between the LBNL estimates, an approximation of the installed base of HID lamps derived from NEMA's decade of sales and the FHWA estimate of 60 million fixtures, an estimate of the installed base was generated.

4.2.4. Aviation Lighting

We included four distinct types of lighting in the consumption estimate: Centerline Lighting, Touchdown Zone Lighting, Runway/Taxiway Edge Lighting, and Approach System Lighting. The buildings associated with aviation (e.g., airport terminal, control tower, etc.) are included in the commercial building estimate.

The Federal Aviation Administration (FAA) assisted us with our estimates including the number of lighted airports, the average number of runways, the average runway length, the average taxiway length, and the percentage of airports with each airport lighting type. (FAA, 2000; FAA Airport Data). The FAA also assisted with our estimates of approach system lighting including the number of each approach system types, typical lamp wattage, and lamp types. We relied on FAA Advisory Circulars to compute the number of lamps within each airport lighting type from these initial estimates.

Airport Lighting Systems also assisted us by providing information on lamp types, wattage, and typical operating hours (Airport Lighting Systems, 2000). The final data used to generate an estimate of energy use by aviation lighting is shown in Appendix G.

4.2.5. Parking

Neither CBECS nor MECS considers outdoor parking or dedicated parking facilities. Parking garages located within commercial buildings are covered by CBECS. Of course, most buildings, including residential, have some associated parking. Our estimates for commercial and industrial buildings already include parking associated with those installations. To estimate parking we did not capture from the XenCAP™ or TPU databases, we estimate the total lighting required for all parking in the U.S. and then deduct the parking lighting derived from those sources.

International Parking Institute (2000) estimates the number of off-street parking spaces to be about 70.5 million. We assumed that all those spaces are illuminated, although that is clearly an upper bound. Walker Parking Consultants (2000) provided estimates of the square footage per parking space (300 sq. ft.) and

the installed lighting wattage per square foot (0.2 W/sq. ft.). Our analysis of parking associated with commercial buildings provided the technologies and mean lamp wattage for each technology installed. All this information allowed us to characterize the total number parking lamps, from which we subtracted those already included in the commercial sector (the industrial sector contributed little to the parking category.) LBNL (2000) estimated that parking lamps operate for an average of 10 hours per day. We adopted that estimate. For comparison, the commercial building parking operating average is 11.1 hours per day. The final data used to generate an estimate of energy use by light sources servicing parking lots is shown in Appendix G.

4.2.6. Sports Facilities

The XenCAP™ database contains space functions that we have designated as athletic facilities. However, we suspect that dedicated sports facilities such as arenas, stadiums, and courts in parks are underrepresented. We could not find a source for a population of lighting athletic facilities in the country. This may deserve additional investigation.

4.3. Supplements to the Lighting Estimates

Certain stationary lighting uses may be underrepresented in the XenCAP™ and TPU databases. We attempted to supplement those estimates by drawing on other data sources or making independent assumptions.

4.3.1. Electric Signs

Exposed lamp signs, luminous tube signs, and luminous element signs are included in the XenCAP™ data and therefore are also included in our estimates to some extent. However, two characteristics of the signage estimates caused us to want to verify our results. First, signage appears only as a space function in the XenCAP™ database, so it is likely that we introduced error through incorrect inclusion or exclusion of data records. Second, electric signs are concentrated in particular building types (e.g. restaurants and service stations), and we have not attempted to ensure that our XenCAP™ subset accurately reflects the population of those buildings.

We attempted to perform an independent estimate of electric sign prevalence through discussions with sign manufacturers and the National Electric Sign Association, however no information was available that would have supported the analysis. No adjustment was made to the XenCAP™ results.

4.3.2. Common Spaces in Multifamily Buildings

Since the TPU data did not contain multifamily units, we did not assess the lighting inventory in multifamily common spaces such as hallways, elevators, and community rooms. XenCAP™ does contain some multifamily samples, but represents much larger buildings than those typical of the national population. We decided not to attempt to develop estimates for lighting in common spaces based on such limited and non-universally representative data. Instead, we assumed that common spaces in multifamily buildings are identical to similar spaces in commercial buildings. These common spaces include hallways and lobbies. Multifamily common space lighting technologies were obtained using the commercial models and plugging in the RECS multifamily common space parameters. Living spaces were estimated using the residential models.

5. National Lighting Inventory and Energy Consumption Estimates

This study's primary objectives are to gain a deeper understanding of how individual lighting technologies contribute to the nation's overall lighting use and to develop a picture of lighting use and technologies across sectors. This chapter and Chapter 6 present the results of our estimates, adjusted to the year 2001.

The first section of this chapter (5.1. Results for Lamp Technologies) examines lighting energy use from the perspective of the lamps used to generate light. The second section (5.2. Results by Sector, Subsector, and Application) looks at the same results, but from the perspective of building subsectors and outdoor stationary applications. Chapter 6 provides estimates across sectors by examining lighting use from the perspective of crosscutting space functions. Comparisons of our results with the results of other studies occur in Chapter 7.

Each table presented in Chapters 5 and 6 is based on the set of underlying tables developed from the refined data as described in Chapters 4 and 6. In some circumstances, because the underlying tables are aggregated versions of the root data, it is not possible to produce results that precisely match those that would be generated directly from the root data themselves. As such, the results we present may include some subtle conflicts, none of which is significant enough to alter the conclusions we can derive from them.

The tables underlying these results appear in Appendix D (Residential), E (Commercial), F (Industrial) and G (Outdoor Stationary). The XenCAP™ and TPU datasets are proprietary, so we cannot provide further disaggregation than that which is provided in the Appendices. Interested parties must contact those companies directly to obtain more detailed access to the data.

5.1. Results for Lamp Technologies

Table 5-1 lists the mean wattage for each lamp type observed. Lamp wattage is one of the fundamental inputs into our calculations. Wattage for ballasted lamps includes the ballast wattage. The black rows separate light source technology groups into lamp and ballast classification groups shown in Table 2-3. The wattages in the black rows represent inventory-weighted average wattages by lamp technology. For example, the average wattage of all the installed residential incandescent lamps is 67 watts.

Table 5-1: Average Lamp Wattage by Building Sector (W), 2001

Technologies	Residential	Commercial	Industrial	Outdoor Stationary	All
Incandescent	**67**	**83**	**64**	**138**	**69**
Standard - General Service	63	83	126	138	65
Standard – Reflector	102	104	102	103	102
Halogen - General Service	200	64	-		195
Quartz Halogen	205	226	452	167	215
Halogen - refl. - low volt	-	48	58		48
Low wattage (less than 25W)	-	15	19		15
Misc incandescent	-	-	-		-
Fluorescent	**38**	**41**	**48**	**150**	**41**
T5	-	8	10		8
T8 – less than 4'	-	23	23		23
T8 – 4'	-	33	31		32
T8 – More than 4'	-	50	53	105	52
T8 – U-bent	-	34	32		33
T12 – less than 4'	-	29	32		29
T12 – 4'	-	45	44		45
T12 – More than 4'	-	93	95	190	93
T12 – U-bent	-	46	46		46
Compact – Pin-base	-	17	31		17
Compact – Screw-in	18	16	14		17
Compact – Pin-base – reflr	-	16	-		-
Compact – Screw-in – reflr	11	16	14		16
Circline	-	30	35		31
Induction discharge	-	-	-		-
Miscellaneous fluorescent	41	18	34	150	41
HID	**151**	**404**	**425**	**227**	**304**
Mercury vapor	179	331	409	239	266
Metal halide	-	472	438	311	440
High pressure sodium	79	260	394	216	229
Low pressure sodium	-	104	90	180	172
Xenon	-	-	-		-
Electrodeless (e.g. mercury)	-	-	-		-
Solid State	**-**	**5**	**5**	**15**	**6**
LED	-	6	6	15	7
Electroluminescent	-	2	2		2
Total	**63**	**56**	**65**	**205**	**62**

Table 5-2 lists the average number of lamps observed in a typical building within each building sector. For residences, a "building" is a single housing unit, even if part of a multifamily structure. Outdoor stationary is not shown because the data cannot be shown on a "per building" basis.

Table 5-2: Average Number of Lamps per Building, 2001

Technologies	Residential	Commercial	Industrial
Incandescent	37	91	33
Standard - General Service	34	53	7
Standard – Reflector	2	17	6
Halogen - General Service	0.2	0.2	-
Quartz Halogen	0.1	4	1
Halogen - refl. - low volt	-	9	0.0
Low wattage (less than 25W)	-	9	20
Misc incandescent	-	-	-
Fluorescent	6	324	1,340
T5	-	1	0.1
T8 – less than 4'	-	7	28
T8 – 4'	-	83	631
T8 – More than 4'	-	0.4	0.1
T8 – U-bent	-	2	12
T12 – less than 4'	-	6	5
T12 – 4'	-	152	354
T12 – More than 4'	-	25	281
T12 – U-bent	-	7	7
Compact – Pin-base	-	21	6
Compact – Screw base	1	10	6
Compact – Pin-base – reflector	-	-	-
Compact – Screw base – reflector	0.0	1	1
Circline	-	5	8
Induction discharge	-	-	-
Miscellaneous fluorescent	5	1	2
HID	0.0	7	67
Mercury vapor	0.0	1	8
Metal halide	-	4	47
High pressure sodium	0.0	1	12
Low pressure sodium	-	0.1	0.3
Xenon	-	-	-
Electrodeless (e.g. mercury)	-	-	-
Solid State	-	0.4	0.3
LED	-	0.3	0.2
Electroluminescent	-	0.1	0.1
Total	43	422	1,440

Note: Individual values may not sum identically to the totals due to rounding

Notice the dominance of incandescent lighting in the residential sector, fluorescent lighting in the commercial and industrial sectors, and the prevalence of HID in the industrial sector. In the commercial sector, the study found that T-12 lamps are twice as common as T-8 lamps in US buildings. However,

this ratio is not static - market trends are shifting away from T-12 toward T-8.

Table 5-3 shows the same information presented in Table 5-2, but as percentages so it is easier to identify the importance of each lamp technology by building sector. Although fluorescent lamps dominate the commercial and industrial sectors, incandescent lamps make up almost two-thirds of the lamps in the nation.

Table 5-3: Distribution of Lamps in each Building Sector (%)

Technologies	Residential	Commercial	Industrial	Outdoor Stationary	All
Incandescent	**86%**	**22%**	**2%**	**22%**	**63%**
Standard - General Service	79%	12%	-	17%	56%
Standard – Reflector	6%	4%	-	2%	5%
Halogen - General Service	-	-	-	-	-
Quartz Halogen	-	1%	-	3%	-
Halogen - refl. - low volt	-	2%	-	-	1%
Low wattage (less than 25W)	-	2%	1%	-	1%
Misc incandescent	-	-	-	-	-
Fluorescent	**14%**	**77%**	**93%**	**3%**	**35%**
T5	-	-	-	-	-
T8 – less than 4'	-	2%	2%	-	1%
T8 – 4'	-	20%	44%	-	8%
T8 – More than 4'	-	-	-	-	-
T8 – U-bent	-	1%	1%	-	-
T12 – less than 4'	-	1%	-	-	-
T12 – 4'	-	36%	25%	-	11%
T12 – More than 4'	-	6%	20%	-	3%
T12 – U-bent	-	2%	-	-	-
Compact – Pin-base	-	5%	-	-	1%
Compact – Screw-in	2%	2%	-	-	2%
Compact – Pin-base – reflr	-	-	-	-	-
Compact – Screw-in – reflr	-	-	-	-	-
Circline	-	1%	1%	-	-
Induction discharge	-	-	-	-	-
Miscellaneous fluorescent	13%	-	-	2%	9%
HID	**-**	**2%**	**5%**	**75%**	**2%**
Mercury vapor	-	-	1%	17%	-
Metal halide	-	1%	3%	6%	-
High pressure sodium	-	-	1%	47%	1%
Low pressure sodium	-	-	-	5%	-
Xenon	-	-	-	-	-
Electrodeless (e.g. mercury)	-	-	-	-	-
Solid State	**-**	**-**	**-**	**-**	**-**
LED	-	-	-	-	-
Electroluminescent	-	-	-	-	-
Total	100%	100%	100%	100%	100%

Table 5-4 provides our estimate of installed lamps in the U.S. by technology and sector. This table provides our best estimate, based on the methodology outlined in this report. The total installed base in the U.S. for 2001 was estimated to be approximately 7 billion lamps.

Table 5-4. Estimated Inventory of Lamps in the U.S. by End-use Sector

Technologies	Residential	Commercial	Industrial	Outdoor Stationary	All
Incandescent	3,948,115,000	425,864,000	7,402,000	16,024,000	4,397,406,000
Standard - General Service	3,653,336,000	244,924,000	1,501,000	12,343,000	3,912,104,000
Standard – Reflector	262,471,000	81,229,000	1,251,000	1,500,000	346,451,000
Halogen - General Service	18,089,000	757,000	-	-	18,845,000
Quartz Halogen	14,219,000	17,496,000	167,000	2,181,000	34,063,000
Halogen - refl. - low volt	-	39,733,000	2,000	-	39,736,000
Low wattage (less than 25W)	-	41,725,000	4,481,000	-	46,207,000
Misc incandescent	-	-	-	-	-
Fluorescent	659,077,000	1,507,796,000	304,380,000	1,894,000	2,473,146,000
T5	-	6,601,000	20,000	-	6,621,000
T8 – less than 4'	-	30,889,000	6,262,000	-	37,150,000
T8 – 4'	-	388,685,000	143,284,000	-	531,969,000
T8 – More than 4'	-	2,017,000	14,000	50,000	2,080,000
T8 – U-bent	-	11,151,000	2,827,000	-	13,978,000
T12 – less than 4'	-	29,258,000	1,059,000	-	30,317,000
T12 – 4'	-	709,485,000	80,320,000	-	789,805,000
T12 – More than 4'	-	115,824,000	63,847,000	50,000	179,720,000
T12 – U-bent	-	33,202,000	1,518,000	-	34,721,000
Compact – Pin-base	-	96,973,000	1,371,000	-	98,344,000
Compact – Screw-in	73,473,000	47,437,000	1,442,000	-	122,352,000
Compact – Pin-base – reflr	-	-	-	-	-
Compact – Screw-in – reflr	559,000	5,563,000	189,000	-	6,311,000
Circline	-	24,569,000	1,824,000	-	26,393,000
Induction discharge	-	-	-	-	-
Miscellaneous fluorescent	585,045,000	6,142,000	403,000	1,794,000	593,385,000
HID	4,307,000	30,912,000	15,223,000	54,915,000	105,356,000
Mercury vapor	3,103,000	5,401,000	1,750,000	12,146,000	22,400,000
Metal halide	-	19,378,000	10,706,000	4,726,000	34,809,000
High pressure sodium	1,204,000	5,814,000	2,694,000	34,347,000	44,058,000
Low pressure sodium	-	319,000	73,000	3,696,000	4,089,000
Xenon	-	-	-	-	-
Electrodeless (e.g. mercury)	-	-	-	-	-
Solid State	-	1,683,000	60,000	96,000	1,840,000
LED	-	1,433,000	42,000	96,000	1,571,000
Electroluminescent	-	250,000	18,000	-	269,000
Total	4,611,499,000	1,966,255,000	327,066,000	72,929,000	6,977,748,000

Table 5-5 considers the distribution of installed wattage across lamp types and sectors. Incandescent lamps make up almost three-fourths of the national installed lighting wattage, but HID, typically higher wattage lamps, also contribute a significant fraction (7 percent), mostly due to lighting in the Outdoor stationary sector. For the Outdoor stationary column, the percentage breakdown of installed wattages represents all sources together, as this data cannot be reported on a 'per building' basis.

Table 5-5: Distribution of Installed Wattage per Building by Lamp Type (%)

Technologies	Residential	Commercial	Industrial	Outdoor Stationary	All
Incandescent	**91%**	**32%**	**2%**	**15%**	**69%**
Standard – General Service	80%	18%	1%	11%	58%
Standard – Reflector	9%	8%	1%	1%	8%
Halogen – General Service	1%	-	-	-	1%
Quartz Halogen	1%	4%	-	2%	2%
Halogen - refl. – low volt	-	2%	-	-	-
Low wattage (less than 25W)	-	1%	-	-	-
Misc incandescent	-	-	-	-	-
Fluorescent	**9%**	**57%**	**68%**	**2%**	**23%**
T5	-	-	-	-	-
T8 – less than 4'	-	1%	1%	-	-
T8 – 4'	-	12%	20%	-	4%
T8 – More than 4'	-	-	-	-	-
T8 – U-bent	-	-	-	-	-
T12 – less than 4'	-	1%	-	-	-
T12 – 4'	-	29%	17%	-	8%
T12 – More than 4'	-	10%	28%	-	4%
T12 – U-bent	-	1%	-	-	-
Compact – Pin-base	-	2%	-	-	-
Compact – Screw-in	-	1%	-	-	-
Compact – Pin-base – reflr	-	-	-	-	-
Compact – Screw-in – reflr	-	-	-	-	-
Circline	-	1%	-	-	-
Induction discharge	-	-	-	-	-
Miscellaneous fluorescent	8%	-	-	2%	6%
HID	**-**	**11%**	**30%**	**83%**	**7%**
Mercury vapor	-	2%	3%	19%	1%
Metal halide	-	8%	22%	10%	4%
High pressure sodium	-	1%	5%	50%	2%
Low pressure sodium	-	-	-	4%	-
Xenon	-	-	-	-	-
Electrodeless (e.g. mercury)	-	-	-	-	-
Solid State	**-**	**-**	**-**	**-**	**-**
LED	-	-	-	-	-
Electroluminescent	-	-	-	-	-
Total	**100%**	**100%**	**100%**	**100%**	**100%**

Table 5-6 shows that although incandescent lamps far outnumber other lamp types, on average they operate for less than three hours per day, compared to fluorescent and HID lamps, which operate almost three times as long. As the operating hours represent sectoral averages, some expected data points are lost in the aggregation. For example, police, fire and other 24-hour public service institutions as well as 24-hour convenience stores are outweighed in the commercial sector by the volume of office and retail space that does not operate 24 hours per day.

Table 5-6: Operating Hours per Day by Light Source

Technologies	Residential	Commercial	Industrial	Outdoor Stationary	All
Incandescent	1.9	10.2	16.7	7.9	2.8
Standard - General Service	1.9	9.4	14.2	8.0	2.4
Standard - Reflector	2.4	9.7	13.4	7.2	4.2
Halogen - General Service	2.3	9.5	-	-	2.5
Quartz Halogen	2.5	9.6	13.6	8.1	6.5
Halogen - refl. - low volt	-	10.3	12.4	-	10.3
Low wattage (less than 25W)	-	16.5	18.6	-	16.7
Misc incandescent	-	-	-	-	-
Fluorescent	2.2	9.7	13.4	10.8	8.2
T5	-	12.8	18.2	-	12.8
T8 – less than 4'	-	9.4	12.7	-	9.9
T8 – 4'	-	9.7	13.5	-	10.8
T8 – More than 4'	-	8.9	14.7	7.3	8.9
T8 – U-bent	-	10.5	13.1	-	11.0
T12 – less than 4'	-	10.2	11.2	-	10.3
T12 – 4'	-	9.4	12.6	-	9.7
T12 – More than 4'	-	9.9	14.6	7.3	11.6
T12 – U-bent	-	10.5	11.2	-	10.5
Compact – Pin-base	-	10.7	14.9	-	10.8
Compact – Screw-in	2.3	10.6	14.4	-	5.7
Compact – Pin-base – reflr	-	-	-	-	-
Compact – Screw-in – reflr	1.7	10.3	9.6	-	9.5
Circline	-	10.4	11.1	-	10.5
Induction discharge	-	-	-	-	-
Miscellaneous fluorescent	2.2	9.7	11.2	11.0	2.3
HID	2.8	10.1	13.9	11.3	11.0
Mercury vapor	2.8	10.0	12.4	11.2	9.9
Metal halide	-	10.1	14.4	10.5	11.5
High pressure sodium	2.8	10.2	13.0	11.3	11.0
Low pressure sodium	-	10.4	11.9	12.0	11.9
Xenon	-	-	-	-	-
Electrodeless (e.g. mercury)	-	-	-	-	-
Solid State	0.0	23.0	23.4	7.0	22.2
LED	-	22.9	23.3	7.0	21.9
Electroluminescent	-	23.4	23.7	-	23.4
Total	2.0	9.9	13.5	10.5	4.8

Table 5-7 lists the contribution of each lamp type to the lighting electricity consumption in each building sector. Although incandescent lamps led the nation in both number and wattage of lamps installed, fluorescent lamps are responsible for almost as much energy consumption, owing to their much higher operating hours. Notice the also the prominence of HID in the Outdoor stationary sector. Some of the cells in the table may appear as a null value, however this does not necessarily mean the light source is not in service, rather it may mean the number of lamps constitutes less than one-half of one percent of electricity consumption in that sector.

Table 5-7: Distribution of Lighting Electricity Consumed per Sector by Lamp Type (%)

Technologies	Residential	Commercial	Industrial	Outdoor Stationary	All
Incandescent	90%	32%	2%	11%	42%
Standard - General Service	76%	18%	1%	9%	31%
Standard - Reflector	11%	8%	1%	1%	7%
Halogen - General Service	1%	-	-	-	-
Quartz Halogen	1%	4%	-	2%	2%
Halogen - refl. - low volt	-	2%	-	-	1%
Low wattage (less than 25W)	-	1%	1%	-	1%
Misc incandescent	-	-	-	-	-
Fluorescent	10%	56%	67%	2%	41%
T5	-	-	-	-	-
T8 – less than 4'	-	1%	1%	-	-
T8 – 4'	-	12%	20%	-	9%
T8 – More than 4'	-	-	-	-	-
T8 – U-bent	-	-	-	-	-
T12 – less than 4'	-	1%	-	-	-
T12 – 4'	-	28%	15%	-	16%
T12 – More than 4'	-	10%	30%	-	9%
T12 – U-bent	-	1%	-	-	1%
Compact – Pin-base	-	2%	-	-	1%
Compact – Screw-in	1%	1%	-	-	1%
Compact – Pin-base – reflr	-	-	-	-	-
Compact – Screw-in – reflr	-	-	-	-	-
Circline	-	1%	-	-	-
Induction discharge	-	-	-	-	-
Miscellaneous fluorescent	9%	-	-	2%	3%
HID	0.3%	12%	31%	87%	17%
Mercury vapor	0.27%	2%	3%	20%	3%
Metal halide	-	9%	23%	9%	8%
High pressure sodium	0.05%	1%	5%	52%	5%
Low pressure sodium	-	-	-	5%	-
Xenon	-	-	-	-	-
Electrodeless (e.g. mercury)	-	-	-	-	-
Solid State	-	0.02%	0.00%	0.01%-	0.01%
LED	-	0.02%	0.00%	0.01%	0.01%
Electroluminescent	-	-	-	-	-
Total	100%	100%	100%	100%	100%

Finally, Table 5-8 illustrates that fluorescent lamps are responsible for nearly two-thirds of all the light produced each year. Incandescent lamps (12%) actually placed third behind HIDs (26%). Since fluorescent and HID lamps operate longer than incandescent lamps and they are currently much more efficient, they produce far more light. This suggests light is produced quite efficiently overall. The efficacies used to calculate these values are the means of the efficacy ranges listed in Appendix A.

Table 5-8: Distribution of Lamp Output (Tlm-hr) per Year by Lamp Type

Technologies	Residential	Commercial	Industrial	Outdoor Stationary	All
Incandescent	2,693	1,777	36	111	4,614
Standard - General Service	2,376	1,114	17	84	3,590
Standard - Reflector	212	270	6	4	491
Halogen - General Service	54	3	-	-	56
Quartz Halogen	51	276	8	23	358
Halogen - refl. - low volt	-	80	-	-	80
Low wattage (less than 25W)	-	34	5	-	39
Misc incandescent	-	-	-	-	-
Fluorescent	1,188	16,733	5,744	68	23,732
T5	-	13	-	-	13
T8 – less than 4'	-	196	55	-	251
T8 – 4'	-	3,876	1,837	-	5,713
T8 – More than 4'	-	29	-	1	31
T8 – U-bent	-	107	32	-	139
T12 – less than 4'	-	202	9	-	211
T12 – 4'	-	8,073	1,206	-	9,279
T12 – More than 4'	-	3,076	2,546	2	5,624
T12 – U-bent	-	402	20	-	421
Compact – Pin-base	-	391	14	-	405
Compact – Screw-in	59	161	6	-	225
Compact – Pin-base – reflr	-	-	-	-	-
Compact – Screw-in – reflr	-	19	1	-	20
Circline	-	164	15	-	179
Induction discharge	-	-	-	-	-
Miscellaneous fluorescent	1,129	24	3	65	1,221
HID	31	3,068	2,320	4,677	10,097
Mercury vapor	23	261	149	532	965
Metal halide	-	2,202	1,605	356	4,163
High pressure sodium	8	587	562	3,381	4,539
Low pressure sodium	-	18	4	408	430
Xenon	-	-	-	-	-
Electrodeless (e.g. mercury)	-	-	-	-	-
Solid State	-	1	-	-	2
LED	-	1	-	-	2
Electroluminescent	-	-	-	-	-
Total	3,912	21,579	8,100	4,856	38,445

5.2. Results by Sector, Subsector, and Application

This section describes how lighting is used in applications by sector and across sectors.

5.2.1. Residential Sector

We used the TPU database to estimate the lighting energy use in a typical residential room, then the AHS to estimate the number of rooms in a typical U.S. household. Table 5-9 presents the results. The living room was the leading lighting energy user in the household (352 kWh per year), followed by the kitchen (322), bathrooms (251) and outdoor lights (248).

Table 5-9: Lighting Electricity Usage -- Typical Residential Unit

Room Type	Operation(Hours per day per room)	Room Type Electricity Use (kWh/yr)	Rank by kWh/yr
Bathroom	1.8	251	3
Bedroom	1.1	215	5
Closet	1.1	19	13
Dining Room	2.5	55	10
Family Room	1.8	74	8
Garage	1.5	103	7
Hall	1.5	171	6
Kitchen	3.0	322	2
Living Room	2.5	352	1
Office	1.7	37	11
Outdoor	2.1	248	4
Utility Room	2.0	67	9
Other	0.8	32	12
Total		1,946	

From the perspective of residential housing units, Table 5-10 provides the electricity usage for typical residential buildings. This table incorporates the estimated room occurrence in each of the five XenCAP™ residential building types. This table shows that manufactured homes have the highest installed wattage per square foot, and even though their operating time is slightly lower than the other residential building types, they rank number one for lighting energy intensity.

Table 5-10: Lighting Electricity Usage -- Typical Residential Buildings

XenCAP™ Subsector	Average Floorspace (sq ft)[1]	Installed Wattage (W/sq ft)	Operation (hrs/day)	Electricity Use per Building (kWh/yr)	Intensity (kWh/yr/ ft^2)	Rank (intensity)
Manufactured	949	2.6	1.8	1,690	1.8	1
Single Family – detached	1,648	1.9	2.0	2,328	1.4	3
Single Family – attached	1,648	1.6	1.9	1,876	1.1	5
Multifamily – <4 units	778	2.2	1.9	1,204	1.5	2
Multifamily – >=4 units	801	2.0	1.9	1,088	1.4	4
Mean	1,425	2.0	1.9	1,946	1.4	

[1]Estimated from 1997 RECS Table HC1-4a

5.2.2. Commercial Sector

Similar to the residential sector, we derived lighting electricity use estimates for typical commercial buildings. However, for commercial buildings, rather than basing the estimate on per room averages, we used per square foot averages. Table 5-11 presents the building type, average floorspace, installed wattage and operating hours per day. From this, the lighting electricity use per building, intensity and rank of lighting energy intensity are determined.

Table 5-11: Lighting Electricity Usage -- Typical Commercial Buildings

XenCAP™ Subsector	Average Floorspace (sq ft)	Installed Wattage (W/sq ft)	Operation (Hrs/day)	Electricity Use per Building (kWh/yr)	Intensity (kWh/yr/ ft^2)	Rank (intensity)
01 Vacant	7,554	2.1	9.8	56,300	7.5	6
02 Office/ Professional	16,303	1.8	10.3	109,212	6.7	9
04 Laboratory	15,767	1.7	13.9	130,157	8.3	3
05 Warehouse (non-refrigerated)	16,284	1.4	9.7	78,565	4.8	16
06 Food sales	5,714	1.9	14.4	56,161	9.8	1
07 Public order/safety	16,191	1.3	9.6	73,030	4.5	18
08 Health Care (outpatient)	9,067	1.7	9.3	52,541	5.8	11
11 Warehouse (refrigerated)	63,850	1.4	10.6	340,119	5.3	14
12 Religious Worship	11,084	1.4	5.0	27,468	2.5	20
13 Public Assembly	14,397	1.4	7.3	52,238	3.6	19
14 Education	26,430	1.8	7.6	130,236	4.9	15
15 Food Service	5,305	1.6	12.6	37,221	7.0	7
16 Health Care (inpatient)	168,174	1.7	16.0	1,605,030	9.5	2
17 Skilled Nursing	26,875	1.3	12.0	144,229	5.4	13
18 Hotel/Motel/Dorm	30,069	1.3	10.1	142,669	4.7	17
23 Strip Shopping	30,229	1.9	11.1	226,343	7.5	5
24 Enclosed Retail	606,771	1.7	13.7	4,872,139	8.0	4
25 Retail (excluding enclosed)	8,933	1.9	10.2	62,286	7.0	8
26 Service (excluding food)	7,085	1.7	9.4	40,736	5.7	12
91 Other	10,651	1.7	10.2	65,040	6.1	10

On a floorspace (sq ft) basis, grocery stores and hospitals use by far the most lighting energy per building. This is a function of their size, lighting intensity, and operating hours. Installed wattage is similar across subsectors. Since the distribution of lighting technologies across subsectors is fairly uniform, this suggests that illuminance levels are also similar.

Table 5-12 provides lighting use estimates on a national level. Offices, warehouses, educational facilities, and retail stores are responsible for the most lighting energy consumption. The national building population is from the 1999 CBECS. Lighting electricity use is reported in Terawatt-hours (TWh) of electricity, equivalent to a billion kilowatt hours.

Table 5-12: Lighting Electricity Use in Commercial Buildings -- Estimate by Subsector

XenCAP™ Subsector	Number of Buildings	Lighting Electricity Use (TWh/yr)	Fraction of Use	Rank (fraction)
01 Vacant	253,000	14.2	4%	10
02 Office/Professional	739,000	80.7	21%	1
03 Laboratory	27,000	3.5	1%	20
05 Warehouse (non-refrigerated)	590,000	46.3	12%	2
06 Food sales	174,000	9.8	3%	13
07 Public orders/safety	72,000	5.3	1%	16
08 Health care (outpatient)	116,000	6.1	2%	15
11 Warehouse (refrigerated)	14,000	4.7	1%	18
12 Religious worship	307,000	8.4	2%	14
13 Public assembly	305,000	15.9	4%	9
14 Education	327,000	42.6	11%	3
15 Food service	349,000	13.0	3%	12
16 Health care	11,000	17.8	5%	8
17 Skilled nursing	25,000	3.7	1%	19
18 Hotel/motel/dorm	128,000	18.2	5%	7
23 Strip shopping	131,000	29.6	8%	5
24 Enclosed shopping	3,000	13.5	3%	11
25 Retail (excluding mall)	534,000	33.2	9%	4
26 Service (excluding food)	478,000	19.5	5%	6
91 Other	75,000	4.9	1%	17
Total	4,657,000	391	100%	

Table 5-13 shows little difference in the proportion of energy consumed across subsectors by the three main lighting types. Incandescent lamps account for about one-third of lighting energy consumed, and fluorescent is between one-half and two-thirds. The numbers behind these percentages can be found in Appendix E.

Table 5-13: Lighting Electricity Use in Commercial Buildings by Lamp Technology

XenCAP™ Subsector	Incandescent	Fluorescent	HID
01 Vacant	38%	59%	4%
02 Office/Professional	33%	56%	11%
03 Laboratory	33%	58%	10%
05 Warehouse (non-refrigerated)	25%	58%	17%
06 Food sales	29%	63%	8%
07 Public orders/safety	38%	47%	15%
08 Health care (outpatient)	32%	56%	12%
11 Warehouse (refrigerated)	27%	58%	15%
12 Religious worship	30%	54%	16%
13 Public assembly	34%	53%	13%
14 Education	28%	58%	14%
15 Food service	46%	45%	8%
16 Health care	34%	57%	9%
17 Skilled nursing	36%	51%	13%
18 Hotel/motel/dorm	39%	47%	15%
23 Strip shopping	31%	59%	10%
24 Enclosed shopping	32%	58%	9%
25 Retail (excluding mall)	31%	60%	10%
26 Service (excluding food)	30%	58%	13%
91 Other	32%	56%	12%

5.2.3. Industrial Sector

Table 5-14 provides estimates for typical industrial buildings using floorspace from the 1998 MECS. The other values are calculated using the methodology described in Chapter 6 and the data presented in Appendices F and J. Transportation equipment, lumber and wood products, and primary metals facilities are the most intense consumers of lighting energy.

Table 5-14: Lighting Electricity Usage -- Typical Industrial Buildings

SIC	Description	Average Floorspace (sq ft)	Installed Wattage (W/sq ft)	Operation (Hrs/day)	Electricity Use (kWh/yr)	Intensity (kWh/yr/ft^2)	Rank (intensity)
20	Food and Kindred Products	72,205	1.1	16.2	490,062	6.8	6
21	Tobacco Products	146,622	1.2	13.7	941,181	6.4	9
22	Textile Mill Products	201,018	1.3	13.5	1,241,737	6.2	13
23	Apparel and Other Textile Products	34,501	1.3	10.1	161,043	4.7	17
24	Lumber and Wood Products	45,796	1.5	15.7	413,835	9.0	2
25	Furniture and Fixtures	53,683	1.2	10.8	260,721	4.9	16
26	Paper and Allied Products	156,346	1.1	16.2	984,205	6.3	11
27	Printing and Publishing	20,606	1.2	14.6	132,004	6.4	10
28	Chemicals and Allied Products	182,403	1.3	14.5	1,245,133	6.8	5
29	Petroleum and Coal Products	77,339	0.8	14.5	312,579	4.0	19
30	Rubber and Miscellaneous Plastics	84,717	1.2	15.1	569,539	6.7	7
31	Leather and Leather Products	43,829	1.8	12.1	333,042	7.6	4
32	Stone, Clay, and Glass Products	57,946	1.2	14.8	372,954	6.4	8
33	Primary Metal Industries	201,817	1.4	15.7	1,618,790	8.0	3
34	Fabricated Metal Products	37,674	1.2	11.3	200,189	5.3	15
35	Industrial Machinery and Equipment	60,583	1.3	14.2	379,325	6.3	12
36	Electronic and Other Electric Equipment	79,488	1.3	12.4	465,191	5.9	14
37	Transportation Equipment	161,367	1.5	16.6	1,604,236	9.9	1
38	Instruments and Related Products	356,695	1.3	10.0	1,643,373	4.6	18
39	Miscellaneous Manufacturing Industries	36,771	1.2	8.0	125,423	3.4	20

According to Table 5-15, transportation machinery is also the largest user of lighting energy overall, followed by food and kindred products and industrial machinery. The building population is provided by the 1998 MECS.

Table 5-15: Lighting Electricity Use in Industrial Buildings -- Estimate by Subsector

SIC	Description	National Population of Buildings	Industrial Lighting Electricity Use (TWh/yr)	Share of Industrial Lighting Electricity Use	Rank
20	Food and Kindred Products	18,100	8.9	8%	4
21	Tobacco Products	300	0.3	0%	20
22	Textile Mill Products	7,200	8.9	8%	3
23	Apparel and Other Textile Products	12,600	2.0	2%	16
24	Lumber and Wood Products	11,700	4.8	4%	10
25	Furniture and Fixtures	11,300	2.9	3%	15
26	Paper and Allied Products	4,700	4.6	4%	12
27	Printing and Publishing	25,800	3.4	3%	14
28	Chemicals and Allied Products	9,000	11.2	10%	2
29	Petroleum and Coal Products	1,800	0.5	1%	18
30	Rubber and Miscellaneous Plastics	11,900	6.8	6%	8
31	Leather and Leather Products	1,000	0.3	0%	19
32	Stone, Clay, and Glass Products	11,300	4.2	4%	13
33	Primary Metal Industries	3,800	6.2	6%	9
34	Fabricated Metal Products	40,700	8.2	8%	5
35	Industrial Machinery and Equipment	19,600	7.4	7%	7
36	Electronic and Other Electric Equipment	9,900	4.6	4%	11
37	Transportation Equipment	8,400	13.4	12%	1
38	Instruments and Related Products	4,500	7.4	7%	6
39	Miscellaneous Manufacturing Industries	13,600	1.7	2%	17
	Total	**227,000**	**107.9**	**100%**	

Finally, Table 5-16 shows that, just as was found in the Commercial sector, lamp technologies played similar roles across industrial subsectors. HID plays a much larger role in the industrial sector than in either of the other sectors, undoubtedly due of the prevalence of high bay lighting fixtures. Incandescent usage is very low. The numbers behind these percentages can be found in Appendix F.

Table 5-16: Share of Lighting Electricity Use in Industrial Buildings by Lamp

SIC	XenCAP™ Subsector	Incandescent	Fluorescent	HID
20	Food and Kindred Products	2%	65%	33%
21	Tobacco Products	1%	62%	37%
22	Textile Mill Products	2%	69%	28%
23	Apparel and Other Textile Products	3%	67%	31%
24	Lumber and Wood Products	2%	62%	36%
25	Furniture and Fixtures	3%	68%	29%
26	Paper and Allied Products	2%	66%	32%
27	Printing and Publishing	3%	72%	25%
28	Chemicals and Allied Products	2%	75%	23%
29	Petroleum and Coal Products	3%	80%	17%
30	Rubber and Miscellaneous Plastics	2%	63%	34%
31	Leather and Leather Products	1%	64%	35%
32	Stone, Clay, and Glass Products	2%	65%	33%
33	Primary Metal Industries	2%	65%	33%
34	Fabricated Metal Products	2%	64%	34%
35	Industrial Machinery and Equipment	2%	69%	28%
36	Electronic and Other Electric Equip.	2%	67%	31%
37	Transportation Equipment	2%	61%	38%
38	Instruments and Related Products	5%	74%	20%
39	Miscellaneous Manufacturing Industries	3%	64%	33%

5.2.4. Outdoor Stationary Lighting

Since outdoor stationary installations are difficult to compare with each other, this section provides insight into the development of the lighting consumption estimates for each type of installation. We condensed the technology list to include only those lamp types present in the estimates.

Table 5-17 provides the number of lamps per installation. Table 5-18 provides the mean lamp wattage we assumed for each installation type. In the case of "Parking", lamp wattage was derived from XenCAP™ data.

Table 5-17: Lamps per Outdoor Stationary Installation

Technology	Billboard – lamps per installation			Traffic signals per intersection			Aviation per airport				Roadway - national proportion lamps	Parking - national proportion lamps
	8 panel	30 panel	Bulletin	Ball	Turn	Pedestrian	Approach	Touch-down	Center-line	Edge		
Incandescent				24	2	8	96	180	120	70	4%	13%
Standard - GS				23.8	2.0	7.9					4%	6%
Standard - Refl							48	90	60	35		2%
Halogen - Refl							48	90	60	35		5%
Low Wattage												
Fluorescent	0.14	0.28	0.42								2%	4%
T8 - >4'	0.07	0.14	0.21									
T12 - < 4'												
T12 - 4'												
T12 - > 4'	0.07	0.14	0.21									
Other											2%	4%
HID	0.86	1.72	2.58								94%	83%
Mercury vapor	0.06	0.12	0.18								20%	20%
Metal halide	0.80	1.60	2.40								5%	10%
HPS											59%	53%
LPS											10%	
Solid State				0.24	0.02	0.08						
LED				0.24	0.02	0.08						
Total	1	2	3	24	2	8	96	180	120	70	100%	100%

For traffic signals, because 1% of the signal balls in the US were assumed to be LED, a fraction of 0.24 lamps per intersection being LED was created. This means that in any four intersections in the U.S., one of the signal balls will be LED. Similar fractions were created for turn signals and pedestrian crossing signals. For roadway and parking lights, because there isn't any single installation metric, the fractions shown are the percentages of lamp types found in the U.S. For instance, 0.94 or 94% of the roadway lighting is HID. And breaking that 94% down to its component parts, 0.2 or 20% is mercury vapor, 59% is high pressure sodium and 10% is low pressure sodium.

Table 5-18 provides the average wattages selected for the outdoor stationary installations. Where a lamp requires a ballast to operate, the wattage of the ballast is included.

Table 5-18: Lamp Wattage Assumed for Outdoor Stationary Installations

Technology	Billboard – lamps per installation			Traffic signals per intersection			Aviation per Airport				Roadway – lamps	Parking – lamps
	8 panel	30 panel	Bulletin	Ball	Turn	Pedestrian	Approach	Touch-down	Center-line	Edge		
Incandescent												
Standard - GS				150	125	125					150	83
Standard - Refl							375	60	120	120		104
Halogen - Refl							375	60	120	120		226
Low Wattage												
Fluorescent												
T8 - >4'	105	105	105									
T12 - < 4'												
T12 – 4'												
T12 - > 4'	190	190	190									
Other											150	150
HID												
Mercury vapor	300	300	300								182	331
Metal halide	300	300	300								200	407
HPS											192	260
LPS											180	
Solid State												
LED				15	10	15						

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Table 5-19 provides the fraction of total outdoor stationary lighting energy consumed by each lamp type in each application. Notice that HID is the most important lamp type within the outdoor stationary sector (87 percent of consumption) because of its prevalence in street lighting, which itself dominates the sector (54 percent of consumption). Parking (39 percent) and traffic signals (6 percent) are also fairly significant. Aviation and billboards play a minor role in lighting energy consumption.

Table 5-19: Fraction of Outdoor Stationary Lighting Energy by Lamp Technology (%)

| Technology | Row Sum of Percentages | Billboard – all installations | | | Traffic - all intersections | | | Aviation – all airports | | | | Roadway – all installations | Parking – all installations |
		8 panel	30 panel	Bulletin	Ball	Turn	Pedestrian	Approach	Touch-down	Center-line	Edge		
Incandescent	11.2%	-	-	-	5.0%	0.1%	1.1%	0.1%	0.2%	0.3%	0.2%	1.7%	2.6%
Standard - GS	8.5%				5.0%	0.1%	1.1%					1.7%	0.7%
Standard - Refl	0.7%							0.0%	0.1%	0.1%	0.1%		0.3%
Halogen - Refl	2.0%							0.0%	0.1%	0.1%	0.1%		1.6%
Low Wattage	-												
Fluorescent	1.9%	0.0%	0.0%	0.0%	-	-	-	-	-	-	-	1.0%	0.9%
T8 - >4'	0.02%	0.0%	0.0%	0.0%									
T12 - < 4'	-												
T12 – 4'	-												
T12 - > 4'	0.04%	0.0%	0.0%	0.0%									
Other	1.9%											1.0%	0.9%
HID	86.8%	0.2%	0.5%	0.2%	-	-	-	-	-	-	-	51%	35%
Mercury vapor	20.0%	0.0%	0.0%	0.0%								10%	9.5%
Metal halide	9.5%	0.2%	0.4%	0.2%								2.9%	5.8%
HPS	52.3%											32%	20%
LPS	5.0%											5.0%	
Solid State	0.01%	-	-	-	0.0%	0.0%	0.0%	-	-	-	-	-	-
LED	0.0%				0.0%	0.0%	0.0%						
Total	100%	0.2%	0.5%	0.2%	5.0%	0.1%	1.1%	0.1%	0.2%	0.3%	0.2%	54%	39%

Table 5-20 presents the derivation of the total lighting energy consumed per installation type annually. Roadway is the largest contributor (31.0 TWh/yr) followed by parking (not including parking in commercial buildings) (22.3 TWh/yr) and traffic signals (3.6 TWh/yr). However, parking lighting probably possesses the highest degree of uncertainty and may be considerably under or overestimated.

Table 5-20: Lighting Energy Use in Outdoor Stationary Sources

	Number of Installations	Installed Wattage per Installation (W)	Operating hours per Installation (h/day)	Lighting Energy Use per Installation (kWh/yr)	Total Lighting Energy Use (TWh/yr)
Billboard	Displays				0.5
8 Sheet	140,000	279	7.3	747	0.1
30 Sheet	200,000	557	7.3	1,493	0.3
Bulletin	56,000	836	7.3	2,240	0.1
Traffic Signal	Intersections				3.6
Ball Signal	300,000	3,568	7.3	9,549	2.9
Turn Arrow	300,000	248	2.2	201	0.1
Pedestrian	225,000	991	7.5	2,713	0.6
Aviation	Lit runways				0.5
Approach	720	36,000	6.0	78,840	0.1
Touchdown	5,000	10,800	6.0	23,652	0.1
Centerline	5,000	14,400	6.0	31,536	0.2
Taxiway/Runway	7,500	8,400	6.0	18,396	0.1
Roadway	37,850,000	187	12.0	818	31.0
Parking	22,670,000	269	10.0	983	22.3
Total					57.8

5.2.5. National Lighting Summary

Table 5-21 summarizes the lighting energy use results for the four sectors in terms of both delivered and primary energy. Delivered energy is the energy, in this case electricity, measured at the point of use (the fixture). Primary energy is the total amount of energy required to supply the delivered energy, including any loss due to generation of electricity or in transmission to the site. The conversion factor (3.156) is derived from the Buildings Energy Databook (DOE, 2002). Total lighting consumption is estimated to be 765 TWh, or 2.6 quads (8.2 quads primary). Commercial buildings were responsible for the most use (51 percent) followed by residential (27 percent), industrial buildings (14 percent), and outdoor stationary (8 percent).

Table 5-21: National Lighting Energy Use Summary

Sector	Lighting Energy use per Building (kWh/yr)	Number of Buildings	Site Energy		Primary Energy (quad/yr)	Percent of Total
			(TWh/yr)	(quad/ yr)		
Residential	1,946	106,989,000	208	0.7	2.2	27%
Commercial	83,933	4,657,000	391	1.3	4.2	51%
Industrial	475,063	227,000	108	0.4	1.2	14%
Outdoor Stationary	n/a	n/a	58	0.2	0.6	8%
Total			765	2.6	8.2	100%

Table 5-22 presents a summary of the national energy use for lighting broken down by end-use sector and lamp type. Energy use is presented in both terawatt-hours of site energy and quads of primary energy. From this table, the dominance of incandescent and fluorescent sources and the importance of the commercial and residential sectors is clearly shown.

Table 5-22: National Lighting Energy Use by Sector and Source

Sector	Incandescent		Fluorescent		HID		Solid State		Total	
	TWh/yr	Quads	TWh/yr	Quads	TWh/yr	Quads	TWh/yr	Quads	TWh/yr	Quads
Residential	187.6	2.02	19.9	0.21	0.7	0.01	0.0	0.000	208.2	2.2
Commercial	124.5	1.34	220.1	2.37	46.2	0.50	0.1	0.001	390.9	4.2
Industrial	2.6	0.03	72.3	0.78	33.0	0.36	0.0	0.000	107.9	1.2
Outdoor Stationary	6.5	0.07	1.1	0.01	50.2	0.54	0.0	0.000	57.8	0.6
Total	321.2	3.5	313.4	3.4	130.0	1.4	0.1	0.0	764.7	8.2

Table 5-23 compares the three building sectors based on illuminance[7] and lighting energy intensity. Since we did not estimate the illuminated area of most outdoor stationary installations (and cannot in the case of signals), the outdoor stationary sector is not included. Installed wattage per square foot is highest for the residential sector, but lighting energy intensities in the commercial and industrial sectors exceed those of the residential sector by a factor of 4. Efficacies are higher in the commercial and industrial sectors (by a factor of 3 to 4), offsetting their higher illuminance levels (which also exceed residential levels by a factor of 2 to 3). However, hours of lamp operation far exceed those in the residential sector (by a factor of 5 to

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[7] For calculation purposes, we assume that half of all light produced reaches the work plane (Coefficient of Utilization (CU) equals 0.5, which is a standard assumption). Applying a CU of 0.5 yields illuminance levels corresponding to IESNA categories C-D in the residential sector and D-E in the industrial and commercial sectors. These agree with the IESNA recommendations for the bulk of tasks carried on in those sectors, lending support to our wattage and efficacy estimates.

7), resulting in the much higher energy intensities. The illuminance level column reports figures in foot-candles (fc), an industry standard measure of light.

Table 5-23: Lighting Use on a Floorspace Basis

Sector	Installed Wattage (W/sq ft)	Mean Efficacy (lm/W)	Illuminance (fc)(CU=0.5)	Operating Hours (hr/day)	Energy Intensity (kWh/yr/ft^2)
Residential	2.0	18	18	2.0	1.4
Commercial	1.7	55	45	9.9	5.8
Industrial	1.3	75	48	13.5	6.4

6. XenCAP Database and Lighting Estimate

Past lighting studies often overlook the similarities in lighting use across sectors due to similarities in lighting requirements. For example, although we typically think of the commercial sector when assessing "office" space, the industrial and residential sectors also have offices that may have similar lighting requirements. Understanding how each one of these types of crosscutting applications contributes to the nation's overall lighting use is important for identifying LR&D opportunities.

6.1. Space Functions

The lighting information from the XenCAP™ audits is contained in two tables. The first table has the lamp groups in which an auditor separates the facility into areas where the lamps have similar operating characteristics. The auditor assigned a descriptor to each lamp group. Since there was no standard list of descriptors from which to choose, the XenCAP™ lamp group table contained 282,260 records, of which there were 87,783 unique. Thus, the challenge of condensing them to a manageable level of aggregation based on the function of the space was considerable. Even simple descriptors such as those for restrooms had many permutations. For example, "men's room", "mens room", "mens rm", and "men's rm." are all unique names that refer to the same space type.

Using an iterative approach, we scanned the lamp group description fields for common key words and phrases, and grouped them into the same space function. For example, for all lamp group descriptions containing the word "restroom" would be assigned to the generic space function "bathroom". Thus descriptions such as "mens restroom", "womens restroom" would all be assigned to the same generic space function. Eventually, we were able to aggregate the nearly 88,000 unique descriptors into 24 unique space functions, including the catch-all "unknown" that contains the records that we could not identify from their descriptors. Table 6-1 describes the space functions.

Clearly the categories are not definitive or without possible errors. It is difficult to ensure, for example, that the group of letters "a-r-c-h-i-t" refers to an architect's "office" rather than a feature of an architectural "structure". Even so, given the enormity of the aggregation task, we believe that most of the classifications are reasonably accurate and provide a good picture of the lighting used in different types of spaces used for different purposes.

Table 6-1: Description of Space Functions

Space Function	Description
Assembly	Public gathering places such as auditoriums, churchs, and museums
Bathroom	Bathrooms
Classroom	Spaces where classes are taught
Dining	Places where food is served and eaten
Exit sign	"Exit" signs
Food prep	Places where food is prepared
Hallway	Pass-through areas such as stairs and lobbies
Healthcare	Medical, nursing, and lab areas
Landscape	Exterior lit spaces including hardscape and softscape and pedestrian walks
Living space	Occupied living spaces not including kitchens and bathrooms
Merchandise	Retail display areas
Office	Spaces where non-manufacturing work is conducted
Parking	Parking areas
Roadway	Streets and highways
Shipping/Receiving	Areas where materials are staged, shipped, and received
Shop	Manufacturing assembly and fabrication areas
Storage	Places where items are stored including food
Signage	Illuminated signs
Signal	Installations such as traffic and aviation signals not intended to illuminate
Sports/Recreation	Athletic and recreational areas
Structure	Exterior illumination of buildings
Task	Illumination focused on specific tasks
Unknown	Unidentifiable areas typically including phrases such as "First Floor" that change with the building function
Utility	Boiler rooms, electrical closets, and other areas dedicated to equipment

Table 6-2 shows the fraction of total energy used for each function across space types. Office and shop space both rely primarily on fluorescent lighting, although other large contributors such as living space, hallways, and food preparation contain a large proportion of incandescent lighting due to the prevalence of those functions in residences. "Unknown" is a blend of fluorescent and incandescent similar to that of "office", suggesting that unidentifiable records classified as 'unknown' were mostly office space. The sectors are abbreviated, but represent the same four carried through the analysis – residential, commercial, industrial and outdoor stationary.

Table 6-2: Lighting Energy Consumed in Each Sector by Space Function (TWh/yr)

	Res	Com	Ind	Out	All	
Assembly	-	12	-	-	12	2%
Bathroom	27	5	1	-	32	4%
Classroom	-	21	1	-	22	3%
Dining	6	16	1	-	23	3%
Exit sign	-	4	1	-	5	1%
Food prep	34	7	-	-	42	5%
Hallway	18	31	2	-	51	7%
Healthcare	-	10	4	-	14	2%
Landscape	27	14	-	-	41	5%
Living space	69	8	-	-	77	10%
Merchandise	-	48	-	-	48	6%
Office	4	73	11	-	88	11%
Parking	-	11	1	22	34	4%
Roadway	-	-	-	31	31	4%
Shipping/Receiving	-	1	2	-	3	0%
Shop	-	17	50	-	66	9%
Storage	13	27	9	-	49	6%
Signage	-	19	2	1	22	3%
Signal	-	-	-	4	4	1%
Sports/Recreation	-	8	1	-	9	1%
Structure	-	10	2	-	12	2%
Task	-	6	1	-	7	1%
Unknown	3	36	15	-	54	7%
Utility	7	8	4	-	19	2%
Total	208	391	108	58	765	100%

Three functions make up a third of all lighting energy use. Office space is responsible for the largest fraction (88 TWh/yr, or 11 percent) followed by living space (77 TWh/yr, or 10 percent) and shop space (66 TWh/yr, or 9 percent).

7. Lighting Market Characterization Comparison

7.1. Comparison to other studies

Table 7-1 presents a comparison of building lighting estimates from various studies.

Table 7-1: Annual Lighting Electricity Consumption Estimates

Residential	Annual Household Lighting Electricity Consumption
EIA (1996)	940 kWh
Hanford (1994)[1]	1,313 kWh
Hwang et. al., LBNL (1994b)	1,469 kWh
Heschong Mahone Group (1997)[2]	1,704 kWh
Tribwell and Lerman (1996)[3]	1,818 kWh
Lighting Market Characterization (2001)	**1,946 kWh**
Manclark et al. (1992) and Nelson (1992)[4]	2,517 kWh
Commercial	**Annual National Lighting Electricity Consumption**
Vorsatz and Koomey (1997)[5]	240 TWh
EIA (1996a)	340 TWh
Lighting Market Characterization (2001)	**391 TWh**
Industrial	**Annual National Lighting Electricity Consumption**
Niefer (1997)[6]	50 TWh
Lighting Market Characterization (2001)	**108 TWh**

Table notes:
1. PG&E metered data scaled by national average floorspace. Incandescent only. Our incandescent estimate is 1,480 kWh/yr.
2. California only based on 697 homes and adjustments based on TPU data.
3. Tacoma, Washington service area only based on the TPU dataset.
4. Yakima, Washington only. Surveys and metering of 53 homes for 3 months.
5. Results of COMMEND model forecast. Cited in Vorsatz (1997)
6. Based on 1991 MECS

In the residential sector, our estimate per household is considerably higher than that of EIA's RECS (EIA, 1996), and our residential incandescent estimate is similar to Hanford (1994). Since our operating hour and lamp type distribution seem to match EIA's fairly closely, the discrepancy may lie in a disparity between the number or wattage of lamps installed. Appendix B presents some lighting energy use calculations derived from the TPU dataset based on building characteristics and number of occupants for comparison with the RECS data.

In the commercial sector, our estimate is 15 percent higher than that of EIA (1992) and 63 percent above that of Vorsatz and Koomey (1997). The major differences lie at the subsector, or building function level. Our data seem to confirm that EIA's lighting energy intensity assumptions for some sectors, particularly

hospitals and lodging, were substantially inflated. On the other hand, the Vorsatz and Koomey lighting energy intensity estimates are consistently below ours. The difference seem to lie in the installed wattage results (lighting power density). Ours is 1.7 W/sq. ft. compared to 1.1 W/sq. ft. for Vorsatz and Koomey (1997). Our estimates of operating hours and the distribution of lighting energy across building sectors are very close to their estimates.

In the industrial sector, our estimate exceeds that of Niefer (1997) based on EIA's 1991 MECS by a considerable 58 percent. Ours is audit-based, so we are confident in the accuracy of our installed wattage estimates. Niefer (1997) does not provide enough information on installed wattage and operating hours to determine the source of the discrepancy.

7.2. Statistical Validity

The samples in the TPU database and most of those in the XenCAP™ database were not selected randomly. So, even though we place a great deal of confidence in the accuracy of each data record, we cannot be sure that the entire dataset is a statistically valid representation of the national population of residences and commercial and industrial buildings. To the extent possible, we searched for bias and tried to detect unusual data records, but we did not perform any statistical adjustments. This chapter discusses some of the issues related to statistical accuracy.

7.2.1. TPU Data

The TPU dataset is based on a relatively small sample of households (161) in a similarly small region of the nation (Washington state). Not all fixtures were monitored, and there is no record of why fixtures were left out of the sample. Since we did not attempt to include those fixtures, the effective assumption is that those fixtures do not operate at all. If those unmonitored fixtures did operate during the monitoring period, this would lead us to underestimate energy consumption.

Some of the data are suspect. For example, there are occurrences of high pressure sodium lamps in a bathroom and a family room. (We reclassified those as incandescent, although we could just have easily reclassified them to "outdoor"). There are also hundreds of occurrences of questionable fixture wattage. The TPU data collect wattage for entire fixtures and the number of lamps per fixture. Sometimes that leads to lamps with unusual wattage (260 watt fixture with 3 lamps: 86.66 watts per lamp) or very high wattage (300 watt fixture with one lamp: 300 watts per lamp). Since we did not know whether the fixture wattage was too high, the number of lamps were too low, or whether the fixture contained an unusual combination of lamps (two 100 watt and one 60 watt), we left the data as they were. Since our energy use estimates are based on the fixture wattage multiplied by the operating hours, a high occurrence of inflated fixture wattage could very well inflate our estimate.

There is also some question of whether the lighting in TPU database households are representative of the lighting in the typical national household. We did not attempt a comparison, but we did examine the lighting use in TPU households based on building size and age and the number of occupants both on a square footage basis and for the whole household. In general we found that the distribution of energy use and wattages matched our intuition. Appendix B shows the distributions. They can be compared with the results of national statistical surveys such as RECS, AHS, and the Census to detect and correct for any biases in our estimates.

One comparison we did perform was the number of illuminated rooms in a TPU area household against

the number of rooms (illuminated or otherwise) as listed in the AHS. Table 7-2 shows that there is very close agreement in bathrooms, bedrooms, kitchens, and living rooms, which are the most important rooms with regard to their lighting energy consumption. However, without applying the AHS room occurrences to the TPU dataset, the household average lighting energy consumption is 1818 kWh/yr (Tribwell, 1996). This implies that, if left unadusted, the TPU data is biased toward overestimating national residential lighting energy use.

Table 7-2: Comparison of AHS and TPU Rooms per Housing Unit

Room Type	AHS Occurrence	TPU Occurence
Bathroom	**1.56**	1.70
Bedroom	**2.61**	2.67
Closet	5.21	**0.47**
Dining Room	**0.38**	0.77
Family Room	**0.35**	0.60
Garage	n/a	**0.57**
Hall	n/a	**2.19**
Kitchen	**1.00**	1.01
Living Room	**0.96**	0.99
Office	**0.05**	0.24
Outdoor	n/a	**1.37**
Utility Room	**0.41**	0.76
Other	0.08	**0.33**
Total	**12.61**	**13.67**

Note: Shaded values indicate those selected for use in this study.
n/a: AHS did not provide data

7.3. XenCAP™ Data

The buildings in the XenCAP™ database, like the houses in the TPU study, are concentrated in one region of the nation. XenCAP™ also spans a larger time period than does TPU. It is possible that variability in building practices based on geography or time frame do introduce some bias when extrapolating the database to the national population of buildings. Unfortunately, testing for and compensating for any bias falls outside the scope of this study.

8. Summary Results

The objective of the Lighting Market Characterization Phase I was to collect and present in one document the fundamental information on the installed base of lighting and the energy consumed by those light sources in the United States. This report presents data pertaining to these objectives at various levels of aggregation and as uniformly as possible across the four end-use sectors.

This study utilized data from existing sources such as the Commercial Building Energy Consumption Survey (CBECS) and the Manufacturing Energy Consumption Survey (MECS), as well as previously untapped data sources, including end-use metering studies and calibrated building audits. One of the new sources of data on lighting use in buildings was the XenCAP™ energy audit database. XenCAP™ incorporates a database of nearly twenty-five thousand detailed facility audits of commercial and industrial buildings conducted throughout the U.S. in the 1990's. A statistical correction was applied to these audits performed over the last decade to establish 2001 as the lighting inventory estimate year.

Government experts, industry representatives and researchers reviewed drafts of this report. This final report incorporates their valuable input and additional insights that were provided to the DOE.

8.1. Lighting Market Characteristics

In the United States, total energy consumption in 2001 was 98.3 quadrillion BTU's, of which about a third – 37 quads – is for electricity production (EIA, 2002a). Figure 8-1 provides a breakdown of electricity consumption by sector (EIA, 2002c).
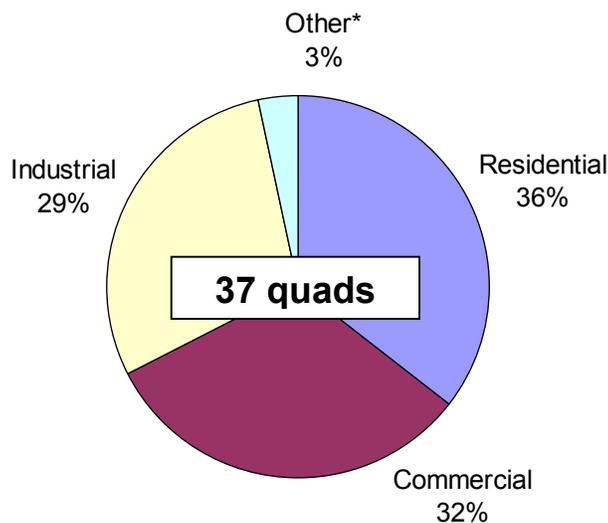
**Figure 8-1. Total U.S. Primary Energy Consumption
for Electricity Production 2001**

* Other includes electricity for street lighting, public authorities, railways, irrigation, and interdepartmental sales.

Energy consumption for all lighting in the U.S. is estimated to be 8.2 quads, or about 22% of the total electricity generated in the U.S Figure 8-2 provides a break-down by end-use sector of the energy consumption for lighting our homes, offices and other metered applications around the country.
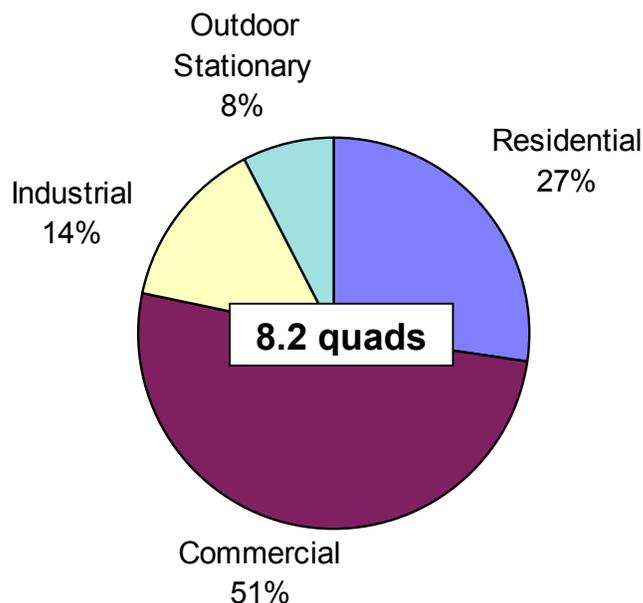
Figure 8-2. Total U.S. Primary Energy Consumption for Electricity for Lighting by Sector 2001, PEC

Figure 8-2 shows that more than half of these 8.2 quads are consumed in the Commercial sector, the largest energy user for lighting. This is one of the principle markets the DOE has targeted to develop more efficient technologies, as lighting contributes to a building's internal heat generation and subsequent air-conditioning loads at peak times. Narrowing the perspective to the commercial and residential sectors, total energy use for lighting was approximately 6.4 quads. Nationally, total energy use in commercial and residential buildings was approximately 36.4 quads, of which electricity use was approximately 21.3 quads (BTS, 2002). Thus, in these two building types, lighting constituted approximately 17.6% of total building energy consumption, or approximately 30.3% of toal building electricity use.

While Figure 8-2 presented the end-use energy for lighting in terms of primary energy[8] consumption (quads), Figure 8-3 presents the same data, disaggregated by sources, in terms of terawatt-hours per year (TWh/yr). These units represent the electrical energy measured by the site meters for lighting throughout the United States. Figure 8-3 illustrates the end-use electricity consumed by incandescent, fluorescent and high intensity discharge lamps.

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[8] Primary energy is the amount of energy used at the power station to produce the electricity delivered to the buildings, incorporating generation, transmission and distribution losses Primary energy is generally reported in terms of "quads" or quadrillion (10E+15) British thermal units (BTU). The factor used to convert the end-use electrical energy to primary energy consumed at the generating power plant is 10,768 BTU/kWh (DOE, 2002). Note that this conversion factor can vary slightly, depending on the mix of electrical generating power plants used in a given year.
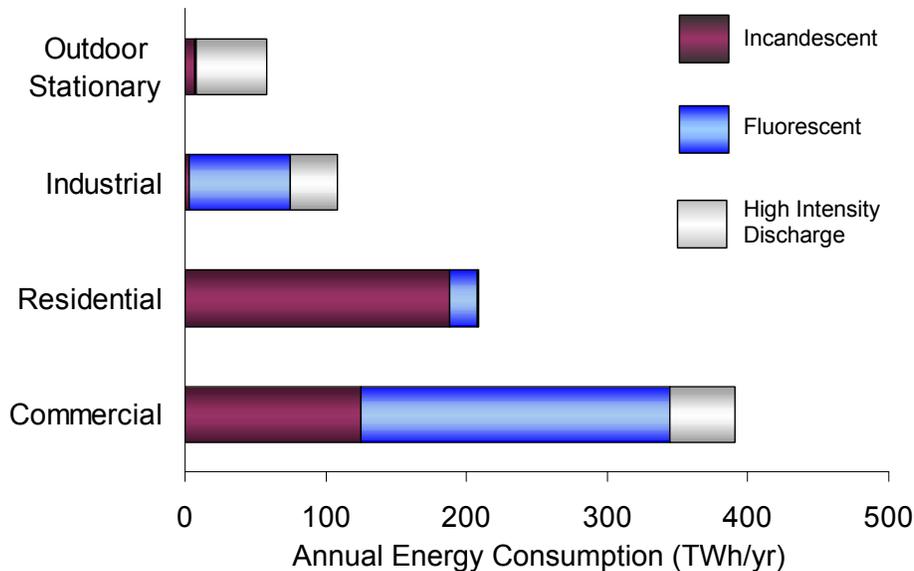
Figure 8-3. Lighting Energy Consumption by Sector & Source

In Figure 8-3, the end-use energy consumption chart shows that fluorescent sources in the commercial sector are the single largest energy-consuming segment in the U.S., slightly greater than residential incandescent. However, across all sectors, incandescent is the leading energy consumer in the U.S. consuming 321 terawatt-hours per year (TWh/yr). Fluorescent lighting is second with about 313 TWh/yr and HID is third with approximately 130 TWh/yr.

On a sectoral basis, Figure 8-3 shows that the outdoor stationary energy consumption is primarily HID sources, which account for 87% of its 58 TWh/year of electricity use. The industrial sector has sizable energy shares of both fluorescent and HID sources, 67% and 31% respectively of this sector's 108 TWh/year consumption. The commercial sector is the largest energy user overall, having large quantities of energy used by all three light sources. Fluorescent and incandescent are the two largest commercial lighting energy users, accounting for 56% and 32% of its annual 391 TWh/year of electricity use. In the residential sector, energy use is primarily driven by incandescent technologies, where 90% of the energy is consumed by this light source.

Electricity is a means to provide a service – visible light – in our workspaces, homes and other installations. Figure 8-4 provides an estimate of the calculated source lumen[9] output in the United States by technology and sector. The units in Figure 8-4 measure annual lighting service – teralumen hours per year (Tlm-hr/yr) is an infrequently used but highly descriptive measure of the number of Tera (10E+12) lumen-hours delivered in one year.

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[9] A lumen is a measure of light production, specifically it is the SI unit of luminous flux, defined as the quantity of light emitted in a unit solid angle (1 steradian) by a point source with uniform intensity of 1 candela. A lumen-hour (lm-hr), the metric used in Figure 8-4, is a measure of lighting service over a period of time (one hour). Tera is a unit modifier referring to a trillion units, or 10E+12.
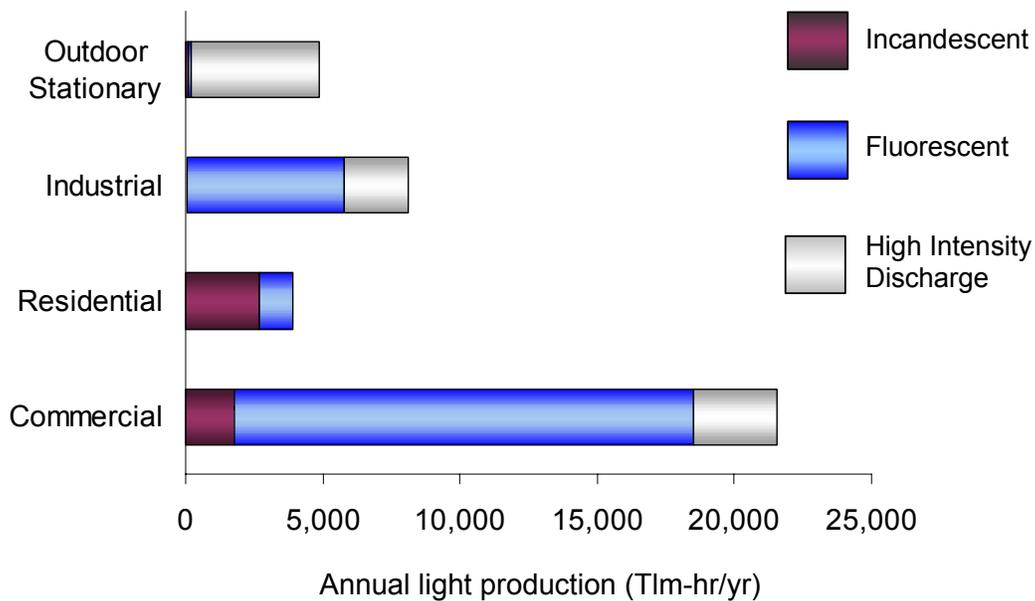
Figure 8-4. Source Light Production by Sector & Source

According to Figure 8-4, the greatest source lumen production in the United States is for the commercial sector. This sector, comprising retail establishments, office buildings, and many other commercial space-types, is generally lit throughout the day and into the evening hours – contributing to the large demand for lighting services. The high prevalence of fluorescent lighting in this sector, the high occupancy rates of many commercial space-types and fluorescent's relatively high efficacy all contribute to this considerable source lumen output.

Comparing Figure 8-3 with Figure 8-4, it becomes clear that the incandescent light production per unit energy consumption is considerably lower than that of fluorescent or HID. For example, within the commercial sector, 32% of its energy use was for incandescent lighting – but only 8% of the commercial lumens were generated by this source. Conversely, 56% of energy use in the commercial sector was for fluorescent sources, which provide 78% of its source lumen production.

Looking across all four sectors in Figure 8-4, fluorescent is the most important light source in the U.S. in terms of lumen service. On a national basis, 62% of the lamp lumens are produced by this source. HID sources are the second most important, generating 26% of the lumens in 2001, followed by incandescent which delivered 12%. Comparing these lumen production figures to the relative energy uses in Figure 8-3, incandescent is the highest, accounting for 42% of the nation's electricity use for lighting. This is followed by fluorescent with 41% and HID with 17%. Thus, incandescent lighting, the light source developed more than 100 years ago and still in use today, consumes the most energy and provides the least amount of light nationally.

Table 8-1 provides further detail on the sectoral lighting energy consumption estimates, specifically the four lighting market sectors in terms of both delivered (end-use) and primary (source) energy. It also provides the estimated average annual energy consumption for lighting per building.

Table 8-1. U.S. National Lighting Energy Use Estimates for 2001

Sector	Electricity Use per Building (kWh/yr)	Number of Buildings	Site Energy (TWh/yr)	Primary Energy (quads)	Percent of Total
Residential	1,946	106,989,000	208	2.2	27%
Commercial	83,933	4,657,000	391	4.2	51%
Industrial	475,063	227,000	108	1.2	14%
Outdoor stationary	n/a	n/a	58	0.6	8%
Totals			765	8.2	100%

Table 8-1 reports the data used to generate Figure 8-2 – the total lighting consumption is estimated to be 765 TWh, or about 8.2 quads of primary energy. Commercial buildings are the most prominent with 51% of the energy consumption, followed by residential (27 percent), Industrial (14 percent) and outdoor stationary (8 percent).

Table 8-2 presents the data used to generate Figure 8-3 – the national lighting energy use broken down by sector and lamp type. For convenience, energy consumption is presented in both terawatt-hours of site energy and quads of primary energy. From this table, the dominance of incandescent and fluorescent sources and the importance of the commercial and residential sectors is clearly shown.

Table 8-2: National Lighting Energy Use by Sector and Source

Sector	Incandescent		Fluorescent		HID		Solid State		Total	
	TWh/yr	Quads	TWh/yr	Quads	TWh/yr	Quads	TWh/yr	Quads	TWh/yr	Quads
Residential	187.6	2.02	19.9	0.21	0.7	0.01	0.0	0.000	208.2	2.2
Commercial	124.5	1.34	220.1	2.37	46.2	0.50	0.1	0.001	390.9	4.2
Industrial	2.6	0.03	72.3	0.78	33.0	0.36	0.0	0.000	107.9	1.2
Outdoor Stationary	6.5	0.07	1.1	0.01	50.2	0.54	0.0	0.000	57.8	0.6
Total	321.2	3.5	313.4	3.4	130.0	1.4	0.1	0.0	764.7	8.2

Table 8-3 provides the national average installed wattages across the sectors. A disaggregated version of this table providing a breakdown by the study's 31 lamp types appears in Table 5-1. The average wattage of ballasted lamps incorporates the wattage consumed by the ballasts, apportioned to the number of lamps it operates.

Table 8-3. Average Installed Wattages by Sector and Lamp Type, 2001

Lamp Type	Residential (watts)	Commercial (watts)	Industrial (watts)	Outdoor (watts)	Weighted Avg. (watts)
Incandescent	67	83	64	138	69
Fluorescent	38	41	48	150	41
HID	151	404	425	227	304
Solid State	-	5	5	15	6

In this summary table, the residential sector has the lowest average installed wattages of the sectors analyzed across all the lamp sources. Solid state in the commercial and industrial sectors refers to exit signs while in the outdoor stationary, it includes traffic and pedestrian crossing signals.

Table 8-4 reports in percent terms the frequency of a particular lamp type in a typical building from a given sector. For example, 86% of the lamps in the average residential building are incandescent, while only 22% of the lamps in an average commercial building are incandescent. As with Table 8-3, these numbers are the sectoral-source type averages. A disaggregated version of this table providing percentages of the 31 lamp types appears in Table 5-3 and a table providing the actual estimates of the inventory appears in Table 5-4.

Table 8-4. Percentage of Installed Lamps in Average Buildings by Sector, 2001

Lamp Type	Residential (% lamps)	Commercial (% lamps)	Industrial (% lamps)	Outdoor (% lamps)	National Avg. (% lamps)
Incandescent	86%	22%	2%	22%	63%
Fluorescent	14%	77%	93%	3%	35%
HID	0%	2%	5%	75%	2%
Solid State	0%	0%	0%	0%	0%
Totals	100%	100%	100%	100%	100%

In the residential sector, incandescent lamps are the most common lamp, while in commercial buildings 77% of the lamps in an average building will be fluorescent. Similarly, in industrial installations, fluorescent dominates with an average 93% of the lamps installed. Outdoor stationary is led by HID sources, due to their prevalence in street lighting installations. Solid state lighting was accounted for in this estimate, however it represented less than one half of one percent in the various sectors, and due to rounding is reported as 0%.

Table 8-5 looks at the total installed wattage of lamps in an average building, and then reports on the percentage of those watts that will be from incandescent, fluorescent, HID and solid state sources. As with the previous tables, all the numbers reported are sectoral-source averages. The disaggregated version of this table providing percentages for each of the 31 lamp types studied in this inventory appears in Table 5-5.

Table 8-5. Percentage of Installed Wattages in Average Buildings by Sector, 2001

Lamp Type	Residential (%W installed)	Commercial (%W installed)	Industrial (%W installed)	Outdoor (%W installed)	National Avg. (%W installed)
Incandescent	91%	32%	2%	15%	69%
Fluorescent	9%	57%	68%	2%	23%
HID	0%	11%	30%	83%	7%
Solid State	0%	0%	0%	0%	0%
Totals	100%	100%	100%	100%	100%

This table shows that nationally, incandescent lamps make up 69% of the installed lighting wattage. And, as expected in the commercial and industrial sectors, fluorescent lamps are the leading installed wattage light source (57% and 68%). Again, due to their comparatively low wattage and low market penetration, solid state sources are reported as 0% after rounding.

Table 8-6 reports the average operating hours for each of the sectors by lamp type. The disaggregated data providing hours by the 31 lamp types studied in this report appears in Table 5-6.

Table 8-6. Average Operating Hours per Day by Sector and Source, 2001

Lamp Type	Residential (hours/day)	Commercial (hours/day)	Industrial (hours/day)	Outdoor (hours/day)	National Avg. (hours/day)
Incandescent	1.9	10.2	16.7	7.9	2.8
Fluorescent	2.2	9.7	13.4	10.8	8.2
HID	2.8	10.1	13.9	11.3	11.0
Solid State	0.0	23.0	23.4	7.0	22.2
Sectoral Average	2.0	9.9	13.5	10.5	4.8

Looking back at Table 8-5, although incandescent lamps have the greatest installed wattage (69%), nationally, they only operate about 2.8 hours per day. Compared to incandescent, fluorescent and HID light sources were found to operate about 3 times as long (8.2-11.0 hours per day). As expected, solid state (exit signs and traffic signals) sources were found to have a much higher average daily operating time. The sectoral average reported in Table 8-6 refer to the lamp inventory weighted averages for each of the sectors.

Table 8-7 provides the distribution of electricity consumption in percentage terms by sector and lamp type. This is a summary table, derived from Table 5-7 which provides a disaggregated perspective on the sectors by 31 different lamp types.

Table 8-7. Percentage of Electricity Consumption by Sector and Source, 2001

Lamp Type	Residential (% electricity)	Commercial (% electricity)	Industrial (% electricity)	Outdoor (% electricity)	National Avg. (% electricity)
Incandescent	90%	32%	2%	11%	42%
Fluorescent	10%	56%	67%	2%	41%
HID	0.3%	12%	31%	87%	17%
Solid State	0%	0.02%	0.00%	0.01%	0.01%
Totals	100%	100%	100%	100%	100%

The national average column reported in Table 8-7 shows that while incandescent lead the nation in both number and wattage of lamps installed, fluorescent lamps are responsible for nearly as much energy consumption because of their considerably longer operating hours. As previously discussed, incandescent is the prominent end-user in the residential sector, fluorescent leads in the commercial and industrial sectors and HID dominates outdoor stationary.

Table 8-8 provides an estimate of the source lumen production by sector and source. These are percentages of source lumen emissions, and as such do not incorporate fixture or other light distribution technology efficiencies. Disaggregated estimates of the 2001 source lumen output by the 31 lamp types evaluated in this study can be found in Table 5-8.

Table 8-8. Percentage of Source Lumen Output by Sector and Source, 2001

Lamp Type	Residential (% lmhr/yr)	Commercial (% lmhr/yr)	Industrial (% lmhr/yr)	Outdoor (% lmhr/yr)	National Avg. (% lmhr/yr)
Incandescent	69%	8%	0%	2%	12%
Fluorescent	30%	78%	71%	1%	62%
HID	1%	14%	29%	96%	26%
Solid State	0%	0%	0%	0%	0%
Totals	100%	100%	100%	100%	100%

Table 8-8 shows that while incandescent is the leading source of lumens in the residential sector, nationally, the fluorescent is the most important source of light. The study found that more than twice as much light is produced by fluorescent sources compared with HID, and over five times more compared with incandescent. For these estimates, solid state sources represented less than one half of one percent of the source lumens produced in 2001.

8.2. Lighting Technology Observations

Generally, the main finding drawn from the U.S. Lighting Market Characterization Inventory study is that lighting is an important consumer of energy. Using more than 20% of all electricity generated in the United States, lighting reaches across industries, sectors and end-uses to provide a service critical to

economic and social well-being. The U.S. lighting market was found to be a diverse, complex entity. For example, although fluorescent sources are omnipresent and provide the most lumens in the United States, comparatively inefficient incandescent sources actually consume more energy than fluorescent while providing about a fourth as much light.

In this section, observations on the lighting database are grouped around the four broad light source classifications, incandescent, fluorescent, high intensity discharge and solid state. These conclusions are drawn from data presented in chapters 5 and 8.

Incandescent lamps are the most common light source in the United States (63%), and the largest consumer of electricity (42%). However they only provide 12% of the nation's light due to their comparatively poor efficacy. The amount of energy consumed by this technology is more than expected, and constitutes a target for efficiency measures. If 50% of the installed base of A-type GLS lamps were replaced with CFL lamps, the United States would save approximately ~0.9 quads of PEC per year.

Fluorescent lamps are work-horse of the installed base of lighting in the U.S. They are the most common lamp found in the commercial and industrial sectors (77% and 93% respectively), and are the second largest consumer of electricity (41%). Looking across the sectors analyzed in this study, fluorescent sources are the top lumen emitter in the US, with 62% of the light production. The commercial sector derives 78% of its lumens from fluorescent, with nearly 30% of total US lighting electricity being consumed just in commercial fluorescent fixtures.

High intensity discharge lamps consume about 17% of the national lighting electricity budget, servicing primarily the commercial, industrial and outdoor stationary end-use sectors. Of the total energy used by HID sources, outdoor stationary installations consume the most energy at 39%. Commercial buildings are second with 35% , followed by industrial installations at 25%. The remaining less than 1% is used in the residential sector, primarily for security lighting.

Solid state light sources tended to report with comparatively low energy consumption and light output. This is because these sources tend to be highly efficient (low energy use) and are mainly found in signal or safety (exit sign) applications, not general illumination where most of the energy is used. However the operating hours of solid state were found to be high compared with other sources, reflecting their high duty-cycle in these sectors.

Phase I established an estimated baseline inventory of lighting technologies in the U.S. Phase II, the Opportunities Phase, will work from this inventory to identify and quantify energy saving opportunities within the U.S. Lighting Market. The Phase II report will be published in 2003.

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10. Appendices

Appendix A. Technology Tables and Assumptions

Appendix B. TPU Residential Dataset Distributions

Appendix C. Examples XenCAP™ Tables of Facility and Lighting Groups

Appendix D. Inventory Matrices for the Residential Sector

Appendix E. Inventory Matrices for the Commercial Sector

Appendix F. Inventory Matrices for the Industrial Sector

Appendix G. Inventory Matrices for the Outdoor Stationary Sector

Appendix H. XenCAP™ Statistical Analysis of Residential Sector Update   *

Appendix I. XenCAP™ Statistical Analysis of Commercial Sector Update   *

Appendix J. XenCAP™ Statistical Analysis of Industrial Sector Update   *

* Appendices H, I and J appear in a separate report, U.S. Lighting Market CharacterizationVolume I — National Lighting Inventory and Energy Consumption Estimate, Appendices H, I and J.

Appendix A. Technology Tables and Assumptions

Table A-1. Approximate Properties of Lighting Technologies Considered

Lamp Type	Available Wattage	Efficacy (lm/W)	CRI	CCT (K)	Life (1000 hrs)
Incandescent					
Standard - General Service	15-250	10-19	97	2,500-3,000	0.75 - 2.5
Standard - Reflector	30-120	8-12	97	2,500-3,000	2
Halogen - General Service	42-150	14-20	99	3,000	2 - 3.5
Quartz Halogen	35-150	11-17	99	2,800-3,000	2 - 5
Halogen - refl. - low volt	15-73	7-10	99		4
Low wattage (less than 25W)	3-25	3-17	99		0.2 - 9
Misc incandescent	0.5 - 37.5		99		0 - 3
Fluorescent					
T5	4-13	25-55	52-75	3,000-6,500	6 - 7.5
T8 – less than 4'	17-30	35-82	60-90	3,000-6,500	15 - 20
T8 – 4'	32	78-87	70-90	3,000-5,000	15 - 20
T8 – More than 4'	35-86	78-87	52-84	3,000-4,100	7.5 - 20
T8 – U-bent	32	80-82	75-84	3,000-4,100	20
T12 – less than 4'	14-55	35-75	52-90	3,000-6,500	7.5 - 18
T12 – 4'	32, 34, 40	60-75	50-90	3,000-7,500	20
T12 – More than 4'	50-220	45-92	60-92	3,000-6,500	9 - 20
T12 – U-bent	34-40	48-74	52-82	3,000-6,500	10 - 20
Compact – Pin-base	5-50	42-77	82	2,700-6,500	10 - 20
Compact – Screw-in	5-55	40-70	82	2,700-5,000	10
Compact – Pin-base – reflector					
Compact – Screw-in – reflector					
Circline	20-40	29-50	60-85	3,000-6,500	10 - 12
Induction discharge	55-85	50-56	80+	3,000-4,000	100
Miscellaneous fluorescent					
HID					
Mercury vapor	40-1000	25-50	15-50	4,000-7,000	29
Metal halide	36-1650	50-115	65-70	3,000-4,400	3 - 20
High pressure sodium	35-1000	50-124	22	1,900-2,200	29
Low pressure sodium	18-180	75-150	0	1,700-1,800	18
Xenon					
Electrodeless (e.g. mercury)					
Solid State					
LED	2-25	3-30	0		
Electroluminescent					
Total					

Table A-2. Ballast Prevalence in Fluorescent Lamps in XenCAP™

	Magnetic			Hybrid	Electronic		
	Standard	High Eff.	T8		Standard	T8 Full Output	T8 Reduced Output
T8	8%	1%	29%	0%	0%	62%	1%
T12	91%	7%	0%	0%	1%	0%	0%
Both	89%	7%	1%	0%	1%	2%	0%

Table A-3. Efficacy Assumptions Used to Calculate National Lumen Production

	Residential		Commercial		Industrial	
Lighting Technology	Wattage	efficacy	Wattage	efficacy	Wattage	efficacy
Standard - General Service	63	15	83	16	126	17
Standard - Reflector	102	9	104	9	102	9
Halogen - General Service	200	18	64	15	-	15
Halogen – Double Ended	205	19	226	20	452	20
Halogen - refl. - low volt	-	-	48	11	58	11
Low wattage (<25W)	-	-	15	9	19	9
Misc incandescent	-	-	-	13	-	13
T5	-	-	8	50	10	50
T8 – less than 4'	-	-	23	82	23	82
T8 – 4'	-	-	33	85	31	85
T8 – More than 4'	-	-	50	88	53	88
T8 – U-bent	-	-	34	74	32	74
T12 – less than 4'	-	-	29	63	32	63
T12 – 4'	-	-	45	74	44	74
T12 – More than 4'	-	-	93	79	95	79
T12 – U-bent	-	-	46	69	46	69
Compact Plug-in	-	60	17	60	31	60
Compact Screw base	18	55	16	55	14	55
Compact Plug-in – reflector	-	55	16	55	-	55
Compact Screw base – reflector	11	55	16	55	14	55
Circline	-	58	30	58	35	58
Induction discharge	-	53	-	53	-	53
Miscellaneous fluorescent	41	60	18	60	34	60
Mercury vapor	179	40	331	40	409	46
Metal halide	-	65	472	65	438	65
High pressure sodium	79	80	260	104	394	112
Low pressure sodium	-	-	104	140	90	140
Xenon	-	-	-	40	-	40
Electrodeless (e.g. mercury)	-	-	-	150	-	150
LED	-	-	6	20	6	20
Electroluminescent	-	-	2	10	2	10

Appendix B. TPU Housing Characteristics

The following plots provide additional detail about the TPU database, which was used in the Residential Energy Consumption estimates in this study.
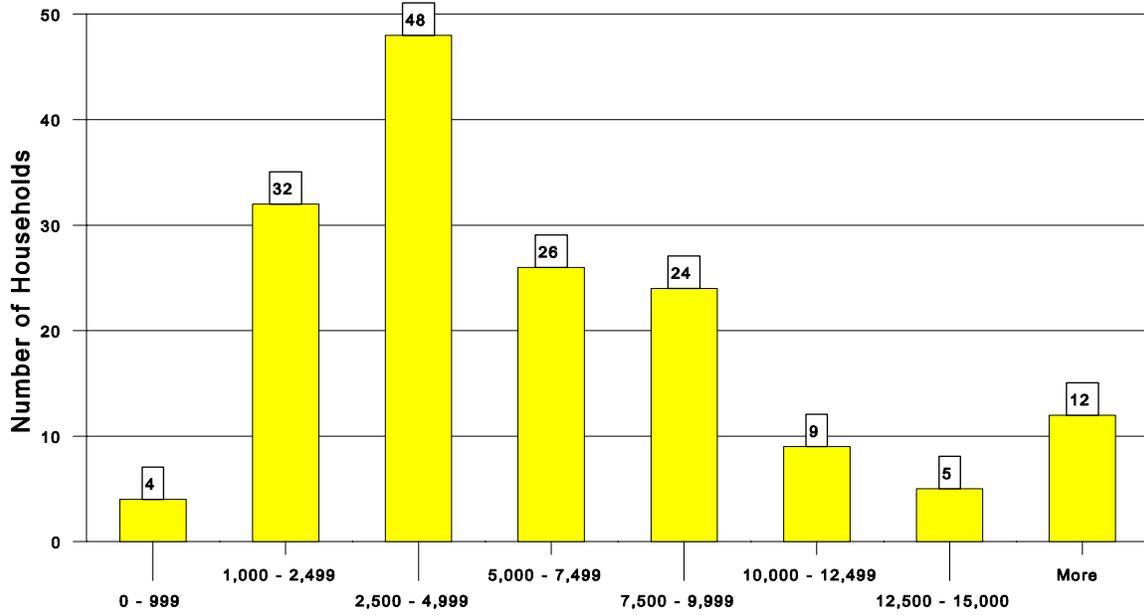
Figure B-1. Annual Household Lighting Electricity Use in the TPU Residential Sample (kWh/yr)
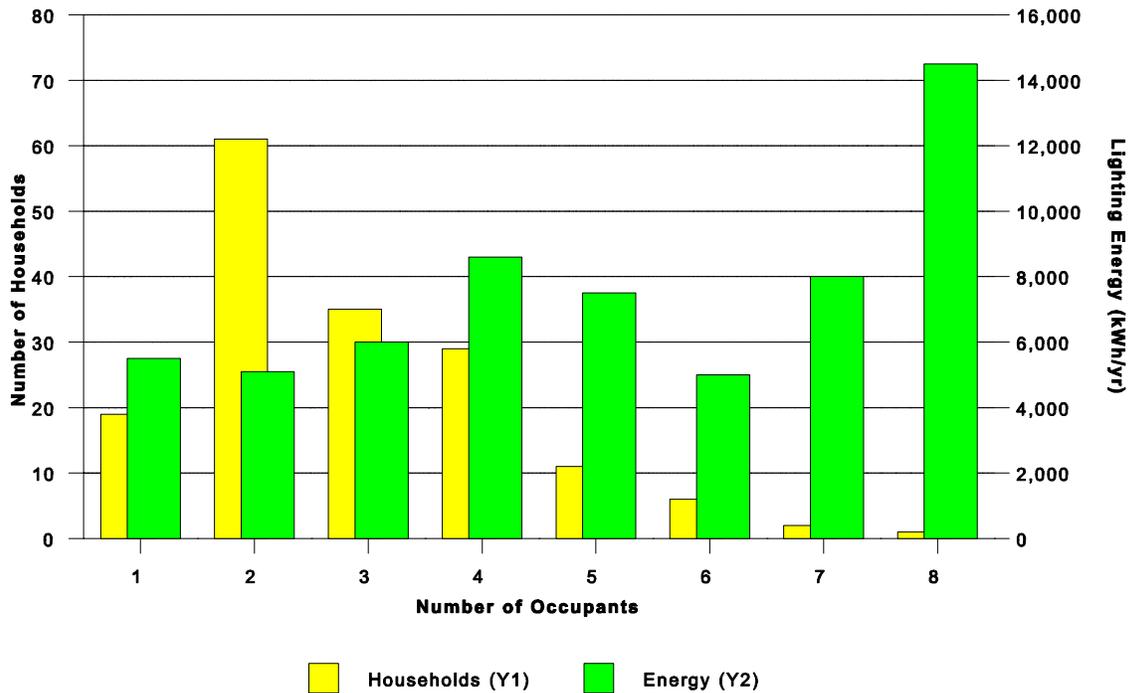
Figure B-2. Composition of TPU Residential Sample by Number of Occupants
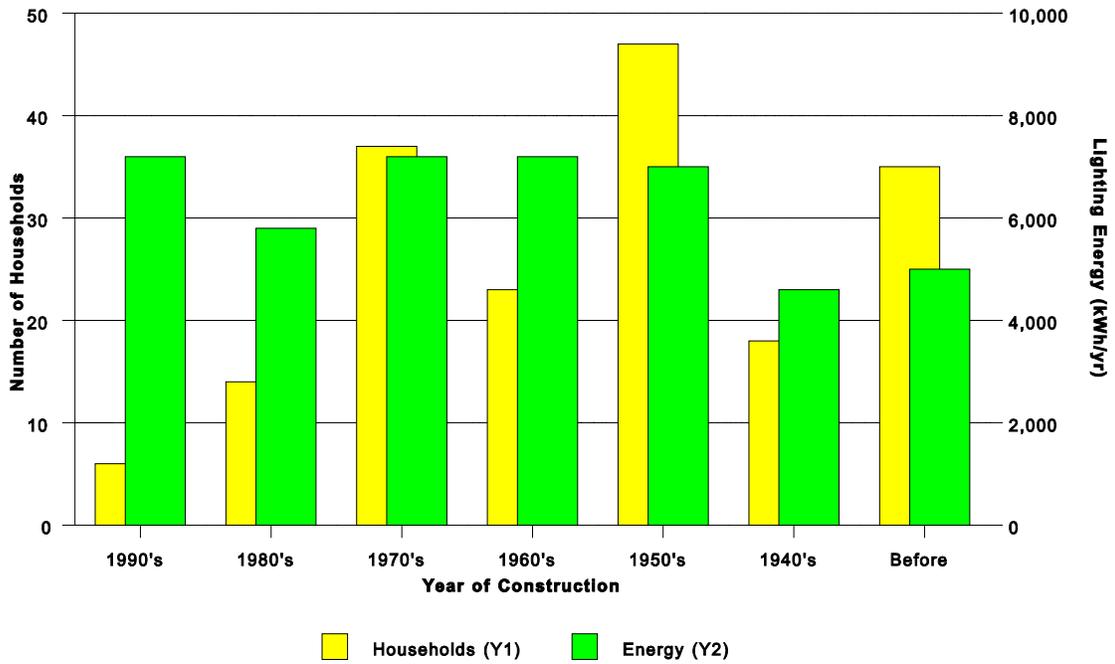
Figure B-3. Composition of TPU Residential Sample by Year of Construction
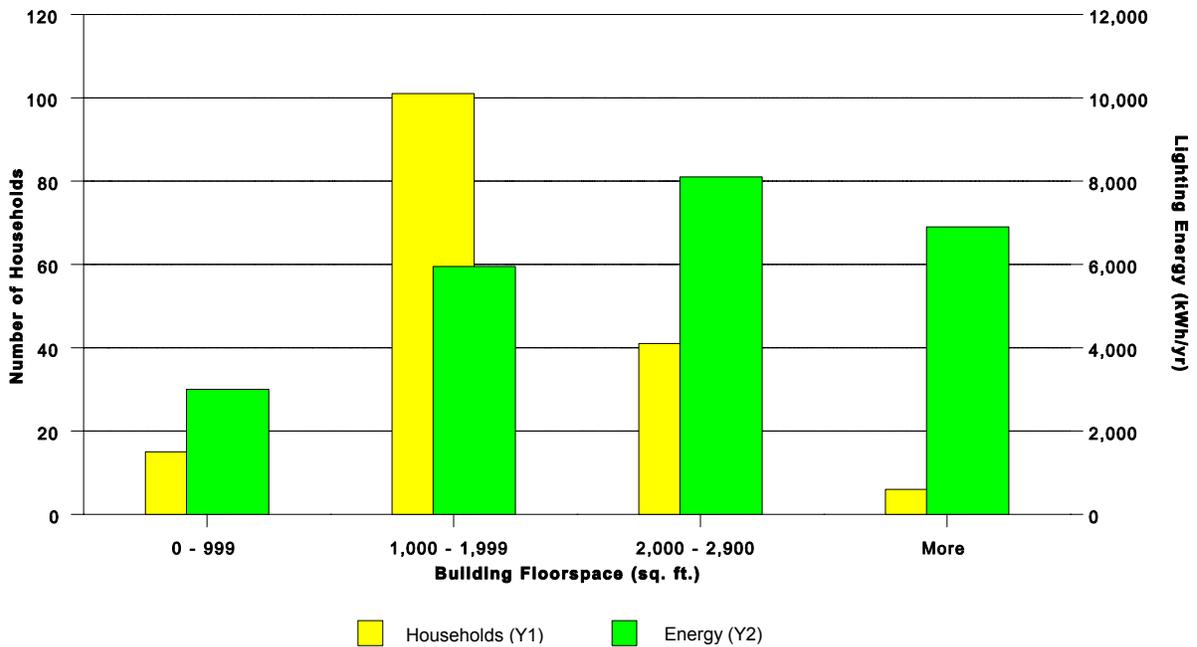
Figure B-4. Composition of TPU Residential Sample by Unit Floorspace

Appendix C.

Appendix C. Examples of tables of information extracted from XenCAP™

The data extracted from XenCAP™ consisted of three tables of information:
*   *Facility Table* - contains information about the site including size (sq. ft.), location, facility type, SIC code, and date of the audit.
*   *Lighting Group Table* - contains information about each cluster of related lighting fixtures within the facility, grouped together based on location and operation. The table contains a description of the group and the operating hours. There are usually multiple entries for each facility.
*   *Lighting Technology Table* - contains information about the specific lighting equipment within each lighting group. The lighting data includes fixture type, number of fixtures, number of lamps, and ballast type. There may be several entries for each lighting group.

Table C.1 Example of a Facility Table from XenCAP™ Database

AudNo	Address	Zip	SICCode	FacilTyp	FloorArea	DateVisit	OpHrs	NoEmpl	Utility
15372S	Staten Island, NY	10305	0000	6	5300	27-Aug-96	79	8	6
15373M	New York, NY	10010	0000	1	9700	28-Aug-96	60	25	6
15374M	New York, NY	10001	0000	4	5200	28-Aug-96	80	15	6
15375Q	Ozone Park, NY	11416	0000	1	9000	27-Aug-96	78	30	6
15376M	New York, NY	10029	0000	16	2268	4-Sep-96	15	10	6
15378W	Pleasantville	10570	0000	6	3000	5-Sep-96	90	7	6
15379M	New York, NY	10014	0000	4	1800	4-Sep-96	84	3	6
15380B	Brooklyn, NY	11237	0000	10	30540	22-Aug-96	58	10	6
15381B	Brooklyn, NY	11211	0000	11	6620	16-Sep-96	144	20	6
15382Q	Long Island City, NY	11101	0000	10	27000	11-Sep-96	60	80	6
15384W	Elmsford, NY	10523	0000	10	70400	5-Sep-96	111	205	6
15385M	New York, NY	10024	0000	6	6600	13-Sep-96	126	30	6
15386X	Bronx, NY	10464	0000	6	5000	10-Sep-96	130	20	6
15387Q	Maspeth, NY	11378	0000	6	1800	13-Sep-96	81	4	6
15388M	New York, NY	10035	0000	11	2420	13-Sep-96	61	25	6
15389Q	Flushing, NY	11354	0000	10	6000	13-Sep-96	84	6	6
15390W	Mount Vernon, NY	10550	0000	6	3200	10-Jul-96	100	10	6
15391Q	Woodside, NY	11377	0000	11	15000	13-Sep-96	40	30	6
15392W	Bronxville, NY	10708	0000	7	7000	11-Sep-96	168	2	6
15393W	Scarsdale, NY	10583	0000	16	3600	11-Sep-96	25	30	6
15394X	Bronx, NY	10454	0000	10	80000	20-Sep-96	80	3	6
15395X	Bronx, NY	10473	0000	10	40000	20-Sep-96	61	5	6
15396X	Bronx, NY	10457	0000	10	10000	20-Sep-96	53	1	6
15397W	New Rochelle, NY	10801	0000	10	20000	20-Sep-96	61	3	6
15398W	Mount Vernon, NY	10550	0000	10	20000	20-Sep-96	66	3	6
15399B	Brooklyn, NY	11201	0000	1	15000	4-Sep-96	60	20	6

Note: SIC Codes have been zeroed out and address information removed to protect identity of facility audited.

Table C.2 Example of a Lighting Group Table from the XenCAP™ Database

AudNo	Light Group	Desc	OpHrs	Utility
15372S	1	Bar	80	6
15372S	2	Entrance	80	6
15372S	3	Mens room	80	6
15372S	4	Ladies room	80	6
15372S	5	Restroom hallwy	80	6
15372S	6	Main room	35	6
15372S	7	Service counter	80	6
15372S	8	Kitchen	80	6
15372S	9	Kitchen prea.a.	80	6
15372S	10	Stairway	80	6
15372S	11	Basement	80	6
15372S	12	Bsmt laundry rm	80	6
15372S	13	Bsmt. restroom	40	6
15372S	14	Outside lights	40	6
15372S	15	Exit signs	168	6
15373M	1	Exit	168	6
15373M	2	Halls	168	6
15373M	3	Halls	65	6
15373M	4	Conference room	40	6
15373M	5	Storage	65	6
15373M	6	Restrooms	50	6
15373M	7	Suite 1015	65	6
15373M	8	Other suites	60	6
15374M	1	Exit	168	6
15374M	2	Reception	80	6
15374M	3	Halls	80	6
15374M	4	Offices	60	6
15374M	5	Storage	30	6
15374M	6	Conference room	40	6
15374M	7	Production area	80	6
15374M	8	Color production	80	6

Appendix C.

Table C.3 Example of a Lighting Technology Table from the XenCAP™ Database

AudNo	Light Group	Lighting Type	Lamps per Fixture	Lamp code	Qty	Pct High Efficiency Lamps	Present Ballast Type	Utility
15372S	1	I	3	15	8			6
15372S	2	I	1	40	2			6
15372S	2	I	1	40	6			6
15372S	3	I	1	60	3			6
15372S	4	I	1	60	6			6
15372S	5	F	1	17	1			6
15372S	5	F	1	19	1			6
15372S	6	I	1	40	16			6
15372S	6	I	6	40	4			6
15372S	7	I	1	25	2			6
15372S	7	I	1	60	1			6
15372S	7	F	1	12	1			6
15372S	8	F	4	3	1	100	1	6
15372S	9	F	4	1	2		1	6
15372S	9	F	2	1	1		1	6
15372S	10	F	1	13	1		1	6
15372S	11	I	1	60	3			6
15372S	12	F	2	1	2		1	6
15372S	13	I	1	60	1			6
15372S	14	MH	1	100	2			6
15372S	14	I	1	100	1			6
15372S	14	I	1	60	4			6
15372S	14	IS	2	150	1			6
15372S	15	I	2	15	3			6
15373M	1	I	2	20	4			6
15373M	2	F	4	1	3		1	6
15373M	3	F	4	1	3		1	6
15373M	3	F	2	1	1		1	6
15373M	3	F	4	3	2		1	6
15373M	3	I	1	60	2			6
15373M	3	MH	1	150	2			6
15373M	3	Q	1	4	4			6

Appendix D. Inventory Matrices for the Residential Sector

This Appendix provides the data from the Lighting Market Characterization, Phase I that was used to generate the estimates of energy consumption in the Residential Sector.

Table D-1. Number of Households for the Residential Sector

	Mobile Home	Single Family Detached	Single Family Attached	Multifamily 2-4 Units	Multifamily >4 Units
Number	6,806,000	63,099,000	10,591,000	9,490,000	17,003,000

Source: RECS, 2001

Table D-2. Average lamps per household for the Residential Sector

Building Type	Mobile Home	Single Family Detached	Single Family Attached	Multifamily 2-4 Units	Multifamily >4 Units
Bathroom	5.38	6.88	6.06	4.05	4.31
Bedroom	7.74	9.94	7.43	5.74	4.69
Closet	0.65	0.77	0.68	0.58	0.59
Dining Room	0.50	1.23	0.95	0.67	0.43
Family Room	0.61	2.38	0.96	0.36	0.13
Garage	1.30	4.23	2.42	0.00	0.00
Hall	4.42	5.12	4.70	3.72	3.83
Kitchen	5.14	5.11	5.14	4.91	4.87
Living Room	6.01	5.97	5.94	6.02	6.00
Office	0.46	1.16	0.75	0.54	0.43
Other	1.88	2.05	1.88	0.00	0.00
Outdoor	3.57	4.06	3.73	0.00	0.00
Utility Room	1.65	1.81	1.40	0.88	0.52
Total per hhld	39.30	50.70	42.04	27.49	25.79

Appendix D.

Table D-3. Number of Lamps by Room-type for the Residential Sector

	Mobile Home	Single Family Detached	Single Family Attached	Multifamily 2-4 Units	Multifamily >4 Units	Total
Bathroom	36,617,857	434,002,906	64,227,443	38,464,990	73,305,796	646,618,991
Bedroom	52,669,576	627,177,520	78,644,774	54,473,798	79,759,677	892,725,346
Closet	4,439,432	48,302,109	7,171,999	5,551,639	9,959,537	75,424,716
Dining Room	3,425,922	77,578,827	10,108,244	6,316,809	7,309,296	104,739,098
Family Room	4,160,922	150,137,826	10,183,334	3,404,712	2,236,188	170,122,982
Garage	8,814,762	267,035,734	25,666,515	-	-	301,517,010
Hall	30,053,656	322,909,621	49,803,292	35,346,727	65,083,481	503,196,778
Kitchen	34,977,887	322,473,072	54,404,859	46,615,142	82,738,315	541,209,275
Living Room	40,915,618	376,648,436	62,942,144	57,137,190	101,986,948	639,630,335
Office	3,099,757	73,489,159	7,920,932	5,165,261	7,310,996	96,986,105
Other	12,786,713	129,053,064	19,928,003	-	-	161,767,781
Outdoor	24,314,406	256,117,677	39,481,650	-	-	319,913,733
Utility Room	11,204,308	114,389,898	14,800,665	8,397,664	8,854,307	157,646,842
Total	267,480,814	3,199,315,848	445,283,855	260,873,933	438,544,540	4,611,498,991

Table D-4. Annual hours of operation by room-type by home for the Residential Sector

	Mobile Home	Single Family Detached	Single Family Attached	Multifamily 2-4 Units	Multifamily >4 Units
Bathroom	603	669	617	647	577
Bedroom	403	406	408	442	423
Closet	314	513	382	264	183
Dining Room	888	829	885	1,088	1,080
Family Room	626	772	676	441	453
Garage	667	720	665	0	0
Hall	519	616	542	462	414
Kitchen	994	1,210	1,089	921	888
Living Room	948	864	921	1,040	1,015
Office	385	708	676	435	401
Other	267	435	299	0	0
Outdoor	981	1,027	989	0	0
Utility Room	487	888	673	448	370

Appendix D.

Table D-5. Percent occurrences by room type for the Residential Sector

	Bathroom	Bedroom	Closet	Dining Room	Family Room	Garage	Hall	Kitchen	Living Room	Office	Other	Outdoor	Utility Room
Standard - General Service	0.892	0.946	0.935	0.947	0.754	0.442	0.942	0.525	0.901	0.740	0.487	0.616	0.752
Standard - Reflector	0.057	0.012	0.029	0.030	0.052	0.005	0.037	0.084	0.039	0.057	0.006	0.315	0.019
Halogen - General Service	-	0.004	-	0.002	0.006	-	0.002	0.003	0.009	0.007	-	0.013	-
Halogen – Quartz	-	-	-	0.001	0.005	0.002	0.001	-	0.003	0.006	0.002	0.027	-
Halogen - refl. - low volt	-	-	-	-	-	-	-	-	-	-	-	-	-
Low wattage (< than 25W)	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc incandescent	-	-	-	-	-	-	-	-	-	-	-	-	-
T5	-	-	-	-	-	-	-	-	-	-	-	-	-
T8 – less than 4'	-	-	-	-	-	-	-	-	-	-	-	-	-
T8 – 4'	-	-	-	-	-	-	-	-	-	-	-	-	-
T8 – More than 4'	-	-	-	-	-	-	-	-	-	-	-	-	-
T8 – U-bent	-	-	-	-	-	-	-	-	-	-	-	-	-
T12 – less than 4'	-	-	-	-	-	-	-	-	-	-	-	-	-
T12 – 4'	-	-	-	-	-	-	-	-	-	-	-	-	-
T12 – More than 4'	-	-	-	-	-	-	-	-	-	-	-	-	-
T12 – U-bent	-	-	-	-	-	-	-	-	-	-	-	-	-
CFL – Plug-in	-	-	-	-	-	-	-	-	-	-	-	-	-
CFL – Screw base	0.006	0.009	0.018	0.007	0.017	0.006	0.006	0.027	0.037	0.024	0.005	0.013	0.046
CFL – Plug-in reflector	-	-	-	-	-	-	-	-	-	-	-	-	-
CFL – Screw base reflector	-	-	-	0.001	-	-	0.001	-	-	-	-	-	-
Circline	-	-	-	-	-	-	-	-	-	-	-	-	-
Induction discharge	-	-	-	-	-	-	-	-	-	-	-	-	-
Miscellaneous fluorescent	0.045	0.029	0.019	0.012	0.167	0.544	0.011	0.362	0.011	0.166	0.500	0.002	0.182
Mercury vapor	-	-	-	-	-	-	-	-	-	-	-	0.010	-
Metal halide	-	-	-	-	-	-	-	-	-	-	-	-	-
High pressure sodium	-	-	-	-	-	-	-	-	-	-	-	0.004	-
Low pressure sodium	-	-	-	-	-	-	-	-	-	-	-	-	-
Xenon	-	-	-	-	-	-	-	-	-	-	-	-	-
Electrodeless (eg. mercury)	-	-	-	-	-	-	-	-	-	-	-	-	-
LED	-	-	-	-	-	-	-	-	-	-	-	-	-
Electroluminescent	-	-	-	-	-	-	-	-	-	-	-	-	-
Row Sum	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Table D-6. Lamp Hours by home and light source for the Residential Sector

	Mobile Home	Single Family Detached	Single Family Attached	Multifamily 2-4 Units	Multifamily >4 Units
Standard-General Service	137,790,185,955	1,746,138,835,677	236,669,078,569	149,881,336,050	241,447,053,446
Standard-Reflector	14,512,940,394	170,076,184,170	24,488,984,093	8,733,324,473	14,543,951,700
Halogen-General Service	918,344,198	10,194,038,322	1,499,556,114	842,481,367	1,405,830,929
Halogen-Quartz	848,671,887	10,085,669,325	1,428,008,521	258,592,236	429,611,276
Halogen-refl.-low volt	-	-	-	-	-
Low wattage (lessthan25W)	-	-	-	-	-
Misc incandescent	-	-	-	-	-
T5	-	-	-	-	-
T8–less than 4'	-	-	-	-	-
T8–4'	-	-	-	-	-
T8–More than 4'	-	-	-	-	-
T8–U-bent	-	-	-	-	-
T12–less than 4'	-	-	-	-	-
T12–4'	-	-	-	-	-
T12–More than 4'	-	-	-	-	-
T12–U-bent	-	-	-	-	-
Compact–Plug-in	-	-	-	-	-
Compact–Screwbase	3,478,406,499	40,889,520,700	5,811,446,689	4,102,814,297	6,783,020,316
Compact–Plug-in–reflector	-	-	-	-	-
Compact–Screwbase–reflector	17,103,705	243,772,767	33,291,605	21,598,984	32,193,733
Circline	-	-	-	-	-
Induction discharge	-	-	-	-	-
Miscellaneous fluorescent	21,444,936,584	348,344,764,730	41,460,514,807	19,582,663,435	32,249,326,283
Mercury vapor	231,320,419	2,552,222,456	378,937,132	-	-
Metal halide	-	-	-	-	-
High pressure sodium	89,727,283	989,986,050	146,986,589	-	-
Low pressure sodium	-	-	-	-	-
Xenon	-	-	-	-	-
Electrodeless (e.g.sulfur)	-	-	-	-	-
LED	-	-	-	-	-
Electroluminescent	-	-	-	-	-
Total	179,331,636,924	2,329,514,994,198	311,916,804,118	183,422,810,843	296,890,987,683

Appendix D.

Table D-7. Average Wattage and Efficacy for the Residential Sector

	Average Wattage	Estimated Efficacy
Standard - General Service	63	15
Standard - Reflector	102	9
Halogen - General Service	200	18
Halogen – Quartz	205	19
Halogen - refl. - low volt	-	-
Low wattage (less than 25W)	-	-
Misc incandescent	-	-
T5	-	-
T8 – less than 4'	-	-
T8 – 4'	-	-
T8 – More than 4'	-	-
T8 – U-bent	-	-
T12 – less than 4'	-	-
T12 – 4'	-	-
T12 – More than 4'	-	-
T12 – U-bent	-	-
Compact – Plug-in	-	60
Compact – Screw base	18	55
Compact – Plug-in – reflector	-	55
Compact – Screw base – reflector	11	55
Circline	-	58
Induction discharge	-	53
Miscellaneous fluorescent	41	60
Mercury vapor	179	40
Metal halide	-	65
High pressure sodium	79	80
Low pressure sodium	-	-
Xenon	-	-
Electrodeless (e.g. mercury)	-	-
LED	-	-
Electroluminescent	-	-

Table D-8. Energy Consumption Estimate for the Residential Sector

	Energy Use by Building Type (Watt-hour)	Number of Buildings	Average per Building (kWh/yr)
Mobile Home	11,499,983,694,082	6,806,164	1,690
Single Family Detached	146,878,349,179,373	63,098,716	2,328
Single Family Attached	19,867,559,000,049	10,591,051	1,876
Multifamily 2-4 Units	11,426,105,726,929	9,490,463	1,204
Multifamily >4 Units	18,498,812,857,877	17,002,880	1,088
Total	208,170,810,458,309	106,989,274	1,946

Appendix E. Inventory Matrices for the Commercial Sector

This Appendix provides the data from the Lighting Market Characterization, Phase I that was used to generate the estimates of energy consumption in the Commercial Sector.

Table E-1. Commercial building types and Area

	Average Square Feet	Number of Buildings	Total Square Feet
01 Vacant	7,554	252,577	1,908,045,611
02 Office/Professional	16,303	738,743	12,044,031,679
04 Laboratory	15,767	26,842	423,211,050
05 Warehouse (non-refrigerated.)	16,284	589,601	9,600,989,844
06 Food sales	5,714	174,029	994,453,090
07 Public order/safety	16,191	72,163	1,168,414,664
08 Health care (outpatient)	9,067	116,085	1,052,504,333
11 Warehouse (refrigerated.)	63,850	13,713	875,547,324
12 Religious worship	11,084	307,216	3,405,192,189
13 Public assembly	14,397	305,152	4,393,215,580
14 Education	26,430	327,314	8,650,756,940
15 Food service	5,305	349,025	1,851,474,623
16 Health care (inpatient)	168,174	11,090	1,865,116,689
17 Skilled nursing	26,875	25,398	682,577,129
18 Hotel/Motel/Dorm	30,069	127,640	3,838,066,239
23 Strip shopping	30,229	130,659	3,949,747,948
24 Enclosed shopping center/mall	606,771	2,771	1,681,392,533
25 Retail (excluding mall)	8,933	533,588	4,766,495,475
26 Service (excluding food)	7,085	478,210	3,388,247,305
91 Other	10,651	74,955	798,321,375
Row Sum		4,656,772	67,337,801,619

Appendix E.

Table E-2. Application Area by Building Type (sq. ft.) for the Commercial Sector

	Assembly	Athletic	Bathroom	Boarding	Class	Dining	Display	Exit	Exit-Archi	Exit-Park	Exit-Sign	Exterior	Food Prep	Hall	Healthcare	Office	Ship / Rec	Shop	Storage	Task	Unknown	Utility
01 Vacant	83	49	87	33	105	78	118	34	159	103	10	363	32	569	129	3917	18	207	346	30	852	233
02 Office/ Professional	317	45	848	133	144	359	194	16303	16303	16303	16303	16303	44	4011	163	5431	35	379	1556	36	1086	1521
04 Laboratory	447	53	524	480	285	393	114	15767	15767	15767	15767	15767	95	5510	2396	1158	16	231	1464	52	1403	1146
05 Warehouse non-refrigerated	346	111	540	51	85	449	227	16284	16284	16284	16284	16284	35	1584	25	1347	178	1070	8325	46	979	884
06 Food sales	278	2	127	21	17	134	1853	5714	5714	5714	5714	5714	319	748	3	131	28	170	1516	10	145	214
07 Public order/safety	693	82	1972	5392	236	641	22	16191	16191	16191	16191	16191	220	4226	18	392	1	225	781	96	432	761
08 Health care (outpatient)	215	33	539	74	107	233	157	9067	9067	9067	9067	9067	29	2386	101	2669	17	224	1004	21	462	794
11 Warehouse (refrigerated.)	811	248	1376	162	175	1504	1628	63850	63850	63850	63850	63850	140	5777	132	4485	904	2412	33086	71	6509	4430
12 Religious worship	4194	36	681	351	930	406	12	11084	11084	11084	11084	11084	150	2365	47	412	1	24	927	10	270	265
13 Public assembly	8214	137	682	276	769	380	251	14397	14397	14397	14397	14397	142	1767	53	441	7	73	557	21	284	344
14 Education	2005	581	1619	387	6304	2003	85	26430	26430	26430	26430	26430	162	8942	238	1072	5	241	716	164	697	1210
15 Food service	181	13	715	24	10	1932	54	5305	5305	5305	5305	5305	608	685	4	87	2	30	717	8	129	106
16 Health care (inpatient)	3726	285	3078	5197	890	4150	685	168174	168174	168174	168174	168174	1047	55085	25615	9793	126	1448	9586	215	23192	24056
17 Skilled nursing	1534	15	2022	3846	129	2120	50	26875	26875	26875	26875	26875	397	10879	1265	1050	2	164	1323	18	619	1440
18 Hotel/ Motel/Dorm	1437	139	3506	10141	426	1119	47	30069	30069	30069	30069	30069	373	7978	35	799	4	341	1213	134	927	1452
23 Strip shopping	1194	52	995	130	422	814	8165	30229	30229	30229	30229	30229	68	5275	64	1464	156	2052	6040	240	1503	1595
24 Enclosed shopping center/mall	8718	188	29262	979	2274	37071	117772	606771	606771	606771	606771	606771	311	146966	1128	16312	1037	49749	72332	2157	46372	74143
25 Retail (excluding mall)	350	17	290	34	114	210	2494	8933	8933	8933	8933	8933	23	1463	19	468	27	807	1857	62	298	401
26 Service (excl. food)	360	108	455	90	93	370	585	7085	7085	7085	7085	7085	50	1339	91	601	51	1000	1107	12	341	435
91 Other	613	70	584	383	496	528	574	10651	10651	10651	10651	10651	115	2380	139	1401	34	361	1689	31	559	694
Total	35715	2262	49901	28184	14011	54893	135087	1089213	1089337	1089281	1089188	1089541	4360	269936	31667	53432	2650	61208	146140	3433	87059	116126

Table E-3. Annual Operating Hours by Building Type and Application for the Commercial Sector

	Assembly	Athletic	Bathroom	Boarding	Class	Dining	Display	Exit	Ext-Archi	Ext-Park	Ext-Sign	Exterior	Food Prep	Hall	Healthcare	Office	Ship / Rec	Shop	Storage	Task	Unknown	Utility
01 Vacant	2,692	3,868	3,280	3,054	2,621	3,251	3,829	8,619	3,883	3,827	3,907	3,674	2,956	4,492	3,584	3,522	4,538	3,455	3,265	3,304	3,773	4,449
02 Office/Professional	2,468	3,860	3,432	3,296	2,824	3,379	3,611	8,649	4,003	3,933	4,295	3,921	2,758	4,814	3,435	3,580	4,364	3,743	3,123	2,908	3,828	4,442
04 Laboratory	4,018	3,747	3,620	3,061	3,349	5,320	4,061	8,700	3,648	4,352	4,604	4,371	4,503	6,268	5,822	3,360	4,852	5,624	4,233	3,519	5,363	5,264
05 Warehouse (non-refrigerated.)	3,186	3,698	3,206	2,503	2,792	3,276	3,373	8,612	3,639	3,823	3,782	3,855	3,270	3,602	2,995	3,054	4,113	3,318	3,627	3,193	3,466	4,013
06 Food sales	6,319	4,585	3,455	4,980	3,640	4,569	5,472	8,633	3,208	3,802	3,432	3,809	5,074	5,539	5,032	3,345	5,544	5,334	5,090	6,754	5,032	6,403
07 Public order/safety	2,911	3,421	2,262	2,443	2,523	3,524	2,925	8,651	3,792	3,978	4,611	3,988	3,612	6,872	2,587	3,510	6,492	4,352	2,954	1,732	3,419	3,744
08 Health care (outpatient)	2,303	3,816	2,973	2,745	2,723	3,220	3,536	8,633	3,736	3,810	3,885	3,874	2,592	4,344	3,015	3,196	3,482	3,320	2,864	2,704	3,354	4,003
11 Warehouse (refrigerated.)	3,285	3,697	3,492	2,836	3,081	3,130	3,337	8,645	3,608	3,462	3,680	3,773	4,692	4,007	2,120	3,755	3,842	3,500	4,073	3,242	3,751	4,428
12 Religious worship	1,123	1,955	1,401	1,696	1,767	1,654	878	8,492	3,113	2,983	2,688	2,895	1,513	2,106	1,282	1,998	827	1,301	1,337	2,088	1,742	1,886
13 Public assembly	2,119	3,735	2,474	2,493	1,893	2,553	5,071	8,558	2,704	3,125	2,965	3,557	2,558	3,234	2,081	2,524	5,294	2,742	2,681	5,817	2,812	2,891
14 Education	1,989	2,778	2,726	2,970	2,311	2,384	2,593	8,666	4,130	3,764	3,653	2,882	2,196	3,768	2,541	2,870	3,421	2,569	2,283	4,228	2,901	2,848
15 Food service	2,745	4,541	4,268	2,532	3,196	4,639	4,932	8,609	3,463	3,432	3,544	3,515	5,163	4,368	3,144	3,638	4,168	3,924	4,382	4,898	4,206	4,254
16 Health care (inpatient)	4,892	4,018	4,605	3,630	3,569	5,778	4,751	8,667	5,025	4,993	5,010	5,708	5,661	7,437	6,029	3,644	6,165	5,005	4,807	3,622	6,190	7,003
17 Skilled nursing	3,248	3,954	2,882	2,913	3,147	3,958	1,763	8,662	4,665	4,117	3,860	4,606	4,351	6,862	3,838	3,176	5,078	3,460	3,469	1,933	5,297	5,824
18 Hotel/Motel/Dorm	3,258	3,612	2,414	2,605	2,612	3,729	3,236	8,653	4,090	4,136	4,611	3,970	4,065	7,204	2,644	3,349	6,926	4,830	3,348	1,677	3,618	4,250
23 Strip shopping	3,804	4,754	3,776	3,805	3,505	3,530	4,177	8,529	3,127	3,784	3,475	3,208	3,745	4,580	3,663	3,397	5,059	3,514	3,949	3,780	4,196	4,808
24 Enclosed shopping center/mall	3,226	4,464	6,669	4,404	3,163	2,253	5,223	8,435	3,483	4,514	3,606	3,980	3,891	6,291	6,744	3,767	4,788	4,224	4,950	4,590	5,679	4,570
25 Retail (excl. mall)	3,727	4,375	3,016	3,321	3,272	3,338	3,872	8,551	3,296	3,594	3,300	3,189	3,513	4,016	3,511	3,255	4,150	3,276	3,433	3,524	3,830	4,818
26 Service (excl. food)	2,785	4,500	3,218	2,193	2,790	3,229	3,562	8,569	4,395	3,690	3,407	3,556	2,958	3,452	3,307	2,890	5,115	3,424	3,284	2,644	3,219	4,201
91 Other	2,214	3,397	3,154	2,784	2,333	3,530	4,278	8,627	3,907	3,870	3,999	3,783	4,249	4,754	4,491	3,525	4,361	3,554	3,602	3,423	3,970	4,571
Average	2,133	3,426	3,033	2,611	2,339	3,380	4,130	8,606	3,745	3,804	3,739	3,603	3,726	4,542	4,246	3,344	4,417	3,474	3,506	3,457	3,812	4,305

Appendix E.

Table E-4. Number of Lamps per Square Foot of Commercial Building Space

	Assembly	Athletic	Bathroom	Boarding	Class	Dining	Display	Exit	Ext-Archi	Ext-Park	Ext-Sign	Exterior	Food Prep	Hall	Healthcare	Office	Ship / Rec	Shop	Storage	Task	Unknown	Utility
Inc. General Service	0.002	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.005	0.000	0.000	0.000	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Inc. Reflector	0.008	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.027	0.000	0.001	0.000	0.032	0.004	0.001	0.001	0.001	0.000	0.000	0.001	0.000
Hal. - General Service	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.001	0.002	0.000	0.000	0.001	0.001	0.000	0.000	0.000	0.000
Hal. - Quartz	0.009	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000	0.001	0.005	0.000	0.000	0.001	0.001	0.000	0.000	0.000	0.000
Hal. - refl. - low volt	0.004	0.001	0.000	0.001	0.005	0.001	0.000	0.000	0.000	0.006	0.000	0.000	0.000	0.040	0.003	0.001	0.000	0.000	0.000	0.000	0.001	0.000
Inc. Low watt (<25W)	0.005	0.004	0.000	0.001	0.005	0.000	0.000	0.000	0.001	0.000	0.000	0.002	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Misc incandescent	0.001	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.029	0.000	0.000	0.000	0.009	0.005	0.001	0.000	0.001	0.000	0.000	0.000	0.000
T5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
T8 – < than 4'	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
T8 – 4'	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
T8 – > than 4'	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
T8 – U-bent	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
T12 – < than 4'	0.004	0.001	0.000	0.000	0.000	0.001	0.000	0.000	0.002	0.033	0.000	0.001	0.000	0.019	0.003	0.001	0.001	0.000	0.000	0.000	0.000	0.000
T12 – 4'	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.004	0.000	0.001	0.003	0.000	0.000	0.000	0.000	0.000
T12 – > than 4'	0.010	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.000	0.000	0.002	0.036	0.001	0.001	0.001	0.002	0.000	0.000	0.001	0.000
T12 – U-bent	0.010	0.001	0.000	0.004	0.000	0.001	0.000	0.000	0.000	0.010	0.000	0.000	0.000	0.027	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000
CFL – Plug-in	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.020	0.000	0.000	0.000	0.003	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CFL – Screw base	0.003	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.014	0.000	0.000	0.000	0.011	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CFL Plug-in – reflector	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.002	0.004	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CFL Screw base – refl.	0.025	0.019	0.000	0.000	0.000	0.000	0.000	0.000	0.030	0.023	0.000	0.000	0.000	0.002	0.001	0.000	0.000	0.005	0.000	0.000	0.000	0.000
Circline	0.012	0.003	0.000	0.000	0.001	0.001	0.000	0.001	0.001	0.014	0.000	0.000	0.000	0.016	0.001	0.001	0.019	0.007	0.000	0.001	0.004	0.000
Induction discharge	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Misc. fluorescent	0.002	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.005	0.000	0.000	0.000	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mercury vapor	0.008	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.027	0.000	0.001	0.000	0.032	0.004	0.001	0.001	0.001	0.000	0.000	0.001	0.000
Metal halide	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.001	0.002	0.000	0.000	0.001	0.001	0.000	0.000	0.000	0.000
High press. sodium	0.009	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000	0.001	0.005	0.000	0.000	0.001	0.001	0.000	0.000	0.000	0.000
Low press. sodium	0.004	0.001	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.006	0.000	0.000	0.000	0.040	0.003	0.001	0.001	0.001	0.000	0.000	0.001	0.000
Xenon	0.005	0.004	0.000	0.001	0.005	0.001	0.000	0.000	0.001	0.000	0.000	0.002	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000
Electrodeless	0.001	0.003	0.000	0.001	0.005	0.000	0.000	0.000	0.001	0.029	0.000	0.002	0.000	0.009	0.005	0.001	0.000	0.001	0.000	0.000	0.000	0.000
LED	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Electroluminescent	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Appendix E.

Table E-5. Commercial Building Lamp Characteristics

Type	Wattage	Efficacy
Standard - General Service	83	16
Standard - Reflector	104	9
Halogen - General Service	64	15
Halogen – Quartz	226	20
Halogen - refl. - low volt	48	11
Low wattage (less than 25W)	15	9
Misc incandescent	0	13
T5	8	50
T8 – less than 4'	23	82
T8 – 4'	33	85
T8 – More than 4'	50	88
T8 – U-bent	34	74
T12 – less than 4'	29	63
T12 – 4'	45	74
T12 – More than 4'	93	79
T12 – U-bent	46	69
Compact – Plug-in	17	60
Compact – Screw base	16	55
Compact – Plug-in – reflector	16	55
Compact – Screw base – reflector	16	55
Circline	30	58
Induction discharge	0	53
Miscellaneous fluorescent	18	60
Mercury vapor	331	40
Metal halide	472	65
High pressure sodium	260	104
Low pressure sodium	104	140
Xenon	0	40
Electrodeless (e.g. mercury)	0	150
LED	6	20
Electroluminescent	2	10

Table E-6. Commercial Building Energy Consumption

	Energy Consumption by Building Type (kWh)	Number of Facilities	Total Consumption (TWh)
01 Vacant	56,300,094	252,577	14.22
02 Office/Professional	109,211,533	738,743	80.68
04 Laboratory	130,157,354	26,842	3.49
05 Warehouse (non-refrigerated.)	78,564,789	589,601	46.32
06 Food sales	56,161,313	174,029	9.77
07 Public order/safety	73,030,177	72,163	5.27
08 Health care (outpatient)	52,541,097	116,085	6.10
11 Warehouse (refrigerated.)	340,119,145	13,713	4.66
12 Religious worship	27,468,033	307,216	8.44
13 Public assembly	52,237,833	305,152	15.94
14 Education	130,236,394	327,314	42.63
15 Food service	37,220,861	349,025	12.99
16 Health care (inpatient)	1,605,030,201	11,090	17.80
17 Skilled nursing	144,228,615	25,398	3.66
18 Hotel/Motel/Dorm	142,668,617	127,640	18.21
23 Strip shopping	226,343,225	130,659	29.57
24 Enclosed shopping center/mall	4,872,138,817	2,771	13.50
25 Retail (excluding mall)	62,286,175	533,588	33.24
26 Service (excluding food)	40,735,581	478,210	19.48
91 Other	65,039,617	74,955	4.88
Total		4,656,772	390.9

Appendix F. Inventory Matrices for the Industrial Sector

This Appendix provides the data from the Lighting Market Characterization, Phase I that was used to generate the estimates of energy consumption in the Industrial Sector.

Table F-1. Industrial Building Types

Establishment	Average Square Feet	Number of Buildings	Total Square Feet
20 Food and Kindred Products	72,205	18,074	1,305,040,151
21 Tobacco Products	146,622	316	46,368,740
22 Textile Mill Products	201,018	7,151	1,437,477,573
23 Apparel and Other Textile Products	34,501	12,566	433,543,336
24 Lumber and Wood Products	45,796	11,663	534,112,917
25 Furniture and Fixtures	53,683	11,274	605,217,632
26 Paper and Allied Products	156,346	4,676	731,075,766
27 Printing and Publishing	20,606	25,782	531,256,157
28 Chemicals and Allied Products	182,403	8,962	1,634,694,790
29 Petroleum and Coal Products	77,339	1,756	135,806,406
30 Rubber and Miscellaneous Plastics Products	84,717	11,944	1,011,864,626
31 Leather and Leather Products	43,829	995	43,609,358
32 Stone, Clay, and Glass Products	57,946	11,333	656,698,618
33 Primary Metal Industries	201,817	3,830	772,960,259
34 Fabricated Metal Products	37,674	40,743	1,534,939,559
35 Industrial Machinery and Equipment	60,583	19,577	1,186,033,391
36 Electronic and Other Electric Equipment	79,488	9,925	788,917,408
37 Transportation Equipment	161,367	8,380	1,352,255,460
38 Instruments and Related Products	356,695	4,526	1,614,400,665
39 Miscellaneous Manufacturing Industries	36,771	13,630	501,181,915
Total		227,103	16,857,454,725

Appendix F.

Table F-2. Industrial Total Square Footage by Application Area and Building Type (sq. ft.)

Building Type	20 Food and Kindred Products	21 Tobacco Products	22 Textile Mill Products	23 Apparel and Other Textile Products	24 Lumber and Wood Products	25 Furniture and Fixtures	26 Paper and Allied Products	27 Printing and Publishing	28 Chemicals and Allied Products	29 Petroleum and Coal Products	30 Rubber and Miscellaneous Plastics Products	31 Leather and Leather Products	32 Stone, Clay, and Glass Products	33 Primary Metal Industries	34 Fabricated Metal Products	35 Industrial Machinery and Equipment	36 Electronic and Other Electric Equipment	37 Transportation Equipment	38 Instruments and Related Products	39 Miscellaneous Manufacturing Industries
assembly	131	0	0	63	12	0	288	349	83	0	157	0	95	5	25	266	370	234	2815	23
athletic	48	0	0	11	3	43	150	44	115	396	56	0	117	497	13	40	20	423	88	11
bathroom	972	0	4504	1680	570	1583	2589	566	4156	3266	1806	0	562	6475	717	1567	1465	7040	6868	1501
boarding	248	0	0	0	472	86	117	13	0	0	63	135	4	0	10	3	92	626	163	103
class	43	0	1645	0	13	47	295	52	78	1906	90	0	165	5185	111	122	369	408	4405	64
dining	3125	0	2441	786	297	2376	3072	380	3393	2662	2735	16	897	3290	847	1663	2523	4547	8343	1609
display	99	0	2373	348	59	167	121	48	371	8	322	0	80	42	132	143	178	53	1299	75
exit	72205	146622	201018	34501	45796	53683	156346	20606	182403	77339	84717	43829	57946	201817	37674	60583	79488	161367	356695	36771
ext-archi	72205	146622	201018	34501	45796	53683	156346	20606	182403	77339	84717	43829	57946	201817	37674	60583	79488	161367	356695	36771
ext-park	72205	146622	201018	34501	45796	53683	156346	20606	182403	77339	84717	43829	57946	201817	37674	60583	79488	161367	356695	36771
ext-sign	72205	146622	201018	34501	45796	53683	156346	20606	182403	77339	84717	43829	57946	201817	37674	60583	79488	161367	356695	36771
exterior	72205	146622	201018	34501	45796	53683	156346	20606	182403	77339	84717	43829	57946	201817	37674	60583	79488	161367	356695	36771
food prep	577	0	10	22	6	27	110	46	19	301	9	11	12	29	38	17	69	247	845	14
hall	2064	0	7047	1759	1050	5295	11287	2615	14948	15856	2311	13	1255	7913	3046	3914	4407	9636	36943	3008
healthcare	492	11580	954	12	78	17	198	69	16428	2073	489	546	758	1537	197	381	1691	1493	7865	39
office	4594	0	15857	3204	2698	4782	14788	4494	23796	3652	8580	5661	6187	21837	4888	6910	13497	9095	58139	3648
ship/rec	1338	0	4438	238	212	1359	3033	293	5162	893	2159	2213	1389	2213	384	374	858	559	6324	427
shop	20171	48184	60053	11682	28075	15169	40413	3695	30637	3895	23944	34528	16644	80005	12565	18838	23234	100933	56592	10230
storage	20975	86858	38900	9464	2965	8702	43208	2582	37200	4022	28483	0	15458	25215	8412	10660	12183	4394	44742	10192
task	0	0	262	17	73	212	58	3	0	0	45	0	0	395	69	61	98	402	12234	55
unknown	5442	0	29111	4126	4769	7540	8527	2367	25756	4971	4979	1923	2866	20338	1980	7323	4730	7759	44628	3243
utility	11886	0	33409	1090	4443	6278	28094	2989	20263	33438	8488	996	11457	26841	4239	8303	13705	13519	64400	2528
Total	433232	879731	1206106	207008	274773	322096	938078	123634	1094417	464031	508304	262971	347674	1210904	226042	363498	476927	968202	2140169	220623

Appendix F.

Table F-3. Industrial Total Operating Hours by Application Area and Building Type (hrs.)

Building Type	20 Food and Kindred Products	21 Tobacco Products	22 Textile Mill Products	23 Apparel and Other Textile Products	24 Lumber and Wood Products	25 Furniture and Fixtures	26 Paper and Allied Products	27 Printing and Publishing	28 Chemicals and Allied Products	29 Petroleum and Coal Products	30 Rubber and Miscellaneous Plastics Products	31 Leather and Leather Products	32 Stone, Clay, and Glass Products	33 Primary Metal Industries	34 Fabricated Metal Products	35 Industrial Machinery and Equipment	36 Electronic and Other Electric Equipment	37 Transportation Equipment	38 Instruments and Related Products	39 Miscellaneous Manufacturing Industries
assembly	7,485	-	-	520	2,600	-	4,971	2,690	3,262	-	3,709	-	1,043	520	297	4,737	5,727	2,730	2,691	3,405
athletic	6,633	-	6,893	2,928	2,600	3,298	4,650	8,330	3,539	8,736	6,042	-	7,671	6,241	4,453	3,969	4,823	7,701	5,114	2,660
bathroom	5,333	-	5,360	6,787	3,564	3,832	5,106	5,684	5,606	7,476	4,688	-	4,081	7,194	3,517	4,539	3,842	6,599	3,524	2,667
boarding	3,935	-	-	-	2,080	2,860	2,347	2,528	-	-	7,578	1,060	2,496	-	3,380	3,120	2,560	2,395	3,696	4,680
class	5,776	-	2,340	-	7,004	2,617	5,103	3,758	2,760	4,680	5,240	-	3,143	7,483	4,238	5,405	5,307	2,569	3,860	2,835
dining	7,442	-	4,495	3,457	5,282	3,043	5,478	5,401	4,405	7,666	5,984	1,040	5,383	5,286	4,236	4,745	3,955	5,581	3,335	3,959
display	5,132	-	2,329	2,608	2,898	1,331	3,464	4,036	3,366	260	3,884	1,040	3,362	6,620	3,325	3,366	3,091	2,916	2,640	2,230
exit	8,542	-	8,736	8,736	8,736	8,736	8,736	8,502	8,596	8,736	8,736	-	8,736	8,725	8,736	8,734	8,645	8,736	8,736	8,736
ext-archi	6,316	-	-	-	8,612	5,200	3,913	4,086	8,424	-	4,216	-	3,299	8,282	3,952	3,618	5,546	8,469	3,651	4,360
ext-park	4,761	-	3,878	4,282	5,646	4,342	4,218	4,298	4,074	3,850	4,644	4,081	4,317	4,544	4,104	4,204	4,254	4,980	4,151	3,899
ext-sign	4,019	-	4,368	4,004	-	4,368	4,179	8,044	4,210	-	4,146	-	-	5,359	4,260	4,317	3,770	3,891	2,765	2,080
exterior	-	-	2,600	-	2,340	3,639	3,515	4,303	3,900	-	2,600	-	3,996	2,340	4,358	3,640	2,828	-	-	2,963
food prep	5,183	-	2,340	2,360	1,718	2,914	5,026	4,432	3,592	8,382	3,609	1,040	1,926	1,793	2,164	3,632	4,030	4,830	2,290	3,926
hall	5,887	-	3,880	4,094	5,811	4,536	6,540	6,377	4,201	4,834	3,622	2,080	4,214	4,726	6,011	5,051	4,751	6,621	4,971	4,149
healthcare	4,856	4,160	3,717	6,791	3,263	2,953	5,161	5,567	6,888	8,017	4,140	7,540	4,404	7,870	3,165	4,418	4,384	4,684	4,226	5,356
office	3,760	-	2,953	2,692	3,030	2,961	3,949	4,031	3,259	4,135	3,580	2,412	3,230	3,358	3,167	3,254	3,663	3,105	3,543	2,482
ship/rec	6,193	-	4,955	2,867	6,919	2,549	6,867	6,365	4,463	8,736	7,333	-	6,051	7,720	3,529	4,776	3,571	4,699	2,772	3,071
shop	6,429	6,240	4,953	3,546	6,340	4,073	6,018	5,552	4,995	6,310	6,587	4,506	6,385	6,044	4,933	4,844	5,137	7,495	3,083	3,019
storage	6,641	6,240	7,190	5,041	4,802	4,039	6,580	5,088	4,619	7,321	6,022	-	6,319	6,131	4,259	5,720	4,864	3,961	2,775	2,792
task	-	-	6,240	2,710	2,514	3,048	5,647	4,554	-	-	3,622	8,271	1,820	2,405	3,795	4,010	2,931	3,541	6,128	2,670
unknown	5,970	-	5,650	3,926	6,557	4,312	7,218	6,357	5,243	4,112	6,234	8,271	6,187	5,954	3,708	6,777	4,586	3,943	2,792	2,433
utility	7,087	-	6,106	4,101	4,288	3,974	7,263	6,003	6,060	4,496	6,008	5,379	7,355	7,446	3,563	5,401	5,693	4,980	3,911	3,719

Table F-4. Number of Lamps per Square Foot of Industrial Building Space

	Assembly	Athletic	Bathroom	Boarding	Class	Dining	Display	Exit	Ext-Archi	Ext-Park	Ext-Sign	Exterior	Food Prep	Hall	Healthcare	Office	Ship / Rec	Shop	Storage	Task	Unknown	Utility
Inc. General Service	0.001	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000
Inc. Reflector	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.000	0.000
Hal. - General Service	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Hal. - Quartz	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Hal. - refl. - low volt	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Inc. Low watt (<25W)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Misc incandescent	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
T5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
T8 – less than 4'	0.000	0.001	0.000	0.000	0.016	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.023	0.001	0.000
T8 – 4'	0.001	0.098	0.005	0.005	0.004	0.009	0.057	0.000	0.000	0.000	0.000	0.000	0.021	0.006	0.061	0.011	0.002	0.001	0.000	0.000	0.040	0.007
T8 – More than 4'	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000
T8 – U-bent	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.001	0.000
T12 – less than 4'	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
T12 – 4'	0.006	0.039	0.001	0.002	0.010	0.003	0.004	0.000	0.000	0.000	0.000	0.000	0.020	0.001	0.012	0.016	0.006	0.004	0.002	0.007	0.005	0.001
T12 – More than 4'	0.000	0.002	0.000	0.000	0.001	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.001	0.002	0.005	0.008	0.002	0.019	0.002	0.000
T12 – U-bent	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.001	0.000	0.000
CFL – Plug-in	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CFL – Screw base	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CFL Plug-in – reflector	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CFL Screw base – refl.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Circline	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.005	0.000	0.000
Induction discharge	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Miscellaneous fluorescent	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mercury vapor	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Metal halide	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.000	0.000	0.000	0.000
High pressure sodium	0.000	0.000	0.000	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Low pressure sodium	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Xenon	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Electrodeless	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
LED	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Electroluminescent	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Appendix F.

Table F-5. Lamp Properties for Average Industrial Sector Light Sources

Lamp Type	Wattage	efficacy	Watts/lamp
Standard - General Service	126	17	83
Standard - Reflector	102	9	104
Halogen - General Service	0	15	64
Halogen – Quartz	452	20	226
Halogen - refl. - low volt	58	11	48
Low wattage (less than 25W)	19	9	15
Misc incandescent	0	13	0
T5	10	50	8
T8 – less than 4'	23	82	23
T8 – 4'	31	85	33
T8 – More than 4'	53	88	50
T8 – U-bent	32	74	34
T12 – less than 4'	32	63	29
T12 – 4'	44	74	45
T12 – More than 4'	95	79	93
T12 – U-bent	46	69	46
Compact – Plug-in	31	60	17
Compact – Screw base	14	55	16
Compact – Plug-in – reflector	0	55	16
Compact – Screw base – reflector	14	55	0
Circline	35	58	30
Induction discharge	0	53	0
Miscellaneous fluorescent	34	60	18
Mercury vapor	409	46	331
Metal halide	438	65	472
High pressure sodium	394	112	260
Low pressure sodium	90	140	104
Xenon	0	40	0
Electrodeless (e.g. mercury)	0	150	0
LED	6	20	6
Electroluminescent	2	10	2

Table F-6. Industrial Energy Consumption

Industrial Sector	Energy Consumption by Building Type (kWh)	Number of Facilities	Total Energy Consumption (TWh)
20 Food and Kindred Products	490,062,280	18,074	8.86
21 Tobacco Products	941,181,204	316	0.30
22 Textile Mill Products	1,241,737,049	7,151	8.88
23 Apparel and Other Textile Products	161,043,492	12,566	2.02
24 Lumber and Wood Products	413,834,647	11,663	4.83
25 Furniture and Fixtures	260,720,794	11,274	2.94
26 Paper and Allied Products	984,205,306	4,676	4.60
27 Printing and Publishing	132,003,715	25,782	3.40
28 Chemicals and Allied Products	1,245,132,750	8,962	11.16
29 Petroleum and Coal Products	312,578,577	1,756	0.55
30 Rubber and Miscellaneous Plastics Products	569,539,468	11,944	6.80
31 Leather and Leather Products	333,041,991	995	0.33
32 Stone, Clay, and Glass Products	372,954,194	11,333	4.23
33 Primary Metal Industries	1,618,790,325	3,830	6.20
34 Fabricated Metal Products	200,188,985	40,743	8.16
35 Industrial Machinery and Equipment	379,325,170	19,577	7.43
36 Electronic and Other Electric Equipment	465,190,702	9,925	4.62
37 Transportation Equipment	1,604,235,846	8,380	13.44
38 Instruments and Related Products	1,643,372,965	4,526	7.44
39 Miscellaneous Manufacturing Industries	125,423,350	13,630	1.71
Total Energy Consumption		**227,103**	**107.89**

Appendix G. Inventory Matrices for the Outdoor Stationary Sector

This Appendix provides the data that was used to generate the estimates of energy consumption in the Outdoor Stationary Sector.

Table G-1. Outdoor Stationary Installations and Hours

Installations	Hours lighted / year	Estimate of Installions	Hours/year All Installations
Billboard 8	2,680	140,000	375,200,000
Billboard 30	2,680	200,000	536,000,000
Billboard bulletin	2,680	56,000	150,080,000
Traffic Signals	2,677	300,000	803,000,000
Turn Arrows	811	300,000	243,333,333
Pedestrian Signals	2,738	225,000	615,937,500
Approach Systems	2,190	720	1,576,800
Touchdown Lights	2,190	5,000	10,950,000
Centerline Lights	2,190	5,000	10,950,000
Taxiway/Runway Edgelights	2,190	7,500	16,425,000
Street Lighting	4,380	37,850,000	165,783,000,000
Parking Lots	3,650	22,670,000	82,745,500,000

Table G-2. Lamps per Installation for Outdoor Stationary Sources

	Billboard 8	Billboard 30	Billboard bulletin	Traffic Signals	Turn Arrows	Pedestrian Signals	Approach Systems	Touchdown Lights	Centerline Lights	Taxiway/R unway Edgelights	Street lighting	Parking Lots
Standard - General Service	-	-	-	23.8	2.0	7.9	-	-	-	-	4%	6%
Standard - Reflector	-	-	-	-	-	-	48	90	60	35	-	2%
Halogen - General Service	-	-	-	-	-	-	-	-	-	-	-	-
Halogen - Quartz	-	-	-	-	-	-	48	90	60	35	-	5%
Halogen - refl. - low volt	-	-	-	-	-	-	-	-	-	-	-	-
Low wattage (less than 25W)	-	-	-	-	-	-	-	-	-	-	-	-
Misc incandescent	-	-	-	-	-	-	-	-	-	-	-	-
T5	-	-	-	-	-	-	-	-	-	-	-	-
T8 – less than 4'	-	-	-	-	-	-	-	-	-	-	-	-
T8 – 4'	-	-	-	-	-	-	-	-	-	-	-	-
T8 – More than 4'	0.1	0.1	0.2	-	-	-	-	-	-	-	-	-
T8 – U-bent	-	-	-	-	-	-	-	-	-	-	-	-
T12 – less than 4'	-	-	-	-	-	-	-	-	-	-	-	-
T12 – 4'	-	-	-	-	-	-	-	-	-	-	-	-
T12 – More than 4'	0.1	0.1	0.2	-	-	-	-	-	-	-	-	-
T12 – U-bent	-	-	-	-	-	-	-	-	-	-	-	-
Compact – Plug-in	-	-	-	-	-	-	-	-	-	-	-	-
Compact – Screw base	-	-	-	-	-	-	-	-	-	-	-	-
Compact – Plug-in – reflector	-	-	-	-	-	-	-	-	-	-	-	-
Compact – Screw base – reflector	-	-	-	-	-	-	-	-	-	-	-	-
Circline	-	-	-	-	-	-	-	-	-	-	-	-
Induction discharge	-	-	-	-	-	-	-	-	-	-	-	-
Miscellaneous fluorescent	-	-	-	-	-	-	-	-	-	-	2%	4%
Mercury vapor	0.1	0.1	0.2	-	-	-	-	-	-	-	20%	20%
Metal halide	0.8	1.6	2.4	-	-	-	-	-	-	-	5%	10%
High pressure sodium	-	-	-	-	-	-	-	-	-	-	59%	53%
Low pressure sodium	-	-	-	-	-	-	-	-	-	-	10%	-
Xenon	-	-	-	-	-	-	-	-	-	-	-	-
Electrodeless (e.g. sulfur)	-	-	-	-	-	-	-	-	-	-	-	-
LED	-	-	-	0.2	0.0	0.1	-	-	-	-	-	-
Electroluminescent	-	-	-	-	-	-	-	-	-	-	-	-

Table G-3. Operating Hours summed for Outdoor Stationary Sources, all US Installations

	Row Sum	Parking Lots	Street lighting	Taxiway/R unway Edgelights	Centerline Lights	Touchdow n Lights	Approach Systems	Pedestrian Signals	Turn Arrows	Traffic Signals	Billboard bulletin	Billboard 30	Billboard 8
Row Sum		82,745,500,000	165,811,944,928	1,149,750,000	1,314,000,000	1,971,000,000	151,372,800	4,927,500,000	486,666,667	19,272,000,000	450,240,000	1,072,000,000	375,200,000
Standard - General Service		4,964,730,000	6,476,226,185	-	-	-	-	4,878,225,000	481,800,000	19,079,280,000	-	-	-
Standard - Reflector		1,654,910,000	-	574,875,000	657,000,000	985,500,000	75,686,400	-	-	-	-	-	-
Halogen - General Service		-	-	-	-	-	-	-	-	-	-	-	-
Halogen - Quartz		4,137,275,000	-	574,875,000	657,000,000	985,500,000	75,686,400	-	-	-	-	-	-
Halogen - refl. - low volt		-	-	-	-	-	-	-	-	-	-	-	-
Low wattage (less than 25W)		-	-	-	-	-	-	-	-	-	-	-	-
Misc incandescent		-	-	-	-	-	-	-	-	-	-	-	-
T5		-	-	-	-	-	-	-	-	-	-	-	-
T8 – less than 4'		-	-	-	-	-	-	-	-	-	-	-	-
T8 – 4'		-	-	-	-	-	-	-	-	-	-	-	-
T8 – More than 4'		-	-	-	-	-	-	-	-	-	31,516,800	75,040,000	26,264,000
T8 – U-bent		-	-	-	-	-	-	-	-	-	-	-	-
T12 – less than 4'		-	-	-	-	-	-	-	-	-	-	-	-
T12 – 4'		-	-	-	-	-	-	-	-	-	-	-	-
T12 – More than 4'		-	-	-	-	-	-	-	-	-	31,516,800	75,040,000	26,264,000
T12 – U-bent		-	-	-	-	-	-	-	-	-	-	-	-
Compact – Plug-in		-	-	-	-	-	-	-	-	-	-	-	-
Compact – Screw base		-	-	-	-	-	-	-	-	-	-	-	-
Compact – Plug-in – reflector		-	-	-	-	-	-	-	-	-	-	-	-
Compact – Screw base – reflector		-	-	-	-	-	-	-	-	-	-	-	-
Circline		-	-	-	-	-	-	-	-	-	-	-	-
Induction discharge		-	-	-	-	-	-	-	-	-	-	-	-
Miscellaneous fluorescent		3,309,820,000	3,887,433,280	-	-	-	-	-	-	-	-	-	-
Mercury vapor		16,549,100,000	33,156,600,000	-	-	-	-	-	-	-	27,014,400	64,320,000	22,512,000
Metal halide		8,274,550,000	8,289,150,000	-	-	-	-	-	-	-	360,192,000	857,600,000	300,160,000
High pressure sodium		43,855,115,000	97,811,970,000	-	-	-	-	-	-	-	-	-	-
Low pressure sodium		-	16,190,565,463	-	-	-	-	-	-	-	-	-	-
Xenon		-	-	-	-	-	-	-	-	-	-	-	-
Electrodeless (e.g. sulfur)		-	-	-	-	-	-	-	-	-	-	-	-
LED		-	-	-	-	-	-	49,275,000	4,866,667	192,720,000	-	-	-

Table G-4. Assumed Wattages of Outdoor Stationary Lighting Installations

	Billboards	Traffic Signals	Turn Arrows	Pedestrian Signals	Approach Systems	Touchdown Lights	Centerline Lights	Taxiway/Runway Edgelights	Street lighting	Parking Lots
Standard - General Service	-	150	125	125	-	-	-	-	150	83
Standard - Reflector	-	150	125	125	375	60	120	120	-	104
Halogen - General Service	-	-	-	-	-	-	-	-	-	-
Halogen - Quartz	-	-	-	-	375	60	120	120	150	226
Halogen - refl. - low volt	-	-	-	-	-	-	-	-	-	-
Low wattage (less than 25W)	-	-	-	-	-	-	-	-	-	-
Misc incandescent	-	-	-	-	-	-	-	-	-	-
T5	-	-	-	-	-	-	-	-	-	-
T8 – less than 4'	-	-	-	-	-	-	-	-	-	-
T8 – 4'	-	-	-	-	-	-	-	-	-	-
T8 – More than 4'	105	-	-	-	-	-	-	-	-	-
T8 – U-bent	-	-	-	-	-	-	-	-	-	-
T12 – less than 4'	-	-	-	-	-	-	-	-	-	-
T12 – 4'	-	-	-	-	-	-	-	-	-	-
T12 – More than 4'	190	-	-	-	-	-	-	-	-	-
T12 – U-bent	-	-	-	-	-	-	-	-	-	-
Compact – Plug-in	-	-	-	-	-	-	-	-	-	-
Compact – Screw base	-	-	-	-	-	-	-	-	-	-
Compact – Plug-in – reflector	-	-	-	-	-	-	-	-	-	-
Compact – Screw base – reflector	-	-	-	-	-	-	-	-	-	-
Circline	-	-	-	-	-	-	-	-	-	-
Induction discharge	-	-	-	-	-	-	-	-	-	-
Miscellaneous fluorescent	-	-	-	-	-	-	-	-	150	150
Mercury vapor	300	-	-	-	-	-	-	-	182	331
Metal halide	300	-	-	-	-	-	-	-	200	407
High pressure sodium	-	-	-	-	-	-	-	-	192	260
Low pressure sodium	-	-	-	-	-	-	-	-	180	104
Xenon	-	-	-	-	-	-	-	-	-	-
Electrodeless (e.g. sulfur)	-	-	-	-	-	-	-	-	-	-
LED	-	15	10	15	-	-	-	-	-	-

Table G-5. Estimated Outdoor Stationary Energy Use

	watt-hours	TWh
Billboards	104,538,974,400	0.10
Traffic Signals	2,864,782,800,000	2.86
Turn Arrows	60,273,666,667	0.06
Pedestrian Signals	610,517,250,000	0.61
Street lighting	30,957,288,159,502	30.96
Approach Systems	56,764,800,000	0.06
Touchdown Lights	118,260,000,000	0.12
Centerline Lights	157,680,000,000	0.16
Taxiway/ Runway Edgelights	137,970,000,000	0.14
Parking Lots	22,279,373,894,239	22.28
		57.35