Energy Consumption Series

Lighting in Commercial Buildings

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Preface

This report, *Lighting in Commercial Buildings*, inaugurates a new analytic series. Extensive information on sectoral energy consumption is collected by the Energy Information Administration (EIA). Almost all of the information is available in statistical publications and public use diskettes. The EIA has initiated a systematic effort to analyze this information to explain what has been happening in energy consumption and efficiency in the energy-consuming sectors. One component of this effort is that each of the energy consumption statistical publications will attempt to incorporate more analysis of the data presented in these reports. A second component, and perhaps most important, the "Energy Consumption Series" will highlight various analyses of the data and the data developmental activities that have provided insights into understanding issues, energy usage, and efficiency in each sector.

This first publication in this series uses EIA's Commercial Buildings Energy Consumption Survey as a basis for analyzing lighting in commercial buildings. This analysis follows on the work undertaken by the EIA in support of the National Energy Strategy.

Feedback from users is critical for continuing improvements in the energy consumption information EIA provides.

If you have any comments and/or suggestions on this new series, or on this report in particular, please contact Miriam L. Goldberg, Team Leader, Analytic Data Bases at:

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Executive Summary

Lighting represents a substantial fraction of commercial electricity consumption. A wide range of initiatives in the Department of Energy's (DOE) National Energy Strategy have focused on commercial lighting as a potential source of energy conservation. This report provides a statistical profile of commercial lighting, to examine the potential for lighting energy conservation in commercial buildings. The principal conclusion from this analysis is that energy use for lighting could be reduced by as much as a factor of four using currently available technology.

The analysis is based primarily on the Energy Information Administration's (EIA) 1986 Commercial Buildings Energy Consumption Survey (CBECS). The more recent 1989 survey had less detail on lighting, for budget reasons. While changes have occurred in the commercial building stock since 1986, the relationships identified by this analysis are expected to remain generally valid. In addition, the analytic approach developed here can be applied to the data that will be collected in the 1992 CBECS.

Lighting Energy Conservation Potential

Substantial energy savings are possible using more efficient commercial lighting equipment and practice. Estimates of the potential savings depend heavily on assumptions regarding the types of lamps and fixtures to be replaced, the effectiveness of various lighting conservation measures, and how strong a lighting level is to be maintained. The savings estimates under various assumptions span a wide range, from under 30 percent to nearly 80 percent of current use (Figure ES1).

- ***Savings from Compact Fluorescent Lamps:*** *Converting all incandescent bulbs (the typical screw-in type) to compact fluorescent lamps with reflectors is estimated to save close to 30 percent of current (1986) energy use for commercial lighting.*

- ***Savings Without Compact Fluorescent Lamps:*** *Even greater savings can be achieved without using any compact fluorescents, but converting all lamps and fixtures to the most efficient version of the same type (fluorescent, high-intensity discharge, or incandescent), together with lighting control devices.*

- ***Savings from Comprehensive Improvements:*** *Universal replacement of lamps and fixtures by more efficient equivalents, together with lighting controls, could save as much as 72 percent of current commercial lighting energy use. The replacements for this case include the best of the previous two cases. If, in addition, lighting levels are reduced by 25 percent, the total savings could reach nearly 80 percent.*

The savings analysis spans a range of plausible assumptions. Nonetheless, other modifications to equipment and practice could be considered, and other assumptions for the effectiveness of these might be more appropriate. This report presents a framework that allows alternate savings estimates under alternate assumptions.

These savings estimates are based on the use of current commercially available technologies and assume that all lights of a given type are replaced immediately. Actual replacements would, of course, occur over time as the new lighting equipment penetrates the marketplace and associated costs are reduced as the technology improves. Indeed, in all likelihood some of the potential savings have already been achieved, through increased penetration of energy-efficient equipment since the time of the survey the analysis is based on. Thus, the savings estimates are provided only to describe the potential for savings and are not a prediction of the level of savings that will be realized in the marketplace.

Commercial Lighting Energy Profile

The potential for commercial lighting energy conservation is derived from a statistical profile developed in this report of commercial lighting energy. This profile reveals important relationships among lighting energy use and building characteristics including activity, building size, operating hours, and lighting equipment.

- ***Lighting Energy:*** *Energy used for lighting in commercial buildings is on the order of 1 quadrillion Btu, 40 to 50 percent of commercial electricity use for 1986.* On a per floorspace basis, energy use for lighting is estimated to be around 6 kWh per square foot.

- ***Lighting Equipment:*** *Incandescent bulbs serve only 19 percent of the lighted commercial floorspace, but account for 37 percent of commercial lighting energy consumption.* Substantial energy could be saved by converting space lighted by incandescent bulbs to more efficient lighting equipment.

- ***Efficient Equipment:*** *Buildings with greater lighting needs tend to have more efficient equipment.* Higher lighting levels and longer hours represent greater lighting needs.

- ***Building Activity:*** *Health care and lodging buildings account for relatively high proportions of commercial lighting energy use compared to their floorspace (Figure ES2).* Both these buildings types tend to have long hours of use. Health care buildings also have high lighting levels. Lodging buildings tend to have a high proportion of space served by incandescent bulbs, which are relatively inefficient.

Figure ES2. Lighting Service Measures by Selected Building Activity

Note: For each principal building activity, the percents are the estimated amounts for the activity as percentages of the total commercial lighted floorspace (49.59 billion square feet), lighted floorspace-hours (3.5 trillion square foot-hours), and lighting energy (321.4 billion kilowatthours).

Sources: Derived from Energy Information Administration, Office of Energy Markets and End Use, Form EIA-871A, "Building Questionnaire" of the 1986 Nonresidential Buildings Energy Consumption Survey.

- ***Building Size:*** *Larger buildings tend to have higher lighting energy use per square foot (Figure ES3).* The higher energy use is related to longer operating hours and activities associated with higher lighting levels. The effects of longer and stronger lighting use are somewhat mitigated by the use of more efficient equipment in larger buildings.

Figure ES3. Lighting Energy per Square Foot by Building Size Category

Note: • Average quantities for each size category are plotted at a horizontal position corresponding to the average size for buildings in that category.

Source: Derived from Energy Information Administration, Office of Energy Markets and End Use, Form EIA-871A, "Building Questionnaire" of the 1986 Nonresidential Buildings Energy Consumption Survey.

Data and Research Needs

This study was performed using the 1986 CBECS data, because the more recent 1989 CBECS had less detail on lighting equipment and conservation features. Extending the methods used here to other survey years would therefore require further assumptions and approximations. However, more detailed lighting questions will be restored for the 1992 cycle. The analysis can be repeated directly with the more up-to-date data when they become available. In addition, the 1992 CBECS sample will be a revisit to the 1986 sample, allowing longitudinal comparisons over the past six years.

Several extensions to this analysis could be made. One would be to reconcile the energy estimates with total building electricity consumption. Another would be to incorporate assumptions about the degradation of equipment efficiency over time. The CBECS data also contain complete weekly operating schedules; together with the estimates obtained here for in-use lighting power densities, these schedules could serve as the basis for estimation of lighting load shapes.

Additionally, the results developed here can be combined with economic equipment assessments to provide estimates of the costs associated with the conservation strategies. As part of the Lighting Initiative sponsored by the Office of Conservation and Renewable Energy, economic analysis of different lighting options is currently being conducted by Lawrence Berkeley Laboratory. Results from this report may be linked to that work.

Introduction

Lighting represents an important opportunity for energy conservation in the commercial sector. The EIA's service report in support of the National Energy Strategy[7] estimates lighting at 1.0 quadrillion Btu, 22 percent of all energy delivered to commercial buildings in 1990, 39 percent of commercial buildings' electricity consumption. The Electric Power Research Institute (EPRI),[4] starting from similar sources, estimates lighting as 41 percent of commercial electricity. Others (e.g., Goldstein and Watson[10]) have estimated lighting at well over half of commercial electricity use. Piette et al.[15] estimate commercial lighting as 0.9 quadrillion Btu.

The current availability in the marketplace of a wide variety of energy-efficient lighting technologies makes substantial efficiency gains a realistic possibility in the commercial sector. DOE initiatives focus on the potential for commercial lighting conservation from many angles. The Federal Energy Management Program relamping initiative is designed to reduce lighting energy use in federal buildings. Technology transfer programs are aimed at increasing the penetration of existing energy-efficient lighting technology. The Integrated Resource Planning Program is initiating its Database for Energy-Efficient Programs (DEEP) with a study on commercial lighting program experience. Commercial lighting guidelines are also under consideration.

Outside the DOE, the Environmental Protection Agency's Green Lights program promotes energy-efficient lighting as a means to reducing environmental emissions associated with electricity production. Utility Demand-Side Management programs are increasingly looking to commercial lighting as a prime opportunity. These activities create a growing need for understanding the factors that drive commercial lighting requirements, and the potential energy savings that could be achieved through improved commercial lighting efficiency.

This report brings together information from several sources on commercial lighting energy consumption and practice. The analysis has two objectives. The first is to provide a statistical profile of the commercial building stock with respect to factors that determine energy consumption for lighting. The second is to illustrate the use of this profile as a basis for estimating the potential savings in commercial lighting energy under various assumptions. In addressing each of these two goals, the emphasis is on developing a framework for analysis that can be used with additional or alternate assumptions. Thus, the specific estimates presented for energy measures and energy savings are more illustrative than conclusive.

The point of reference for this analysis is the Commercial Buildings Energy Consumption Survey (CBECS). The CBECS collects detailed data on the structure, equipment, use, and energy consumption for a nationally representative sample of commercial buildings. This survey is the only comprehensive source of national-level data on energy-related characteristics of commercial buildings. The CBECS defines the boundaries of the population considered, and the parameters that are accessible to analysis. In addition, building characteristics from the CBECS provide the basis for attaching technical specification from the engineering literature to the survey data base.

In the next section, "Technical Framework," the key factors described by the statistical profile are introduced and defined. The methodology for developing that profile, and for using it to assess the potential for lighting energy conservation is then described. The data sources used and their limitations are also discussed.

Statistical Profile of Commercial Lighting Energy

With the technical framework established in that section, the analytic results are presented in two major sections. The "Commercial Lighting Energy Profile" addresses the first objective of this study. That is, lighting-related building characteristics are cross-tabulated with basic building characteristics including activity, size, age, and location.

The commercial lighting profile presents statistics not previously published in any CBECS report. Particular emphasis is given to statistics that indicate the joint effect of two or more factors, as opposed to tabulating each individually. The factors examined in combination include the building floorspace, operating hours, percents lighted by different types of equipment, percent lighted off-hours, and presence of various lighting conservation features.

The statistics on combined factors indicate the breadth of information available from the CBECS alone, even without incorporating supplementary information and assumptions from other sources. With the inclusion of the supplementary information, rough estimates are obtained of average illumination levels, lighting power densities, lighting end-use intensity, and lighting energy consumption.

In previous publications based on the CBECS data, the only measures provided of lighting use was the amount of floorspace lighted. The statistical profile developed in this report shows how a subgroup (such as buildings used for a particular activity) can contribute to commercial lighting energy consumption in substantially greater or less proportion than its floorspace alone would indicate. These differences are the result of differences in illumination levels maintained, hours of lighting use, and lighting equipment efficiency.

Health care and lodging buildings, for example, each are estimated to have lighting energy use roughly comparable to that for office buildings, which account for nearly four times as much floorspace. Incandescent light bulbs serve less than one fifth of commercial lighted floorspace, yet are estimated to account for nearly two-fifths of commercial lighting energy use.

Averaging over all building activities, higher lighting energy consumption per square foot is estimated in general for larger buildings, despite the fact that energy-efficient lighting equipment is more common. Countering the effect of the more efficient equipment, activities requiring higher illumination levels and longer operating hours are also more common among larger buildings.

Conservation Potential

In the section on "Lighting Energy Conservation Potential," the lighting energy profile provides the framework for estimating the effect of adopting certain technologies or practices on commercial lighting energy consumption. Estimates are presented under varying sets of assumptions. Both the framework for savings estimation and the data inputs could be expanded or refined to incorporate greater detail and accuracy, or to reflect alternate assumptions.

The results indicate that substantial savings are possible using existing energy-efficient lighting technologies, even under modest assumptions as to the effectiveness of the efficient equipment. Under more optimistic assumptions, including the possibility of reducing illumination levels without loss of amenities, dramatic energy savings are possible.

Economic variables are not considered in the statistical profile or savings analysis presented here. The monetary costs and savings are not estimated for the various changes considered in lighting practices. These changes are evaluated strictly in terms of the energy impact should they be adopted. No explicit estimate is attempted as to which of these possible changes are likely, practical, or desirable. It is anticipated that the analysis presented here can be used in conjunction with other studies that examine these issues.

Technical Approach

General Framework

Lighting energy requirements depend on the amount of floorspace lighted, the duration of lighting use, the illumination level, and the efficiency of lighting equipment in using energy to produce light. Thus, the analysis presented here focuses on four key components of indoor lighting energy consumption[1]:

1. **Floorspace**: the amount of floorspace lighted, broken down by type of equipment serving the space. (Floorspace is derived from CBECS only.)

2. **Hours**: the number of hours per week lighting is used. This measure is not just the reported operating hours, but also incorporates the lighting used during off-hours. (Hours are derived from CBECS only.)

3. **Illuminance:** the technical measure of how strongly lighted the space is. (Illuminance is obtained from the engineering literature, based on CBECS building activity.)

4. **Efficacy**: an energy efficiency measure. Technically, the amount of light produced per unit of energy consumed. (Efficacy is obtained from the engineering literature, based on CBECS lighting equipment categories.)

Statistics are presented on combinations, as well as on each factor individually. The principal combinations considered are:

- **Floorspace-Hours**: a measure of the total lighting service needed, in terms of duration and area of service. Together with the lighting power density, this determines the energy requirement.

- **Lighting Power Density**: the lighting energy requirement per square foot (during periods when the lighting is in use).

- **Lighting End-Use Intensity (EUI)**: the lighting energy requirement per unit of floorspace. The EUI is derived from the duration of use, illumination level, and equipment rating.

No data source completely specifies the four key components for each portion of commercial floorspace. However, the CBECS provides national estimates for closely related factors. The approach adopted here is to use these related factors as a basis for assigning assumed values for the unknown factors.

The assignments are made at the individual building level. Thus, various lighting-related quantities are derived for each building in the CBECS data set. Statistics on these derived quantities are presented, by principal building activity, by building size, by construction year, and by Census region. In addition, floorspace within each building is allocated among the different types of lighting equipment, so that lighting statistics are given also by equipment type. The statistics presented include both national aggregates, such as total floorspace, power, and energy use, and floorspace-weighted averages. Appendix A, "Methodology for Computing Aggregates and Averages," describes the computational procedures. Appendix D, "Motivation and Computation of Lighting Measures," gives the details of specific computations.

[1]Attention is restricted to indoor lighting, because the CBECS collects no data on the type, extent, presence, or use of outdoor lighting equipment. Some energy for outdoor lighting is included in the CBECS estimate of electricity consumption, to the extent that outdoor lighting is included in the electricity bills associated with CBECS buildings.

Formal Specification:
The end-use intensity (EUI) can be expressed as the product of the illumination level (brightness), the hours of lighting, and the amount of energy required per unit of illumination. Multiplying the **EUI** by the floorspace served gives the total lighting energy use for that floorspace. Summing over all floorspace gives total commercial lighting energy consumption.

Thus, the quantities of interest for this analysis are the illuminance **I**, the hours **H** of lighting use, the efficacy **Q** of the lighting equipment, and the floorspace **S** served by each combination of equipment, illuminance, and usage hours. Formally,

Energy	**= Σ**	**floorspace x**	**hours x**	**illuminance /**	**efficacy**
E (kWh)		**S (ksf)**	**H (h)**	**I (l/sf)**	**Q (l/w)**

where the summation is over portions of commercial floorspace defined by lighting level (illuminance), equipment (efficacy), and usage (hours). The units ksf, h, l/sf, and l/w, respectively, indicate thousand square feet, hours per week, lumens per square foot, and lumens per watt.

Methodology for the Lighting Energy Profile

In the "Commercial Lighting Energy Profile," statistics are first presented on the factors that rely on the CBECS alone. These are the floorspace, hours, and their product, the overall floorspace-hours. The last quantity is not a conventional measure of lighting use, but is of interest as a complement to the lighting power density, which is commonly used. Total energy use is the product of the lighting power density and the overall floorspace-hours.

Illuminances are then assigned to CBECS buildings on the basis of the principal building activity, using engineering guidelines. These assignments (listed in Appendix B, "Illuminance Assignments for CBECS Buildings Activity Categories") are necessarily somewhat speculative. As a result, the statistics derived from these assignments have a lower degree of reliability than statistics obtained directly from the CBECS data. Nonetheless, these derived statistics are useful at least as qualitative indicators of the relationship among illuminance and factors such as building structural characteristics, hours of lighting use, and lighting equipment.

For each of the lighting categories identifiable from the CBECS data, efficacies are assigned from the technical literature. Deflation factors representing the effect of conservation features are similarly assigned. Details on these assignments are given in Appendix C, "Equipment Technical Characteristics."

These technical specifications complete the information necessary to estimate lighting energy consumption and end-use intensity for different equipment configurations and for different types of buildings. Because several assumptions and uncertainties underlie the assignment of technical specifications based on the CBECS characteristics, the sensitivity of the overall estimates to the assumptions is considered. Moreover, in comparisons among groups of buildings or types of equipment, attention is focused on less sensitive quantities, such as their relative contributions to total commercial lighting energy consumption.

Methodology for Estimating Potential Savings in Commercial Lighting Energy Use

Using the results of the "Commercial Lighting Energy Profile," the potential energy savings are estimated in the section on "Lighting Energy Conservation Potential." For these savings estimates, the existing lighting equipment is assumed to be replaced by other, more efficient equipment. Savings are estimated under various assumptions for the equipment replacements.

The conservation cases considered indicate the effects of immediate full penetration of specific groups of existing technologies. In practice, of course, replacements would occur gradually over a period of time. However, the purpose of this analysis is not to examine alternate forecasts for the future, but to estimate the potential for conservation in the current stock.

The replacements considered do not necessarily represent cost-effective strategies, nor are they intended to cover the full range of realistic options. The savings estimates are developed in such a way that estimates can easily be derived under alternate assumptions, using the elements presented here. The estimation method is detailed in Appendix E, "Savings Estimation Methodology."

Defining the Conservation Cases for Analysis

For this analysis, a *conservation case* is defined by three elements. First is the *equipment replacement scheme*, which specifies what combination of more energy-efficient equipment is assumed to be installed in place of each configuration of existing equipment. Second is the *conservation effect*, that is, the quantitative effect each conservation feature is assumed to have. Third is the extent of *delamping*, which is the assumed reduction in illumination level.

Equipment Replacement Schemes

The three equipment replacement schemes considered are:

(1) *Comprehensive*: replace all existing equipment by the most efficient for that lamp type (fluorescent, incandescent, or high-intensity discharge), together with lighting controls, high-efficiency ballasts, and reflectors where applicable.

(2) *Compact Fluorescent Conversion Only*: all incandescent bulbs are converted to compact fluorescent lamps, with reflectors. No other improvements are made.

(3) *Comprehensive Improvements Without Compact Fluorescent Conversions*: all the changes of the comprehensive scheme except conversion of incandescents to compact fluorescents.

Conservation Effects

The conservation features considered are high-efficiency ballasts, lighting controls, and reflectors. Each equipment replacement scheme is evaluated with the effects of all these features assumed at a *modest* level, and with all assumed at an *optimistic* level.

For each conservation feature, the *modest* and *optimistic* effects are the endpoints of a range of plausible effects suggested by a review of the literature and consultation with experts. *Modest* indicates a modest (low) level of conservation. Likewise, the *optimistic* effect is the high-conservation end of the range. The terms *modest* and *optimistic* are, thus, used to indicate the relative level of conservation. The quantitative effects assumed for the *modest* and *optimistic* levels are specified in Appendix C.

Delamping

With no delamping, it is assumed that existing illumination levels are maintained, so that the improved equipment is associated with fewer fixtures serving a given space. That is, more efficient equipment does not imply more brightly lit space, but a need for less equipment. Thus, efficiency improvements translate directly into energy savings, rather than serving to increase lighting service.

Delamping is defined here as a reduction in illumination level. The implicit assumption of the delamping cases is that commercial space is more strongly lit, on average, than necessary for comfort and function. (More generally, delamping refers to the removal of lamps.) Each combination of a basic replacement scheme with an assumed conservation effect (modest or optimistic) is evaluated also with delamping assumed at a modest and at an optimistic level, as well as with no delamping. The modest level represents a small reduction in lighting levels, the optimistic level a more extensive reduction. The quantitative levels corresponding to "modest" and "optimistic" are specified in Appendix C.

Error Estimation

The main source of uncertainty in the energy and savings estimates is the technical assumptions. This uncertainty is addressed by developing estimates under a range of plausible assumptions, testing the sensitivity of results to alternate assumptions, and providing the components of the analysis in a form that facilitates the incorporation of other assumptions.

An additional source of uncertainty is the random error from the CBECS sample. The CBECS data set does not include the entire stock of commercial buildings, but is a statistically selected sample. Estimates of population totals based on the CBECS have random errors due to the random selection of the sample. The magnitude of the random errors is estimated by the Relative Standard Errors (RSE's) given in Appendix F, "Relative Standard Errors for the Lighting Profile Tables." In general, the RSE's for the statistics presented here are sufficiently small that the random error can be ignored in comparison to the uncertainty in the technical assumptions.

For smaller population subsets, the RSE's would generally be larger, so that this component of error would not be as easily ignored. For this analysis, only a few population subsets are examined, each supported by a sufficiently large sample size to provide reliable estimates.

Data Sources

Building Characteristics Data

The CBECS is a nationally representative probability sample of commercial buildings. For purposes of this survey, commercial includes all buildings whose principal activity is not residential or industrial. The survey covers all commercial buildings over 1,000 square feet. For each of the roughly 6,000 buildings in the sample, the CBECS collects data on energy-related characteristics of the building as well as on the amount of energy consumed in the building.

The 1986 CBECS, which provides data for that calendar year, was used for the present analysis because this survey had more detail on lighting equipment and lighting conservation features than did the more recent 1989 survey. Previous reports have provided summary statistics on 1986 building characteristics,[5] on 1986 energy consumption and expenditures in relation to those characteristics,[6] and on 1989 building characteristics.[8]
The detail of the lighting questions was reduced on the 1989 CBECS for budget reasons. Because of the importance of this information, as evidenced by findings from this report, detailed lighting questions will be restored for the 1992 CBECS.

It is anticipated that the data for 1992 will reveal increased penetration of more efficient lighting technologies compared to the 1986. Nonetheless, given the general pace of change in the commercial building stock, the overall statistical profile has probably not shifted dramatically since 1986. For example, the estimated fraction of lighted floorspace served by fluorescent lamps increased from 76.2 percent in 1986 to 79.2 percent in 1989, but the change was not statistically significant. Thus, the qualitative relationships revealed by this analysis should still hold. Moreover, the approach developed here can be applied to the 1992 CBECS lighting data when they become available.

The data collected on the 1986 CBECS included the following:

- total floorspace
- the percent of floorspace lighted during usual operating hours
- the percent of floorspace lighted during off hours
- the percent of the floorspace lighted during usual operating hours that was lighted by each of several types of lamp
- the presence in the building of various lighting conservation features
- the number of operating hours per week
- the principal activity taking place in the building.

The CBECS data are collected for the building as a whole, not for separate portions of the building. It is therefore not known which conservation features are associated with which specific activities within the building, nor with which types of lamps or how much floorspace. Nor is it known which equipment is used for the space lighted during off-hours.

A further limitation of the CBECS data is the level of knowledge of the respondent. These data are collected not by a trained auditor, but by an interview with a respondent knowledgeable about the building. Respondents vary in their understanding of question terminology and knowledge about their buildings. For this reason, the CBECS questions are phrased to be meaningful to a broad set of respondents, rather than emphasizing precise technical distinctions.

Despite these limitations, the CBECS data provide a basis for characterizing the combinations of factors affecting commercial lighting requirements. This characterization requires that technical information from other sources be linked to the CBECS data.

Illuminance Data

The CBECS does not collect data on lighting levels, either in terms of power density (watts per square foot, or w/sf) or illuminance (lumens per square foot, or l/sf). However, the CBECS does identify the principal building activity, which is a strong determinant of lighting requirements.

The Illumination Engineering Society[11] publishes lighting guidelines by detailed space function. The guideline for each function consists of a low, medium, and high value, ranging from low to high by a factor of two or two and one-half. Actual levels in place may be outside this range. Nevertheless, the guidelines serve as an indicator of relative lighting requirements for different types of buildings. Appendix B describes how IES guidelines were used to assign illuminances to CBECS building activities.

Technology Specification Data

Technology specifications were drawn from a number of sources. A comprehensive review of lighting technologies has been performed by Piette et al.[15] A similar, somewhat less detailed, overview was prepared for the New York State Energy Research and Development Authority.[14] The Lighting Research Group at Lawrence Berkeley Laboratory (LBL) is conducting a life-cycle cost analysis for an extensive list of equipment combinations.[1] The California Energy Commission (CEC)[2] has issued a series of lighting technology guidelines with technical specifications for several types of equipment.

The CEC guidelines include efficacies, in lumens per watt (l/w) for the major lamp types considered here. Because this source offered a comprehensive and consistent set of specifications, efficacies for the broad lamp classes considered here were taken from the CEC guidelines whenever possible. Efficacies reported by other sources were similar. Some missing elements were filled in from other sources. Details are given in Appendix C, "Equipment Technical Characteristics."

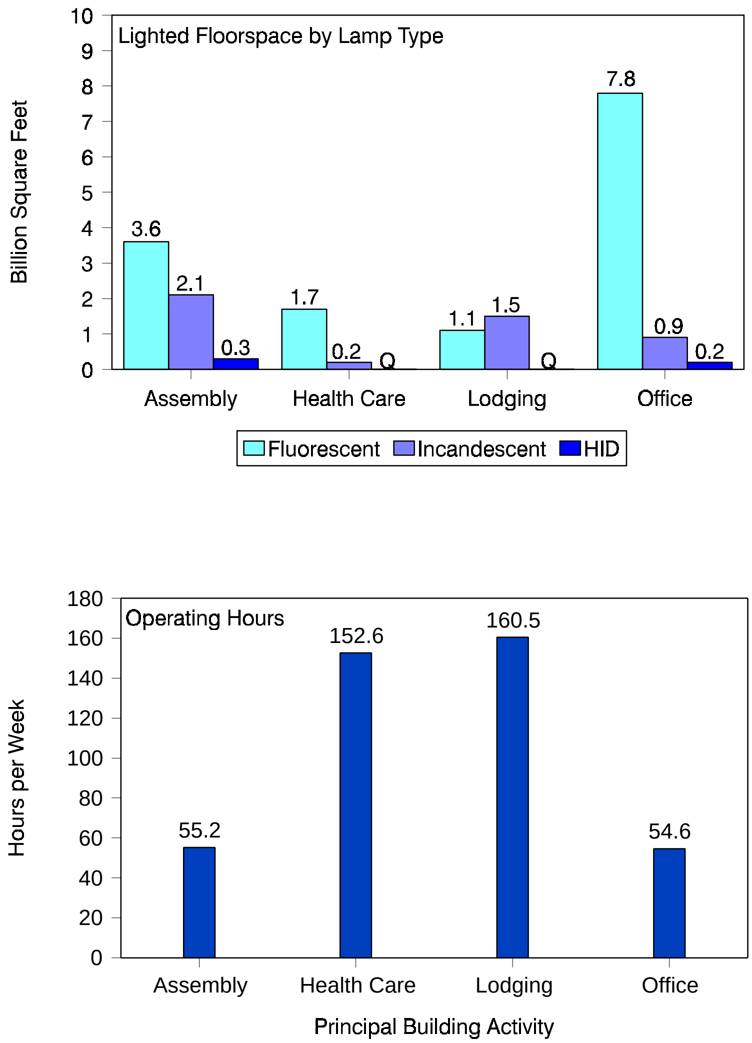
Technical characteristics of different lamps and fixtures are given fairly consistently in the literature. For the effects of different conservation features, though, there is less agreement. For this reason, a high and low value were used for each effect, roughly covering the range of values suggested by the literature. Details on the particular values adopted are given in Appendix C.

Commercial Lighting Energy Profile

As discussed in the "Technical Approach" section, the energy required for lighting in a particular space depends on a number of factors. These factors include the amount of lighted floorspace, the hours of lighting, the illumination level (illuminance), and the effectiveness (efficacy) of the lighting equipment. A useful starting point in the analysis of lighting energy requirements is therefore to characterize commercial floorspace with respect to these factors. Because lighting power and energy requirements depend on the product of these factors, it is important to consider them in combination as well as individually.

As discussed previously, the CBECS cannot measure all the lighting determinants directly. Instead, the survey provides data on closely related features, including the type of lighting equipment, building operating hours, and principal building activity (Figure 1).

Figure 1. Lighting-Related Features by Selected Principal Building Activity



Notes: • Q indicates that the statistic was withheld because the Relative Standard Error (RSE) is greater than 50 percent. • Fluorescent and Incandescent categories each include standard and energy-efficient lamps. • The HID category refers to high-intensity discharge lamps, which include metal halide and high-pressure sodium lamps.

Source: Energy Information Administration, Office of Energy Markets and End Use, Form EIA-871A, "Building Questionnaire" of the 1986 Nonresidential Buildings Energy Consumption Survey.

Even these simple summary statistics indicate potential opportunities for lighting energy conservation. Office buildings, for example, contain nearly 8 billion square feet of floorspace served by fluorescent lights; programs targeted at fluorescent lighting in offices, thus, have a large potential market. Health care buildings contain less than one-fourth as much floorspace as office buildings, but operate nearly three times as long, suggesting that their energy requirements and conservation potential may be of comparable magnitude. Lodging buildings also have long operating hours, and have incandescent bulbs for more than half their lighted floorspace. High-intensity discharge (HID) lamps, which are well suited to large open spaces, serve only 5 percent of the lighted floorspace in public assembly buildings, while incandescent bulbs serve 35 percent. Thus, both lodging and assembly buildings may be good targets for conservation programs directed toward incandescent bulbs.

In the analysis that follows, these simple indicators serve as the basis for quantitative estimates of lighting energy requirements and conservation potential. The analysis links directly measured factors from the CBECS to derived values for unmeasured factors of interest, obtained both from CBECS and from the technical literature.

Floorspace Lighted by Equipment Type

The amount of floorspace lighted by different types of lighting equipment is a very basic measure of lighting service. More efficient equipment is associated with more lighting-intensive building activities, and with newer buildings. (This information is available from the CBECS data alone.)

The CBECS provides direct measures of the amount of floorspace served for each of five broad lamp types: energy-efficient fluorescent, standard fluorescent, energy-efficient incandescent, standard incandescent, and high-intensity discharge (HID). The floorspace lighted by different lamps varies considerably by building activity and size. (The calculations of aggregate statistics, including lighted floorspace, are detailed in Appendix A.) Energy-efficient lamps are much more common among large buildings (Figure 2). Health care buildings, which tend to be highly lighted for long periods of time, have the greatest fraction of floorspace under energy-efficient fluorescent lamps. (See Table 2 of the Detailed Tables). More efficient lamps are also more common among newer buildings. Less variation is apparent by region.

Floorspace and Lighting Hours

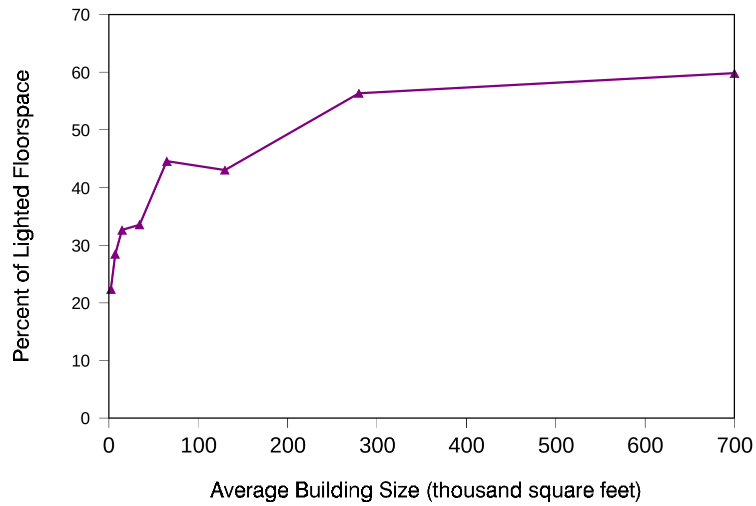
A more comprehensive measure of lighting usage than floorspace alone is the total lighted floorspace-hours. This usage measure complements the lighting power density in determining the total lighting energy requirement. Even without knowing lighting power densities, health care, lodging, and food buildings are seen to contribute to commercial lighting usage in far greater proportion than their shares of floorspace, while education and assembly buildings contribute proportionately less. (These statistics rely on no additional data beyond CBECS, but do depend on an assumption about off-hours lighting use.)

The floorspace lighted during the building's usual operating hours is a first measure of lighting use. To quantify the lighting energy requirement, the number of hours the lighting is in use must also be considered. Previous CBECS reports[5 and 8] tabulated the median building operating hours by various building characteristics. However, it is necessary to consider lighting use during off-hours as well as during usual operating hours. Furthermore, hours and floorspace must be considered jointly.

Effective Lighting Hours

To estimate the average hours of lighting use for each building, the usual operating hours are extended by an amount proportional to the fraction of floorspace that is lighted during off-hours. The resulting estimate is referred to here as the "effective lighting hours."

Figure 2. Percent of Lighted Floorspace Served by Energy-Efficient Lamps by Building Size Category



Notes: ● At each size category, the total floorspace lighted by energy-efficient lamps is shown as a percentage of all lighted floorspace for that category. ● The values are plotted at a horizontal position corresponding to the average building size for the category. ● Energy-efficient lamps are energy-efficient fluorescents and energy-efficient incandescents.

Source: Energy Information Administration, Office of Energy Markets and End Use, Form EIA-871A, "Building Questionnaire" of the 1986 Nonresidential Buildings Energy Consumption Survey.

Formal Specification:
The effective lighting hours is computed as

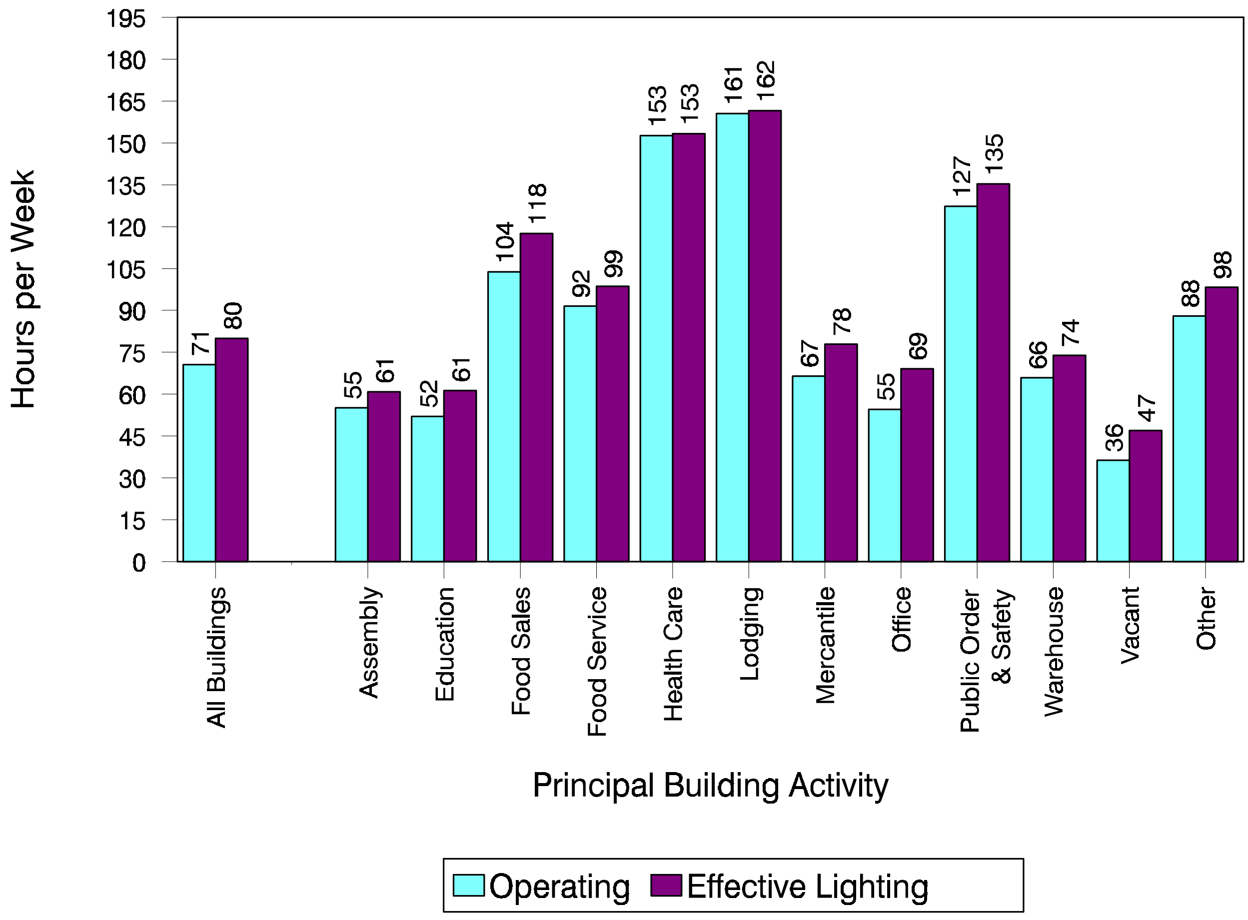
$$H^e = H^o + (S^n/S^o)\, H^n,$$

where H^o and H^n, respectively, are the weekly operating and nonoperating hours, and S^o and S^n, respectively, are the amounts of floorspace lighted during operating and nonoperating hours. With this formulation of the effective lighting hours, the floorspace S^o is assumed lighted for more than the weekly operating hours. Specifically, additional usage is attributed to S^o for each nonoperating hour, in proportion to the fraction of (operating-hours lighted) floorspace that is lit during off hours.

With the floorspace lighted during off-hours taken into account, the effective lighting hours are 13 percent higher on average than the usual operating hours. (See Table 3 in the Detailed Tables.) Thus, considering only operating-hours usage could result in substantial understatement of lighting demand. The effect of off-hours lighting is different for different types of buildings. As a result, comparisons of lighting energy requirements among building types are also distorted by ignoring off-hours lighting use.

For buildings that tend to be open almost all the time, including health care, lodging, and public order and safety buildings, the effective lighting hours are only slightly higher than the operating hours (Figure 3). For office, mercantile, education, and vacant buildings, all of which have fewer than 60 operating hours per week, the effective lighting hours are 17 to 30 percent higher than the usual operating hours.

Figure 3. Average Operating Hours and Effective Lighting Hours by Principal Building Activity



Source: Energy Information Administration, Office of Energy Markets and End Use, Form EIA-871A, "Building Questionnaire" of the 1986 Nonresidential Buildings Energy Consumption Survey.

Lighted Floorspace-Hours

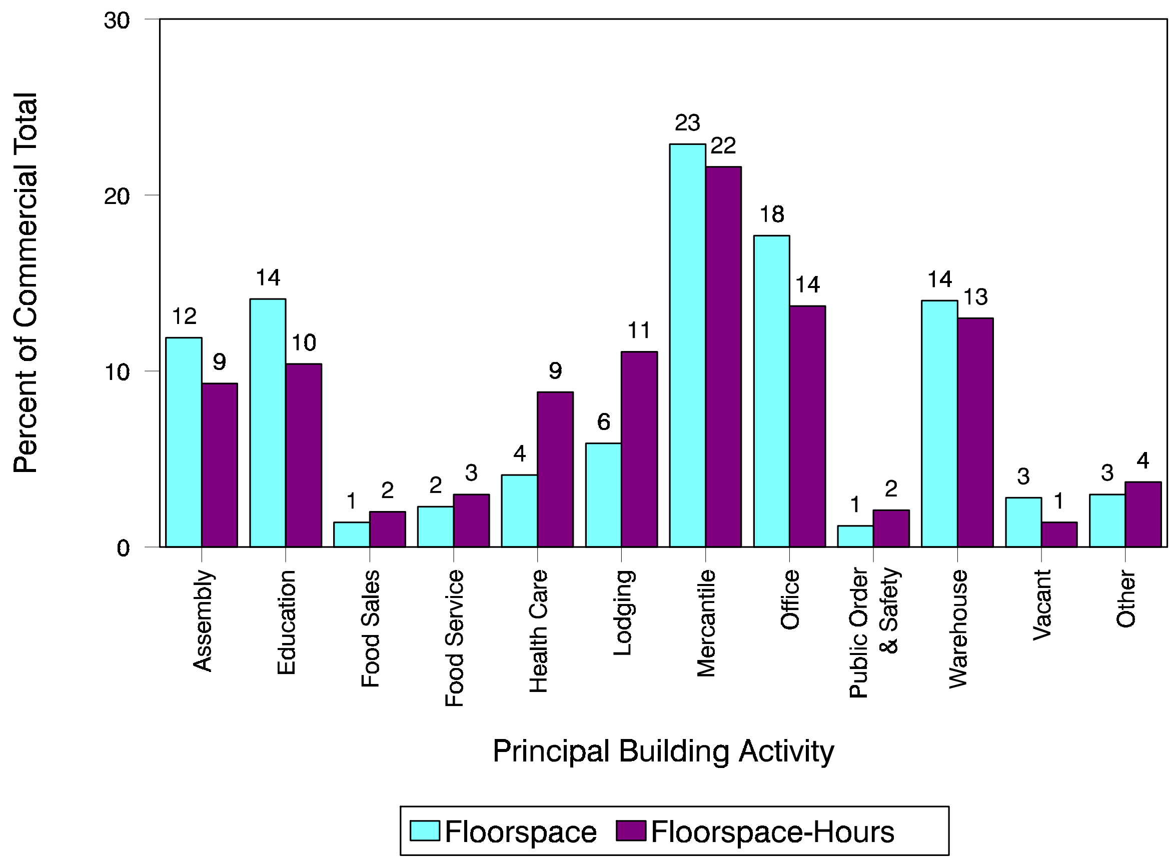
Combining the lighted floorspace with the effective lighting hours for that floorspace gives the total lighted floorspace-hours. This quantity complements the installed lighting power density, in watts per square foot, as a measure of lighting requirements.

Formal Specification:
The amount of energy required for a given lighting power density **P** depends on the lighted floorspace-hours **SH**. For this analysis, the floorspace-hours are computed using the floorspace lighted during open hours and the effective lighting hours, as defined above. Thus,

$$\mathbf{SH} = \mathbf{S^o H^e}.$$

Nationally, education and assembly buildings together account for 26 percent of lighted floorspace, but, with relatively low effective hours, only 20 percent of the lighted floorspace-hours (Figure 4). With longer hours, health care, lodging, food, and public order and safety buildings each account for a larger percentage of floorspace-hours than of floorspace.

Figure 4. Percent of Lighted Floorspace and Lighted Floorspace-Hours by Principal Building Activity



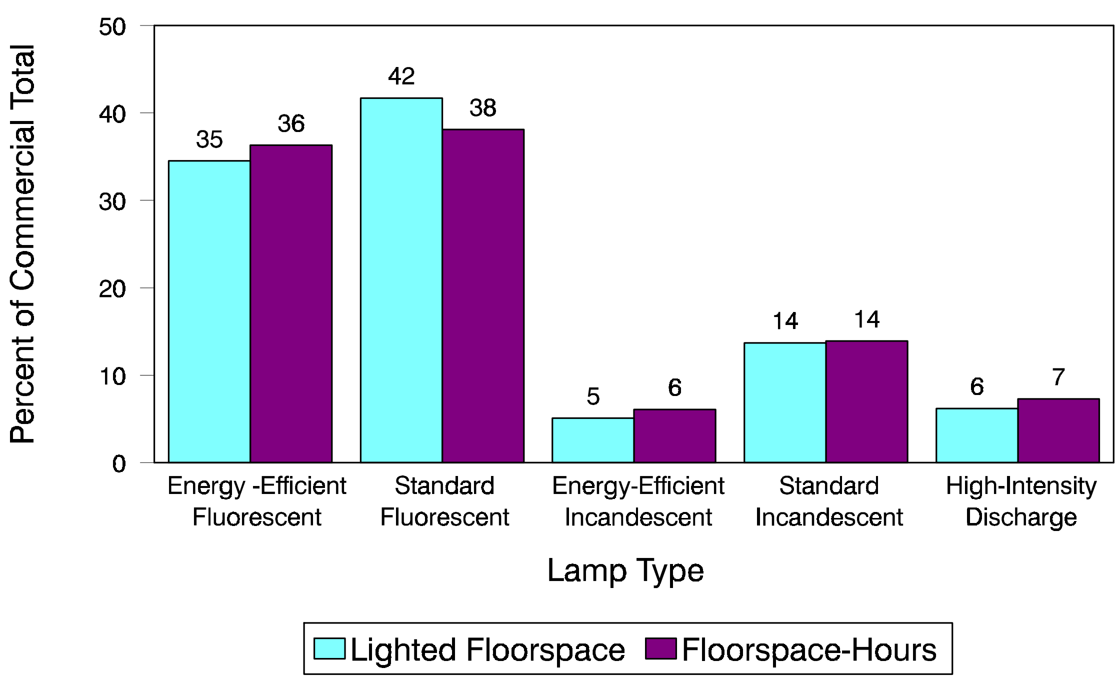
Note: Percent of lighted floorspace and lighted floorspace-hours for each building activity category are computed as percents of the commercial total lighted floorspace (49.59 billion square feet) and total lighted floorspace-hours (3.5 trillion square foot-hours).
Source: Energy Information Administration, Office of Energy Markets and End Use, Form EIA-871A, "Building Questionnaire" of the 1986 Nonresidential Buildings Energy Consumption Survey.

Floorspace-Hours and Lighting Equipment

Relating the usage measures accurately to different types of lighting equipment requires information not available from the CBECS. The floorspace lighted during operating hours is broken down by type of lamp, but the floorspace lighted during off hours is not. As a rough approximation, the same proportions reported for operating hours are assumed to apply to off hours. (This assumption would lead to an overstatement or understatement of total lighting usage, depending on whether the lamps used during off-hours tend to be the more efficient or the less efficient equipment available within the building.) The same calculations performed for overall lighted floorspace are then repeated for the floorspace lighted by each lamp type.

The estimated proportion of floorspace-hours served by each lamp type is similar to the proportion of floorspace served (Figure 5). Within each of the two broad classes, fluorescent and incandescent lamps, energy-efficient lamps are associated with longer operating hours and greater fractions of floorspace lighted during off-hours. (See Table 4 of the Detailed Tables.) Fluorescent and high-intensity discharge lamps have higher ratios of effective lighting hours to operating hours than do incandescent lamps. These relationships indicate that some attention is already being paid to the need for efficient lighting in commercial buildings.

Figure 5. Percent of Lighted Floorspace and Lighted Floorspace-Hours by Lamp Type



Notes: • Percent of lighted floorspace and lighted floorspace-hours for each lamp type are computed as percents of the commercial total lighted floorspace (49.59 billion square feet) and total floorspace-hours (3.5 trillion square foot-hours). • Components sum to slightly more than 100 percent because some floorspace is lighted by more than one lamp type.

Source: Energy Information Administration, Office of Energy Markets and End Use, Form EIA-871A, "Building Questionnaire" of the 1986 Nonresidential Buildings Energy Consumption Survey.

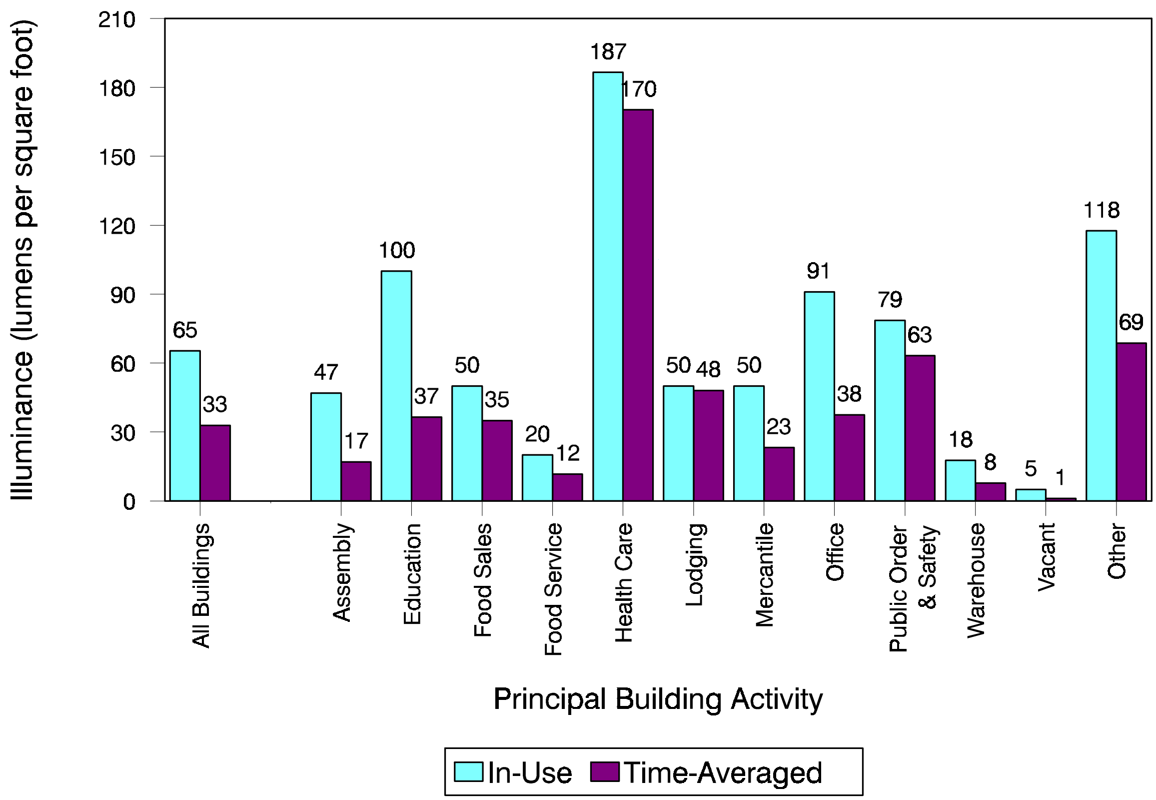
Illumination Levels

The different illumination levels (illuminance) associated with different building activities are a major contributor to differences in lighting end-use intensities. The illuminance together with the hours of use defines the lighting service requirement per unit of floorspace. Higher illuminance and longer hours are associated with larger buildings, and with more efficient lighting equipment. (Illuminance estimates are obtained by attaching engineering guidelines to the CBECS data set, according to the principal building activity.)

An illuminance is assigned to each CBECS building on the basis of the building's principal activity. The assignment uses the high IES guidelines, averaged over the different detailed activities included in each broad CBECS activity. Details of the assignment process are given in Appendix B.

The average assigned illuminance for health care buildings is about three times the average over all buildings, indicating the use of stronger lighting in hospitals (Figure 6). The average assigned illuminance for warehouse and vacant buildings are quite low.

Figure 6. Illuminance by Principal Building Activity



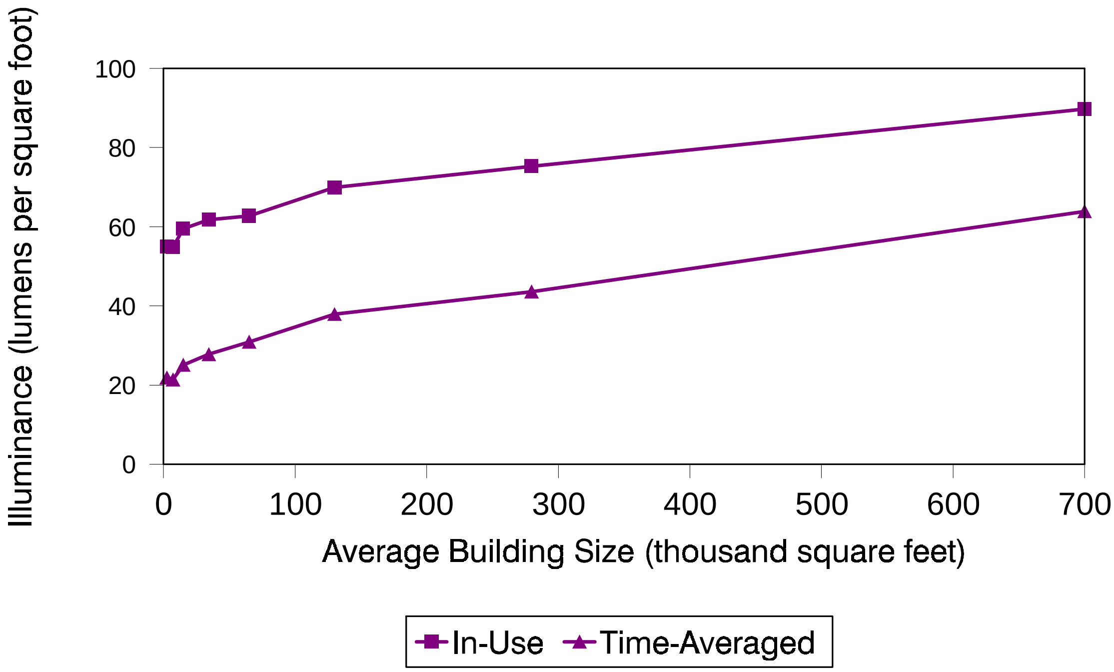
Notes: • In-use illuminances are average assigned values based on IES recommended categories. • Time-averaged illuminance is in-use illuminance adjusted by the usage factor, that is, the estimated proportion of time the lighting is in use.

Source: Usage factor from Energy Information Administration, Office of Energy Markets and End Use, Form EIA-871A, "Building Questionnaire" of the 1986 Nonresidential Buildings Energy Consumption Survey; Illuminance derived from sources described in Appendices B and C.

Illuminance by Building Size Characteristics

The mix of building activities, hence the average assigned illuminance, differs for buildings of different size, age, or location. For example, higher illuminances are generally associated with larger buildings (Figure 7). Some differences in illuminance are also seen for buildings of different ages, but there is no consistent trend. (See Table 5 of the Detailed Tables.) Regionally, there is little difference in average assigned illuminances.

Figure 7. Illuminance by Building Size Category



Notes: • For each size category, average illuminances are plotted at a horizontal position corresponding to the average size for buildings in the category. • In-use illuminances are average assigned values based on IES recommended categories. • Time-averaged illuminance is in-use illuminance adjusted by the usage factor, that is, the estimated proportion of time the lighting is in use.

Source: Usage factor from Energy Information Administration, Office of Energy Markets and End Use, Form EIA-871A, "Building Questionnaire" of the 1986 Nonresidential Buildings Energy Consumption Survey; Illuminance derived from sources described in Appendices B and C.

In practice, there may in fact be differences in illuminance by region or building age. For instance, the lighting level considered comfortable for a given activity may differ somewhat between northern and southern areas, or between colder and warmer areas. Illuminance design guidelines and practice have changed over time, so that older and newer buildings may differ. However, the assumptions used here do not include any such differences. Further discussion of changes in illuminance with building age is included in Appendix B.

Illuminance and Usage

The total lighting service requirement per unit of floorspace depends equally on the illuminance and the hours of lighting use. For lodging buildings, long hours of use are offset by relatively low (assigned) illuminance (Figures 3 and 6 above). For health care buildings, by contrast, both the illuminance and the hours of use are high.

The usage factor is the percentage of time the lighting equipment is in use. Combining the assigned illuminance with the usage factor gives the time-averaged illuminance, which is the building's average level of lighting service over the week.

The assigned in-use illuminance represents the peak lighting service, the level during periods of normal full use of the building. For analysis of peak electricity loads, the in-use illuminance is most important. For analysis of annual energy requirements, the time-averaged illuminance has advantages. In particular, for a given lighting equipment efficiency, the lighting EUI is directly proportional to the time-averaged illuminance.

Formal Specification:
The lighting usage factor, which estimates the fraction of the time the lighting is used, is calculated from the effective lighting hours as

$$\mathbf{U} = \mathbf{H^e/168},$$

where the divisor 168 is the number of hours in a week. The time-averaged illuminance is then calculated from the in-use illuminance **I** as

$$\mathbf{T} = \mathbf{I\,U}$$

$$= \mathbf{I\,H^e/168}.$$

For example, a building with in-use illuminance of 120 l/sf and 84 effective hours per week would have a time-averaged illuminance of (120)(84/168) = 60 l/sf.

Education buildings have twice the in-use illuminance of food sales buildings but a usage factor half as large, resulting in about the same time-averaged illuminance. By contrast, lodging and mercantile buildings have about the same in-use illuminance, but lodging buildings have twice the usage factor, hence about twice the time-averaged illuminance.

Health care buildings, with long hours and high in-use illuminance, have high time-averaged illuminance. Assembly, office, and warehouse buildings have low time-averaged illuminance. Since larger buildings tend to have both longer hours and higher in-use illuminance, their time-averaged illuminance is also higher. Buildings built before 1920 have low hours and in-use illuminance, resulting in low time-averaged illuminance. (See Tables 3 and 7 of the Detailed Tables.)

Illuminance and Lighting Equipment

Translating time-averaged illuminance into energy intensity requires information about the equipment supplying the illumination. Ideally, in-use illuminance and lighting hours would be determined separately for each element of floorspace served by different equipment or differently operated. This level of detail is not available from the CBECS (nor from any other source). Instead, effective lighting hours are determined and in-use illuminance assigned for the building as a whole.

To obtain a rough indicator of the amounts of light provided by different types of equipment, the in-use illuminance and hours of use are assumed to apply uniformly to all lighting equipment within the building. Under this assumption, the same time-averaged illuminance determined for the building as a whole is assigned to all floorspace served by each type of equipment. This assignment gives a rough estimate of the illuminance by lamp type. Details of this calculation are given in Appendix A.

In practice, of course, different types of equipment are used in differently lighted spaces and for different amounts of time within the building. Incorporating these differences into the present analysis would require a complex set of essentially unverifiable assumptions. To the extent that more efficient equipment serves the space within a building that is lighted longer or more brightly, the simplistic assumption of uniform hours and illuminance overstates the use of less efficient equipment and understates the use of more efficient equipment.

Even with the simplistic uniform assumptions, the different application of higher efficiency equipment can be seen. Energy-efficient fluorescent lamps are associated with buildings with higher time-averaged illuminance than are standard fluorescents. The same is true for energy-efficient versus standard incandescent bulbs (Figure 8).

Lighting Equipment Technical Characteristics

Technical characteristics of lighting equipment are required to obtain energy requirements from lighting service characterizations. For each general class of lamps considered here, the light output per unit of energy (efficacy) is fairly well established in the engineering literature. The effects of various conservation features considered is less well determined, in part because the categories considered are so broad. (Lighting technology specifications are obtained from the engineering literature for the broad equipment classes identified in the CBECS data set.)

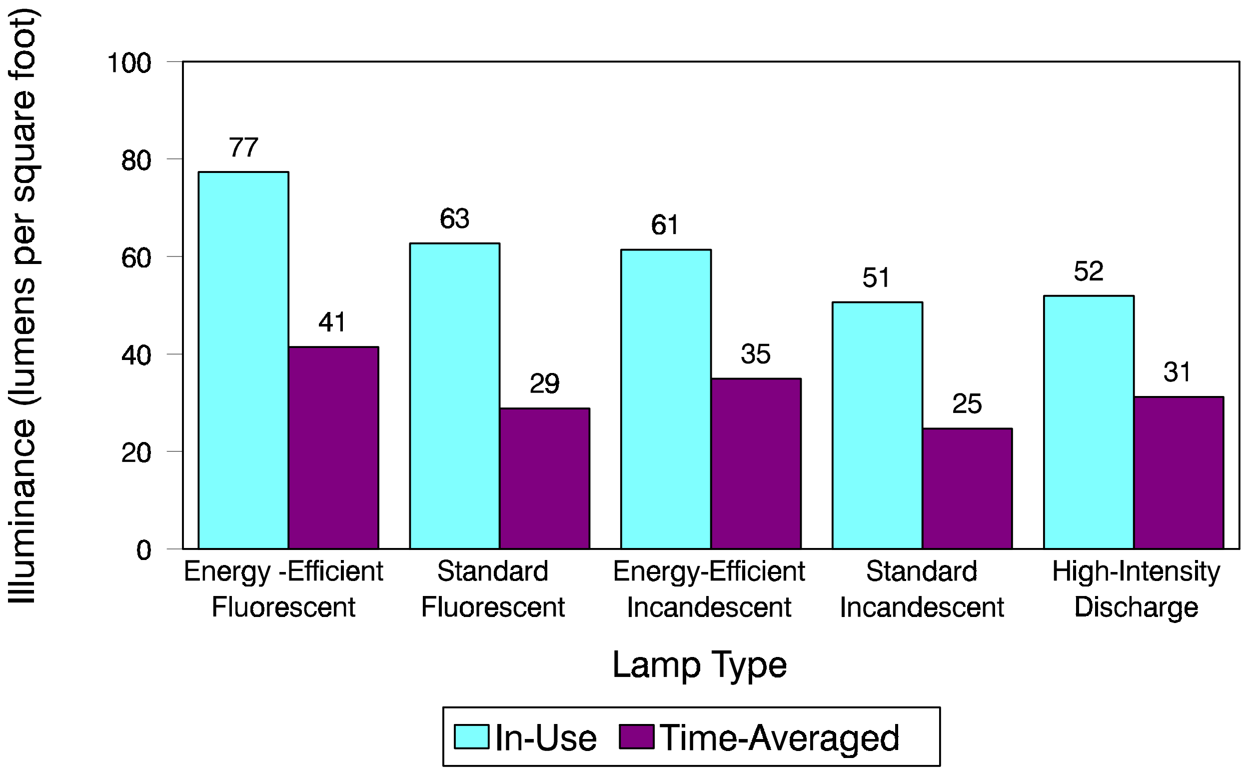
Although several simplifying assumptions went into the estimates of the average illuminances associated with different lighting equipment, these estimates at least offer qualitative comparisons of the amount of lighting service provided by the different equipment. To derive comparative energy requirements from the service measures, technical characteristics of the equipment must be known.

The CBECS data include lighting equipment characteristics only in very broad categories. Technical specifications for typical equipment were extracted from the literature, as discussed above and detailed in Appendix C. The categories specified included those for which CBECS data were available, plus a few frequently considered alternatives.

Efficacies by Lamp Type

The efficacies of different lamp types are fairly well determined, based on engineering studies. The particular values assumed for this analysis are given in Table C1 of Appendix C, where the basis for the technical specifications is described.

Figure 8. Illuminance by Lamp Type



Notes: • In-use illuminances are average assigned values based on IES recommended categories. • Time-averaged illuminance is in-use illuminance adjusted by the usage factor, that is, the estimated proportion of time the lighting is in use.

Source: Usage factor from Energy Information Administration, Office of Energy Markets and End Use, Form EIA-871A, "Building Questionnaire" of the 1986 Nonresidential Buildings Energy Consumption Survey; Illuminance derived from sources described in Appendices B and C.

Energy-efficient variants of fluorescent and incandescent lamps are 5 to 10 percent more efficient than their standard counterparts. A much greater difference is between the efficiency of incandescent bulbs on the one hand and fluorescent or high-intensity discharge lamps on the other. Fluorescent and HID are on the order of three times as efficient as incandescent in terms of the energy required per unit of light delivered (watts per lumen).

Conservation Effects

With each type of lamp, various lighting conservation features might be used. The CBECS includes data on the presence in the building of lighting controls, energy-efficient ballasts, and delamping. The 1986 CBECS does not include data on the presence of reflectors, but this feature is included among the conservation options considered in this analysis.

Because the CBECS equipment definitions are very general, the interpretation and effect of a particular conservation feature may vary considerably across the buildings reporting its presence. In addition, the CBECS data do not indicate what fraction of the lighted floorspace was served by a given feature, only that the feature was in the building.

Even if the CBECS data were more precise, the estimated effect of each conservation feature varies in the literature. In addition, within buildings where a particular feature is present, the fraction of floorspace affected by the feature is unknown.

For this reason, two different quantitative effects are assumed for each conservation feature, spanning a range of reasonable values. For a given feature, the effect that corresponds to less conservation is designated the *modest* level, and the effect that corresponds to more conservation is the *optimistic* level. Computations that involve the effects of conservation features are performed with all conservation effects set at the *modest* level, or with all at the *optimistic* level.

For these calculations, the assumed effect represents an average over all buildings where the feature is present. Thus, a more substantial (i.e., more optimistic) assumed conservation effect implies either that the feature is more effective over the floorspace it serves, or that it serves a greater fraction of floorspace in buildings where it is present.

Formal Specification:
For each conservation feature **f**, a deflation factor $\mathbf{d}_f$ was determined from the technical literature. The deflation factor is the ratio of energy consumption with the feature present to energy consumption without the feature. For example, a feature that reduces energy consumption by 10 percent would have a deflation factor of 0.9.

A high deflation factor corresponds to little conservation, a low deflation factor to substantial conservation. This factor represents an average over all the floorspace where the feature could apply, in buildings that have the feature. Assuming a lower penetration of the feature would imply a higher value of the deflation factor. Thus, a higher assumed deflation factor is more *modest*, a lower assumed value more *optimistic*, in terms of the assumed effectiveness of the conservation feature.

For each broad class of conservation features, a (more) modest and a (more) optimistic deflation factor were determined from the literature. (See Table C2). Reasons for choosing the particular values assumed are discussed in Appendix C.

Lighting Power Density

The lighting power density, a standard measure of the intensity of lighting energy use, is estimated at around 1 w/sf for floorspace lighted by fluorescent lamps, and 3 w/sf for floorspace lighted by incandescent bulbs. Within each of these two broad lamp types, floorspace currently under the energy-efficient variety is estimated to have somewhat higher lighting power densities than floorspace under the standard variety. This difference stems from the fact that buildings where energy-efficient equipment is found tend to be those that have higher illuminance requirements. In the next subsection, this difference in power densities translates into higher lighting end-use intensities for energy-efficient varieties. (The lighting power density is derived from the assumed technical specifications.)

The lighting power density is the rate of lighting energy use during periods when the lighting is in use. This rate is a standard measure of the intensity of lighting energy use, and depends only on the illuminance and the equipment efficacy.

In this analysis, both illuminance and efficacy are based entirely on assigned engineering specifications, not on measured or reported values. Thus, whatever weakness is inherent in those assignments carries over to the lighting power densities derived from them.

By building activity, the derived lighting power densities range from less than 0.1 w/sf for vacant buildings to 3.6 w/sf for health care buildings. (See Table 7 of the Detailed Tables.) By lamp types, the averages were around 1 w/sf for fluorescent lamps and 3 w/sf for incandescent. (See Table 6 of the Detailed Tables.)

The lighting power densities for energy-efficient fluorescents and for energy-efficient incandescents are slightly higher than for their standard counterparts. This result is the reverse of what would be expected if energy-efficient and standard lamps were used to provide comparable levels of light. However, as indicated above, it is the buildings with higher lighting requirements that are more likely to have energy-efficient equipment. Even with the more efficient equipment, the higher illuminances result in higher lighting power densities. For each type of lamp, the derived lighting power density increases with building size, reflecting increasing illuminance.

Lighting End-Use Intensity

The lighting end-use intensity is estimated at around 6 kWh/sf for the commercial sector as a whole, and also for office buildings. The estimate for health care buildings is about four times as large, and the estimate for warehouses about one-fourth as large. The differences in EUI show the combined effects of differences in illuminance, hours, and equipment efficacies. The estimated lighting EUI increases with building size. (The EUI estimates are obtained from the derived lighting power density and the estimated hours of lighting use.)

An alternate measure of the rate at which lighting energy is required is the annual lighting end-use intensity (EUI), in kWh per lighted square foot. The EUI combines the lighting power density with the usage factor. Thus, this estimate carries with it the errors embedded in the derived lighting power density, from uncertainties in illuminance and efficacy.

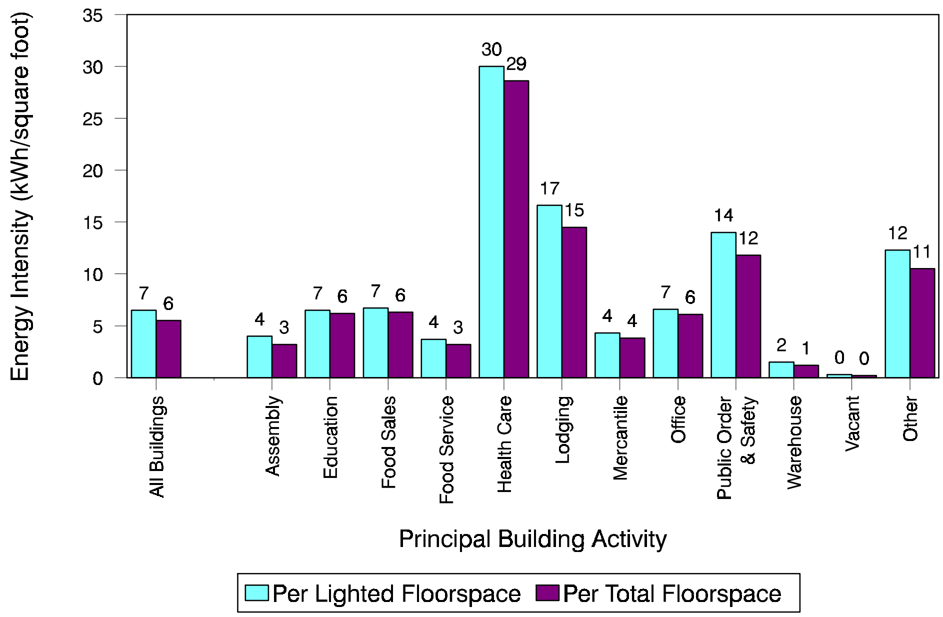
For nonvacant buildings, the estimated EUI’s range from 1.5 kWh/sf for warehouses to 30 kWh/sf for health care buildings, with an overall average of 6.5 kWh/sf (Figure 9). These EUI’s are computed relative to the lighted floorspace only. Using the total floorspace as a base, the EUI’s are 10 to 20 percent higher, depending on the building type.

Other than health care, the only building activity types with lighting EUI above 10 kWh/sf are lodging, public order and safety, and other. Lodging buildings have long hours and a high fraction of floorspace lighted by incandescent (i.e., relatively inefficient) lamps. Public order and safety buildings have long hours and high illuminance. The "other" category includes a wide range of uses, including some partly industrial buildings.

Corresponding to the differences in lighting power densities, end-use intensities are higher for energy-efficient than for standard fluorescent lamps. The same is true for energy-efficient versus standard incandescent.

Reflecting the trends seen separately for illuminance (Figure 7 above) and hours, the lighting EUI increases with building size (Figure 10).

Figure 9. Lighting Energy Intensity by Principal Building Activity



Note: For each building activity category, the lighting energy intensity per lit floorspace (per total floorspace) is the estimated lighting energy divided by the lighted floorspace (total floorspace) in the category.

Sources: Floorspace from Energy Information Administration, Office of Energy Markets and End Use, Form EIA-871A, "Building Questionnaire" of the 1986 Nonresidential Buildings Energy Consumption Survey. Illuminance and efficacy derived from sources described in Appendices B and C. Lighting energy intensity derived from illuminance, efficacy, and floorspace.

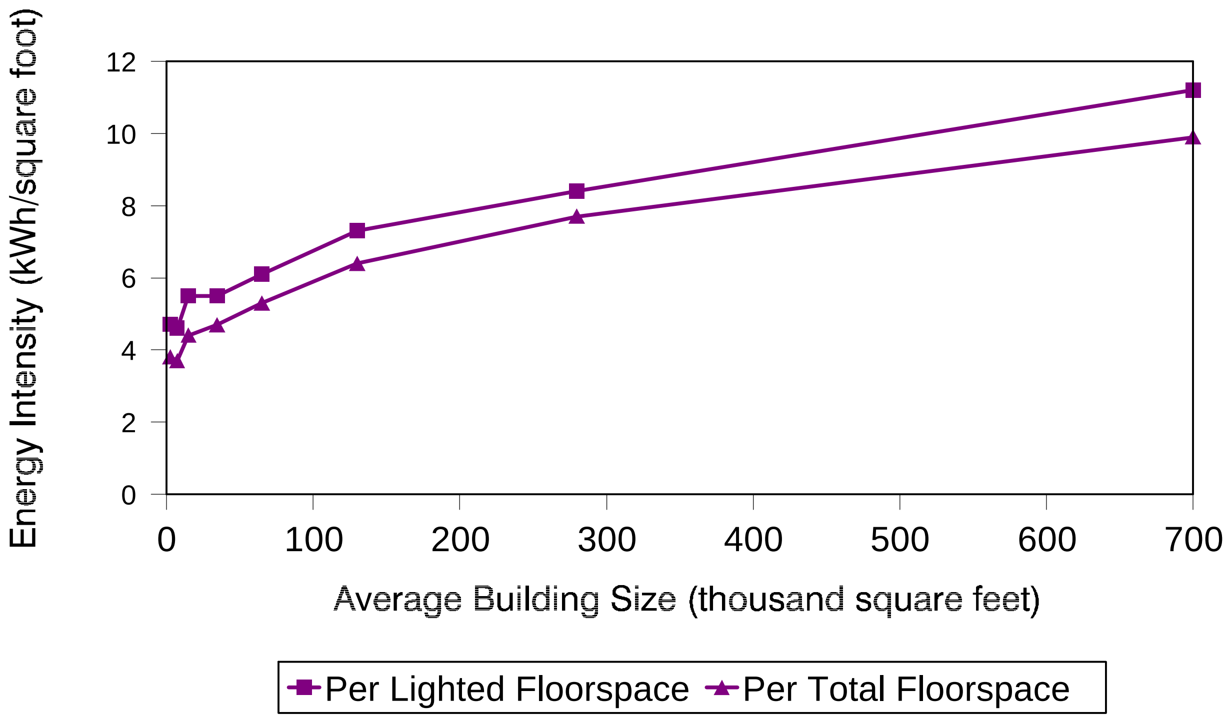
Lighting Energy Consumption

The derived end-use intensities yield an estimate of 321 billion kWh, or 1.1 quadrillion Btu, for annual indoor lighting energy use in commercial buildings. Alternate assumptions considered here give estimates as low as 0.7 quadrillion Btu. Incandescent bulbs account for 37 percent of the lighting energy consumption, but only 19 percent of lighted commercial floorspace. Health care and lodging buildings each consume roughly as much lighting energy as office buildings, though each constitutes less than one-third as much floorspace as office buildings.

The starting point for this analysis was the purely CBECS-based estimate of floorspace served by different types of lamps. Combining the floorspace estimates with the derived end-use intensities gives estimates of annual lighting energy use. (See Table 9 of the Detailed Tables.)

This calculation gives an estimate for total commercial lighting energy of 321 billion kWh, or 1.1 quadrillion Btu per year for 1986. This estimate is toward the high end of the range of estimates cited in the "Introduction," and represents about 46 percent of commercial electricity consumption as measured by the CBECS for 1986.

Figure 10. Lighting Energy Intensity by Building Size Category



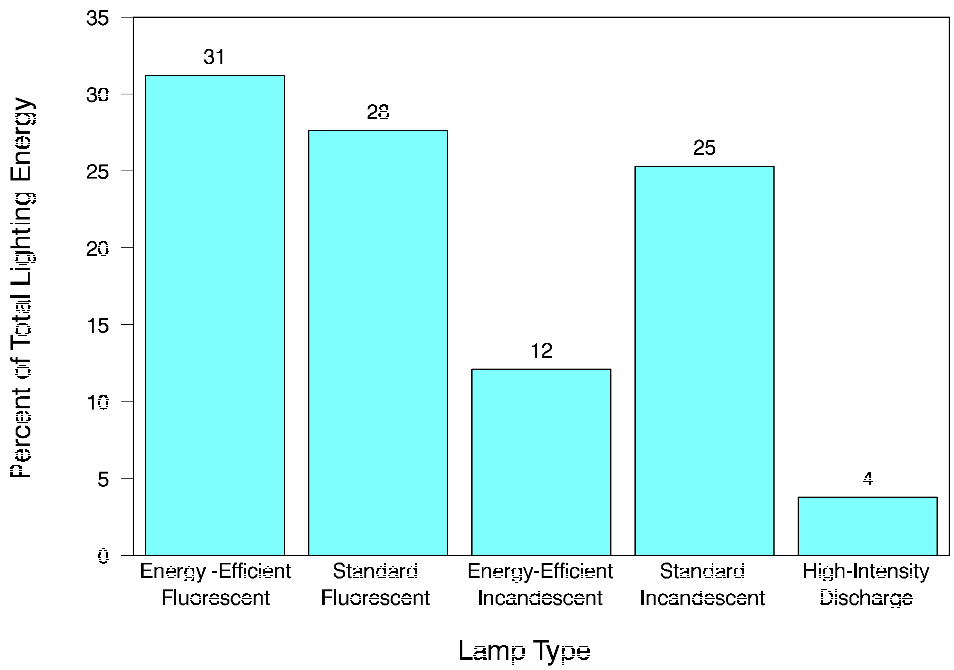
Notes: • For each building size category, lighting energy intensity per lighted floorspace (per total floorspace) is the estimated lighting energy divided by the lighted floorspace (total floorspace) in the category. • For each size category, the energy intensities are plotted at a horizontal position corresponding to the average size for building in the category.

Sources: Floorspace from Energy Information Administration, Office of Energy Markets and End Use, Form EIA-871A, "Building Questionnaire" of the 1986 Nonresidential Buildings Energy Consumption Survey. Illuminance and efficacy derived from sources described in Appendices B and C. Lighting energy intensity derived from illuminance, efficacy, and floorspace.

Regional Economic Research,[16] also using the 1986 CBECS data and assigning in-use lighting intensity based on building activity, estimated commercial indoor lighting energy consumption at 249 billion kWh.

In relative terms, incandescent lamps serve one-quarter as much floorspace as fluorescent, yet account for almost two-thirds as much lighting energy consumption (Figure 11). The contribution of incandescent lamps is about 37 percent of commercial indoor lighting energy consumption.

Figure 11. Commercial Buildings Lighting Energy by Lamp Type



Note: For each lamp type, the estimated lighting energy provided by that type is shown as a percent of the total estimated indoor commercial lighting (321.4 billion kilowatthours).

Sources: Floorspace by lamp type from Energy Information Administration, Office of Energy Markets and End Use, Form EIA-871A, "Building Questionnaire" of the 1986 Nonresidential Buildings Energy Consumption Survey. Illuminance and efficacy derived from sources described in Appendices B and C. Lighting energy is derived from illuminance, efficacy, and floorspace.

Lighting Energy Consumption by Building Characteristics

The combined effect of illuminance and lighting hours is seen in a comparison of lighting energy use by principal building activity (Figure 12). Office buildings account for about 18 percent of both lighted floorspace (Figure 4 above) and lighting energy. Health care and lodging buildings, respectively, represent 4 and 5 percent of lighted floorspace, but 19 and 13 percent of commercial buildings' lighting energy. Assembly buildings, by contrast, account for 12 percent of lighted floorspace but only 7 percent of lighting energy.

The basis for the differences between the proportion of lighted floorspace and the proportion of lighting energy is the difference in EUI (Figure 9 above). For health care and lodging buildings, high EUI's result from long hours combined with high illuminance for health care buildings and low efficacy for lodging. The low efficacy for lodging buildings stems from relatively large fractions of floorspace lighted by incandescent bulbs.

Formal Specification:

The lighting power density (w/sf)is simply the ratio of the in-use illuminance **I** (l/sf) to the equipment efficacy **Q** (l/w).

$$P = I/Q.$$

Thus, as indicated above, lighting energy is the product of the lighted floorspace-hours and the lighting power density:

$$E = (SH)\,P.$$

The annual end-use intensity **EUI** (kWh/sf) is obtained by adjusting the lighting power density by the usage factor, then scaling by the number of hours (thousand) in a year:

$$EUI = 8.760\,U\,P.$$

The **EUI** can also be expressed in terms of the time-averaged illuminance as

$$EUI = 8.760\,T/Q.$$

Each expression applies for individual buildings or floorspace components within buildings. The relationship between an aggregate EUI and the EUI's for individual buildings or components is discussed in Appendix D. In general, the average product is not equal to the product of averages.

Alternate Assumptions for Lighting Energy Estimates

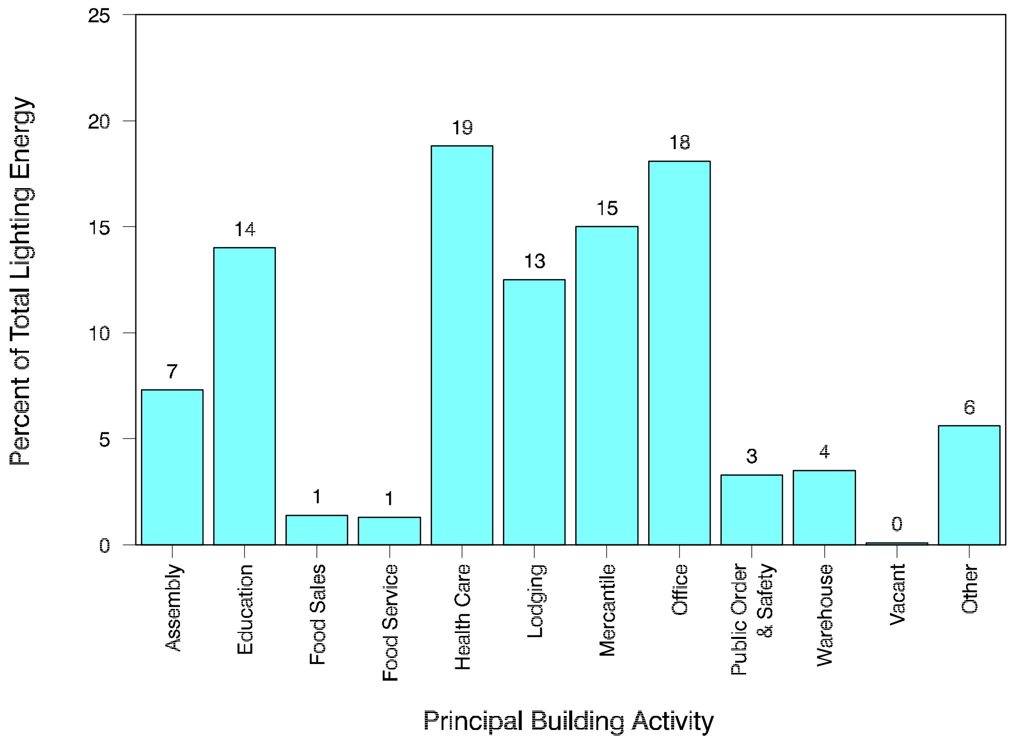
Because of the uncertainty and simplifications at each step of the lighting energy computation, the resulting estimates are only approximate. To gauge the possible errors introduced by some of the assumptions made, overall commercial lighting energy was recomputed under some alternate assumptions.

The estimates presented above assume that the current effect of conservation features in place is negligible. As indicated, this assumption does not imply that the features are inherently ineffective, only that the fraction of floorspace they apply to is very small, even in buildings where they are present.

An alternate energy calculation was made under the assumption that lighting controls, high-efficiency ballasts, and delamping are all at their modest levels (as defined in Appendix C) in the buildings where they are present. That is, these features were assumed to have some effect, but not a substantial effect, on average. Reflectors were still assumed to have negligible penetration, since there were no data from the CBECS on whether these were even present in a given building.

With the three indicated conservation features assumed to have modest effects, the lighting energy estimate is 294 billion kWh, or 1.0 quadrillion Btu. This estimate coincides with the EIA estimate cited in the "Introduction." The base case estimate above, which assumes the conservation features to have no effect, is about 10 percent higher.

Figure 12. Commercial Buildings Lighting Energy by Principal Building Activity



Note: For each principal building activity category, the lighting energy for that category is shown as a percent of the commercial indoor lighting energy (321.4 billion kilowatthours).

Sources: Floorspace by building activity from Energy Information Administration, Office of Energy Markets and End Use, Form EIA-871A, "Building Questionnaire" of the 1986 Nonresidential Buildings Energy Consumption Survey. Illuminance and efficacy derived from sources described in Appendices B and C. Lighting energy is derived from illuminance, efficacy, and floorspace.

As an average across all applicable floorspace, even the conservation effect designated as modest is probably a generous estimate of the effect of features in place in 1986. (The designations "modest" and "optimistic" are relative, and refer to the impact if the conservation feature were adopted wherever possible.) Thus, if all other factors were well determined, a realistic value for commercial lighting energy would probably lie somewhere between the base case of 1.1 quadrillion Btu and the alternate estimate of 1.0 quadrillion Btu.

The other major unknown factor is the set of illuminances assumed. The base case estimate uses the high illuminance guidelines, on the principle that equipment of all kinds has historically been designed toward high capacity, to ensure adequate service to occupants. Adopting the middle guideline instead would lower the energy estimate by about one-third, to around 0.7 quadrillion Btu. Under this alternate assumption, all illuminance, power density, and energy intensities would likewise drop by one-third.

Lighting Energy Conservation Potential

Lighting, as already noted in this report, is a major focus of conservation efforts in the commercial sector. The statistical profile developed in the previous section provides a basis for estimating the potential for lighting energy conservation under various assumptions. A simple estimation procedure utilizing that profile is described next. The procedure is then applied under various assumptions about the conservation measures adopted.

Using the estimates described above (and presented in Tables 1 through 9 of the Detailed Tables) the savings estimation procedure described below could be implemented under other conservation assumptions. The different conservation cases evaluated in this report vary both in terms of what changes are assumed implemented, and in terms of the impact assumed for each change. These varying assumptions are designed to cover a range of plausible situations. Nonetheless, arguments could certainly be made for impacts outside the ranges considered here, as well as for implementing other changes.

No assessment of cost-effectiveness is made for any of the cases considered. The changes suggested by a cost-effectiveness analysis might be less extensive, more radical, or simply different from any of the combinations considered here. In addition, actual changes would not occur instantaneously, as implicitly assumed by the analysis here.

As noted earlier, the base estimate of commercial lighting energy is also subject to wide variation depending on technical assumptions. To avoid undue dependence on these assumptions, particularly the illuminance assignments, the conservation estimates are presented primarily in terms of the percentage of lighting energy saved. Uniformly higher or lower base-case illuminance assignments would yield the same percentage savings, though substantially different absolute savings. The percent savings are translated into approximate energy amounts at the end, to indicate the magnitude of the impact.

Savings Estimation Methodology

Savings are estimated by computing the percent reduction according to the equipment currently in place and the assumed improved technology or practice adopted. Since the statistical profile provides estimates of energy use for each lighting equipment configuration, savings estimates are easily calculated under alternate assumptions.

Potential lighting energy savings are evaluated for several conservation cases. Each case is defined by an assumed equipment replacement scheme, together with the assumed effects of the conservation features adopted under that scheme. For each conservation case an overall deflation factor is computed for each of the five lamp types considered for the base case energy calculations. The overall deflation factor is obtained as the product of the deflation factors for the conservation features adopted.

Applying the deflation factor to the base case energy gives the estimated energy use by that lamp type after implementing the assumed replacements. From the conservation-case energy estimates for each lamp type, the total energy use after replacements and the percent savings relative to the base case are obtained.

This procedure is kept relatively simple because the base case assumes no effect of conservation features in place. Under this assumption, the deflation factors depend only on the lamp type. Under an alternate base case, assuming some conservation effect for the features currently in place, different overall deflation factors would be computed for each lighting configuration (combination of lamp type with conservation features). The same basic method would still apply. The procedure is described in more detail in Appendix E.

Formal Specification:

For lamp type **L**, to be replaced by lamp type **L***, the overall deflation factor is computed as

$$d = (Q_L/Q_{L^*})\ [d_{CTL}]\ [d_{HEB}]\ [d_{RFL}]\ [d_{DEL}],$$

where Q_L is the efficacy of lamp type **L**, and d_{CTL}, d_{HEB}, d_{RFL}, and d_{DEL}, respectively, indicate the deflation factors for controls, high-efficiency ballasts, reflectors, and delamping. The square brackets indicate that the deflation factor d_f is included in the product if (and only if) feature **f** is adopted for that lamp type under the replacement scheme. Each equipment replacement scheme assumes that all lamps of a given type **L** are changed to the designated replacement **L***. Selection of the modest and optimistic values of the deflation factors is discussed in Appendix C.

Savings Potential

Converting all incandescent bulbs to compact fluorescent lamps with reflectors saves close to 30 percent of the base case lighting energy, with the conservation effects assumed for this analysis. A complementary scheme excludes compact fluorescents but converts all equipment to the most energy-efficient version of that specific lamp type, together with lighting controls. This scheme is estimated to save 30 to 50 percent of the base case lighting energy without reducing illumination levels. The most extreme conservation case considered for this analysis indicates savings of nearly 80 percent of the base case lighting energy. This case includes lighting controls and extensive reductions in illumination, as well as universal lamp replacement by more efficient equipment. All these estimates depend heavily on the effectiveness (including penetration) assumed for the conservation measures.

Equipment Replacement Schemes

The potential energy savings that would be obtained by converting commercial floorspace to more efficient lighting equipment is evaluated for several different conservation cases. Three basic equipment replacement schemes are considered (Figure 13). Each of the three basic schemes is evaluated at the more modest and at the more optimistic assumed conservation effects, with and without delamping.

Each conservation feature applied in a building is assumed to apply uniformly to all floorspace lighted by equipment that can use the feature. That is, the effect assumed for each feature is an average over all applicable floorspace; lower penetration would correspond to a lower assumed effect.

The no-delamping cases assume that whatever lighting levels currently exist are to be maintained. The delamping cases assume that substantial fractions of floorspace are currently overlit, so that average lighting levels could be reduced without loss of amenity or productivity. The extent of delamping adopted for the conservation case is also assumed at a modest (10 percent) and an optimistic (25 percent) level.

The first replacement scheme considered (*comprehensive*) represents a replacement of all existing lighting equipment with a more efficient counterpart. The second (*compact fluorescent conversion only*) represents the effect of a single, very commonly considered strategy. The third scheme serves as a complement to the second, to indicate what can be accomplished without that dominating effect.

Specifically, the three replacement schemes are defined as follows.

1) Comprehensive. All lighted floorspace is converted to the most efficient possible equipment of the same type. Fluorescent lamps are converted to very-high efficiency fluorescent lamps with high-efficiency ballasts and reflectors. Incandescent lamps are all converted to compact fluorescents with reflectors. High-intensity discharge lamps are assumed to be metal halide currently, and to convert to the more efficient high-pressure sodium.

2) Compact Fluorescent Conversion Only. A substantial fraction of the savings from the comprehensive scheme are due to the conversion of incandescent bulbs to compact fluorescents. To examine this effect, standard and energy-efficient incandescents are assumed to be replaced by compact fluorescent lamps with reflectors, with no other changes.

3) Comprehensive Improvements Without Compact Fluorescent Conversions. As a complement to scheme (2), this replacement scheme assumes all the changes of the comprehensive scheme (1), except that incandescent bulbs are not converted to compact fluorescent lamps. Instead, incandescent bulbs are converted to energy-efficient incandescents with controls.

Figure 13. Schematic of Equipment Replacement Schemes

Lamp Type	Conservation Features	Equipment Replacement Scheme (1) Comprehensive	(2) Compact Fluorescent Conversion Only	(3) Comprehensive Improvement Without Compact Fluorescent Conversions
Incandescent				
	Controls	X		X
	Compact Fluorescent	X	X	
	Reflector	X	X	
	Energy-Efficient Bulb			X
Fluorescent				
	Controls	X		X
	High-Efficiency Ballast	X		X
	Very-High Efficiency Lamp	X		X
	Reflector	X		X
High-Intensity Discharge (HID)				
	Controls	X		X
	High-Pressure Sodium	X		X

X = Addition of or conversion to this feature is assumed under the indicated scheme, for all floorspace lighted by the indicated lamp type.

Note: For the base case, controls, high-efficiency ballasts, reduced illumination (delamping), and reflectors are assumed to serve negligible fractions of floorspace, even though present for some buildings. High-intensity discharge lamps are assumed to be metal halide in the base case, and to convert to high-pressure sodium under schemes (1) and (3).

Formal Specification:
The overall deflation factors for the replacement schemes with no delamping are:

	(1) Comprehensive	(2) Compact Fluorescent Conversion Only	(3) Comprehensive Improvements without Compact Fluorescent Conversions
Fluorescent:	$(Q_L/Q_{VHE})\ d_{RFL}\ d_{HEB}\ d_{CTL}$	**1.0**	$(Q_L/Q_{VHE})\ d_{RFL}\ d_{HEB}\ d_{CTL}$
Incandescent:	$(Q_L/Q_{CF})\ d_{RFL}\ d_{CTL}$	$(Q_L/Q_{CF})\ d_{RFL}$	$(Q_L/Q_{EEI})\ d_{CTL}$
HID:	$(Q_{MH}/Q_{HPS})\ d_{CTL}$	**1.0**	$(Q_{MH}/Q_{HPS})\ d_{CTL}$

With illuminance reductions (delamping) all the above deflation factors are multiplied by the delamping deflation factor d_{DEL}.

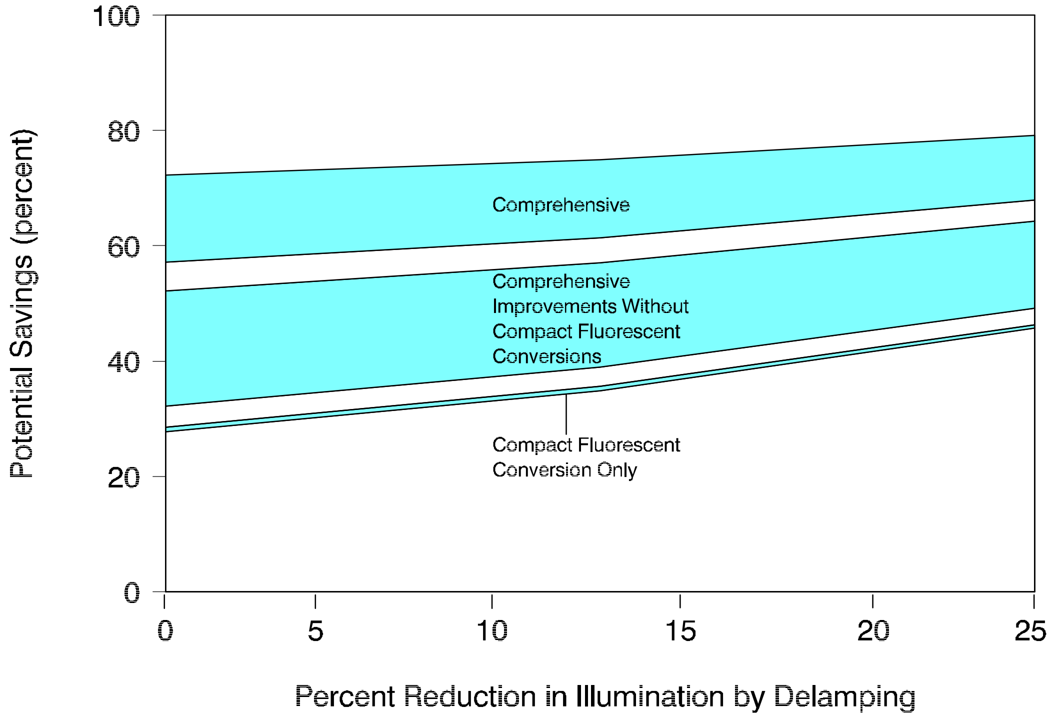
Results

The most drastic conservation case considered was the comprehensive replacement scheme with the optimistic assumptions for the conservation effects, including delamping. For this case, potential savings are estimated at nearly 80 percent of current (1986) use (Figure 14). Savings of close to 30 percent of current use come from converting incandescent bulbs to compact fluorescent lamps with reflectors (scheme 2). With compact fluorescent conversions excluded, but all other replacements made (scheme 3), savings estimates are in the range of 30 to 50 percent with no delamping, and as high as 64 percent with optimistic conservation effects and delamping. (See Table 12 of the "Detailed Tables" section.)

Different lamp types dominate the savings under different replacement schemes. (See Table 10 of the Detailed Tables for savings estimates by lamp type under the no-delamping conservation cases.) Under the schemes that include compact fluorescent conversions, the amount of energy saved by converting space currently served by incandescent bulbs to better equipment (including controls) is between 90 and 100 billion kWh. (See Table 10 of the Detailed Tables.) A comparable amount is saved by improving the equipment for space currently lighted by fluorescent lamps, but the savings for incandescents amounts to about three-quarters of their base case use. (See Table 11 of the Detailed Tables). Under the third replacement scheme, which excludes compact fluorescents, the savings for incandescent bulbs are from controls only, and contribute relatively little to the total savings.

In total, the savings under the most drastic conservation case considered would be about 254 billion kWh, or 0.9 quadrillion Btu. Under the least effective case, the potential savings estimate translates into about 89 billion kWh, or 0.3 quadrillion Btu.

Figure 14. Range of Potential Savings for Various Conservation Cases



Note: A conservation case is defined by an equipment replacement scheme together with an assumed effect of conservation features and reduction in illumination. Each band shows the range of estimated savings from the modest to the optimistic assumptions for the effect of conservation features, as described in Appendix C. The equipment replacement schemes are:

(1) Comprehensive: highest efficiency fluorescent and high-intensity discharge lamps and equipment; incandescent bulbs converted to compact fluorescent with reflectors; lighting controls on all lamps;

(2) Compact Fluorescent Conversion Only: incandescent bulbs converted to compact fluorescent with reflectors; no lighting controls;

(3) Comprehensive Improvement Without Compact Fluorescent Conversions: highest efficiency fluorescent, incandescent and high-intensity-discharge lamps and equipment; no conversions of incandescent to compact fluorescent; lighting controls on all lamps.

The potential savings are shown for each case as a percent of the base case lighting energy estimate (321.4 billion kilowatthours).

Sources: Adapted from Energy Information Administration, Office of Energy Markets and End Use, Form EIA-871A, "Building Questionnaire" of the 1986 Nonresidential Buildings Energy Consumption Survey; and sources described in Appendices B and C.

Sensitivity Test

Savings estimates for all cases were recomputed assuming a uniform illuminance and uniform lighting hours across all buildings. This set of computations was performed as a check on the sensitivity of the results to the illuminances assumed and the method of estimating lighting hours. For the Comprehensive and Compact Fluorescent Conversion Only schemes (1 and 2), savings estimates were three to four percentage points higher, corresponding to a 5 to 10 percent increase in the savings estimated. For the scheme (3) that allowed no compact fluorescent conversion, assuming illuminance and hours were uniform made essentially no difference in the estimate of potential savings.

Thus, while the assignment of illuminance to buildings is not precise, errors in these assignments do not appear to affect the estimates of potential savings, expressed as a percent of total current lighting energy. In absolute terms, of course, the illuminance assumptions directly affect the estimates of both energy and savings.

Consideration of the illuminances affects the potential savings estimates primarily by indicating a lower effect of converting incandescent bulbs to compact fluorescent lamps than would be obtained by ignoring illuminance differences. The association of more efficient (i.e., nonincandescent) lighting equipment with higher illuminances means that a smaller fraction of energy is currently supplied by incandescent bulbs, hence less can be achieved by converting these bulbs to more efficient equipment.

Future and Related Analyses

This report is intended as a building block for the development of a more comprehensive understanding of commercial lighting and the potential for lighting energy savings. Steps to build on this analysis can be taken in many directions. One possibility already noted is to obtain revised estimates under alternate assumptions with the framework presented here.

The same methods could also be applied to CBECS data from other years. Because of the reduced detail on lighting equipment in 1989, and the lack of any lighting equipment data from the earlier surveys, characteristics from 1986 would have to be extrapolated to other years. However, collection of more detailed lighting data is again planned for the 1992 CBECS, which will be a longitudinal follow-up of the 1986 sample. Thus, a more up-to-date and longitudinal analysis will be possible when the 1992 data become available.

Other dimensions of commercial lighting can be explored through the combination of the CBECS data with engineering estimates. For example, this analysis considers total energy requirement, or average power requirement, but not peak power requirements. Commercial lighting load curves could be developed for the CBECS data, using the weekly operating schedules from CBECS together with the in-use power density assigned for the present analysis. Another interesting extension would involve comparison between lighting energy estimates developed for each building via this methodology and the building's total annual electricity use.

An important issue not addressed by this analysis is the cost of the various conservation strategies considered. The economics of implementing some of the conservation features considered here are being examined as part of the lighting initiative being conducted by Lawrence Berkeley Laboratory for the Office of Conservation and Renewable Energy. It is hoped that the results of the present analysis will be useful in connection with that effort.

The potential for lighting energy conservation in other sectors can also be addressed using EIA data. The 1990 Residential Energy Consumption Survey (RECS) collected household lighting equipment data similar to that collected by CBECS, providing the basis for a similar analysis. The 1991 Manufacturing Energy Consumption Survey (MECS) is attempting to collect data on the amount of electricity consumption devoted to lighting, as well as on participation in energy efficiency programs.

EIA's energy consumption surveys continue to evolve in response to users' growing and changing data needs. Appropriate analysis of these surveys can mine a wealth of information about the complex patterns of energy use in the United States, and the Nation's progress toward greater energy efficiency.

Detailed Tables

A variety of statistics relating to lighting energy are presented in this section. Statistics are presented by subgroups based on building characteristics, and by subgroups based on lighting equipment. The three sets of subgroups presented are:

(1) Four classes of building characteristics: principal activity, size, year constructed, and Census region;

(2) Five lamp types: standard incandescent, energy-efficient incandescent, standard fluorescent, energy-efficient incandescent, high-intensity discharge (HID);

(3) Lighting configurations (combinations of lamps and conservation features): controls, high-efficiency ballast, reduced illuminance in (delamping).

The statistics presented are aggregate totals, such as lighted floorspace, and averages, such as illuminance and lighting power density. The averages shown for a particular building or equipment category are floorspace-weighted averages of the corresponding values for the individual buildings in that category. (Appendix A describes the computation of floorspace-weighted averages.) Because the quantities are computed at the building level and then averaged, it is not always possible to derive one column of a table from the statistics in corresponding columns of components.

For each table in this section, Appendix F gives a corresponding Relative Standard Error Table. The following Quick Reference Guide indicates the table numbers and what statistics each contains.

Quick Reference Guide to the Detailed Tables

Statistics on	By Building Characteristics	By Lamp Type	By Lamp and Conservation Features
Aggregate Totals			
Floorspace	1, 9		
Lighted Floorspace	1, 3, 9	1, 4	8
Lighted Floorspace by Lamp Type	1		
Lighted Floorspace-Hours	3	4	
Lighting Energy	9	8	8
Energy Savings		10, 11	
Floorspace-Weighted Averages			
Operating Hours	3	4	
Effective Lighting Hours	3	4	
Illuminance	5, 7	6	6
Efficacy		6	6
Lighting Power Density	7	6	6
End-Use Intensity	9	8	8

Savings Estimates by Conservation Case: Table 12.

Table 1. Lighted Floorspace by Type of Lamp and Building Characteristics
(Million Square Feet)

Building Characteristics	Type of Lamp: Fluorescent Standard	Fluorescent Energy-Efficient	Fluorescent Total	Incandescent Standard	Incandescent Energy-Efficient	Incandescent Total	High Intensity Discharge	Total Lighted Floorspace	Total Floorspace
All Buildings	20,700	17,131	37,831	6,774	2,551	9,325	3,064	49,590	58,199
Principal Activity									
Assembly	2,327	1,306	3,633	1,556	553	2,109	327	5,918	7,339
Education	2,854	3,372	6,225	442	181	623	242	6,968	7,292
Food Sales	281	256	538	77	Q	104	Q	668	712
Food Service	342	231	573	430	109	539	Q	1,133	1,281
Health Care	515	1,233	1,748	103	96	199	Q	2,010	2,107
Lodging	529	552	1,081	1,001	452	1,452	Q	2,423	2,785
Mercantile/Service	5,900	3,652	9,552	914	464	1,378	500	11,361	12,805
Office	3,704	4,059	7,763	537	382	919	170	8,763	9,546
Public Order and Safety	210	231	440	Q	Q	Q	Q	573	680
Warehouse	2,859	1,480	4,339	1,204	100	1,304	1,304	6,917	8,996
Vacant	683	309	992	245	114	358	38	1,392	2,931
Other	495	452	947	158	66	223	296	1,464	1,726
Building Size (square feet)									
1,001 to 5,000	2,745	972	3,717	1,051	150	1,201	74	5,023	6,209
5,001 to 10,000	2,833	1,281	4,114	1,016	296	1,311	163	5,545	6,861
10,001 to 25,000	3,580	1,953	5,532	1,187	462	1,650	275	7,405	9,119
25,001 to 50,000	3,430	2,205	5,636	1,101	295	1,396	445	7,451	8,661
50,001 to 100,000	2,856	2,821	5,677	817	455	1,272	534	7,350	8,559
100,001 to 200,000	2,409	2,394	4,803	691	306	998	543	6,275	7,161
200,001 to 500,000	1,764	3,107	4,872	672	386	1,058	527	6,198	6,737
Over 500,000	1,083	2,398	3,482	239	200	439	503	4,342	4,893
Year Constructed									
Before 1920	1,794	1,032	2,826	970	317	1,287	61	4,139	5,735
1920-1945	3,083	1,885	4,968	1,424	452	1,876	164	6,907	8,894
1946-1959	3,451	2,150	5,600	1,043	247	1,289	371	7,180	8,534
1960-1969	4,174	3,665	7,839	1,403	409	1,812	470	10,000	11,117
1970-1979	5,163	4,911	10,074	1,286	556	1,842	961	12,644	14,036
1980-1986	3,035	3,488	6,523	649	570	1,219	1,037	8,721	9,883
Census Region									
Northeast	3,760	4,103	7,863	1,330	410	1,740	543	9,963	11,830
Midwest	5,513	4,125	9,638	1,879	696	2,576	1,107	13,140	16,034
South	7,775	4,959	12,734	2,385	959	3,344	968	16,790	19,397
West	3,652	3,943	7,595	1,179	486	1,665	446	9,697	10,937

Q Data withheld because the Relative Standard Error (RSE) was greater than 50 percent.

Notes: • The sum across lamp types may be greater than the total lighted floorspace because some floorspace is lighted by more than one type of lamp. The discrepancy is approximately 2 percent or less. • Table of RSE's can be found in Appendix F. • See Appendix A for an explanation of floorspace computations and the Glossary for explanations of abbreviations and definitions used in this report.

Source: Energy Information Administration, Office of Energy Markets and End Use, Form EIA-871A, "Building Questionnaire" of the 1986 Nonresidential Buildings Energy Consumption Survey.

Table 2. Percent of Lighted Floorspace by Type of Lamp and Building Characteristics

Building Characteristics	Type of Lamp							Total Lighted Floorspace
	Fluorescent			Incandescent			High-Intensity Discharge	
	Standard	Energy-Efficient	Total	Standard	Energy-Efficient	Total		
All Buildings	41.7	34.5	76.3	13.7	5.1	18.8	6.2	100.0
Principal Activity								
Assembly	39.3	22.1	61.4	26.3	9.3	35.6	5.5	100.0
Education	41.0	48.4	89.3	6.3	2.6	8.9	3.5	100.0
Food Sales	42.1	38.4	80.5	11.6	3.9	15.5	Q	100.0
Food Service	30.2	20.3	50.5	38.0	9.6	47.6	Q	100.0
Health Care	25.6	61.4	87.0	5.1	4.8	9.9	Q	100.0
Lodging	21.9	22.8	44.6	41.3	18.6	59.9	Q	100.0
Mercantile/Service	51.9	32.1	84.1	8.0	4.1	12.1	4.4	100.0
Office	42.3	46.3	88.6	6.1	4.4	10.5	1.9	100.0
Public Order and Safety	36.6	40.2	76.9	18.8	Q	20.3	Q	100.0
Warehouse	41.3	21.4	62.7	17.4	1.4	18.8	18.9	100.0
Vacant	49.1	22.2	71.3	17.6	8.2	25.7	2.8	100.0
Other	33.8	30.9	64.7	10.8	4.5	15.3	20.2	100.0
Building Size (square feet)								
1,001 to 5,000	54.6	19.3	74.0	20.9	3.0	23.9	1.5	100.0
5,001 to 10,000	51.1	23.1	74.2	18.3	5.3	23.6	2.9	100.0
10,001 to 25,000	48.3	26.4	74.7	16.0	6.2	22.3	3.7	100.0
25,001 to 50,000	46.0	29.6	75.6	14.8	4.0	18.7	6.0	100.0
50,001 to 100,000	38.9	38.4	77.2	11.1	6.2	17.3	7.3	100.0
100,001 to 200,000	38.4	38.2	76.5	11.0	4.9	15.9	8.6	100.0
200,001 to 500,000	28.5	50.1	78.6	10.8	6.2	17.1	8.5	100.0
Over 500,000	24.9	55.2	80.2	5.5	4.6	10.1	11.6	100.0
Year Constructed								
Before 1920	43.3	24.9	68.3	23.4	7.7	31.1	1.5	100.0
1920-1945	44.6	27.3	71.9	20.6	6.5	27.2	2.4	100.0
1946-1959	48.1	29.9	78.0	14.5	3.4	18.0	5.2	100.0
1960-1969	41.7	36.7	78.4	14.0	4.1	18.1	4.7	100.0
1970-1979	40.8	38.8	79.7	10.2	4.4	14.6	7.6	100.0
1980-1986	34.8	40.0	74.8	7.4	6.5	14.0	11.9	100.0
Census Region								
Northeast	37.7	41.2	78.9	13.4	4.1	17.5	5.5	100.0
Midwest	42.0	31.4	73.4	14.3	5.3	19.6	8.4	100.0
South	46.3	29.5	75.8	14.2	5.7	19.9	5.8	100.0
West	37.7	40.7	78.3	12.2	5.0	17.2	4.6	100.0

Q Data withheld because the Relative Standard Error (RSE) was greater than 50 percent.

Notes: • The percentage in each cell was computed by taking the floorspace from the corresponding cell in Table 1 and dividing it by the total lighted floorspace for that row. • The sum of percentages over types of lamps may be greater than 100 because some floorspace is lighted by more than one type of lamp. The discrepancy is approximately 2 percent or less. • Table of RSE's can be found in Appendix F. • See Appendix A for an explanation of floorspace computations and the Glossary for explanations of abbreviations and definitions used in this report.

Source: Energy Information Administration, Office of Energy Markets and End Use, Form EIA-871A, "Building Questionnaire" of the 1986 Nonresidential Buildings Energy Consumption Survey.

Table 3. Usage Measures by Building Characteristics

Building Characteristics	Total Lighted Floorspace (million square feet)			Operating Hours per Week	Total Weekly Lighted Floorspace-Hours (billion square foot-hours)			Effective Lighting Hours per Week	
	Open	Closed	Ratio (Closed/ Open)		Open	Closed	Total (Open + Closed)	H^e	Ratio (Effective Lighting/ Operating)
All Buildings	49,590	8,304	0.17	70.6	3,501	465	3,965	80.0	1.13
Principal Activity									
Assembly	5,918	505	0.09	55.2	327	33	360	60.8	1.10
Education	6,968	589	0.08	52.1	363	64	427	61.3	1.18
Food Sales	668	231	0.35	103.8	69	9	78	117.5	1.13
Food Service	1,133	160	0.14	91.6	104	8	112	98.7	1.08
Health Care	2,010	1,102	0.55	152.6	307	1	308	153.3	1.00
Lodging	2,423	1,211	0.50	160.5	389	2	391	161.5	1.01
Mercantile/Service	11,361	1,522	0.13	66.5	756	129	885	77.9	1.17
Office	8,763	1,272	0.15	54.6	478	127	606	69.1	1.27
Public Order and Safety	573	295	0.51	127.3	73	5	78	135.3	1.06
Warehouse	6,917	847	0.12	65.9	456	55	511	73.9	1.12
Vacant	1,392	143	0.10	36.3	50	15	65	47.0	1.30
Other	1,464	428	0.29	88.0	129	15	144	98.3	1.12
Building Size (square feet)									
1,001 to 5,000	5,023	563	0.11	59.4	298	39	337	67.2	1.13
5,001 to 10,000	5,545	485	0.09	60.5	336	39	375	67.6	1.12
10,001 to 25,000	7,405	967	0.13	63.7	472	55	526	71.1	1.12
25,001 to 50,000	7,451	1,004	0.13	64.3	479	64	543	72.8	1.13
50,001 to 100,000	7,350	1,192	0.16	74.0	544	70	614	83.5	1.13
100,001 to 200,000	6,275	1,270	0.20	74.4	467	68	535	85.2	1.15
200,001 to 500,000	6,198	1,545	0.25	82.5	512	67	579	93.4	1.13
Over 500,000	4,342	1,278	0.29	90.8	394	62	456	105.1	1.16
Year Constructed									
Before 1920	4,139	563	0.14	60.5	250	44	294	71.0	1.17
1920-1945	6,907	1,022	0.15	66.9	462	57	518	75.0	1.12
1946-1959	7,180	932	0.13	65.0	467	58	525	73.1	1.12
1960-1969	10,000	1,658	0.17	70.0	700	95	794	79.4	1.14
1970-1979	12,644	2,443	0.19	76.2	963	132	1,096	86.7	1.14
1980-1986	8,721	1,686	0.19	75.6	659	79	738	84.6	1.12
Census Region									
Northeast	9,963	1,812	0.18	73.5	733	103	836	83.9	1.14
Midwest	13,140	2,133	0.16	70.0	920	130	1,049	79.9	1.14
South	16,790	2,833	0.17	70.5	1,184	143	1,327	79.0	1.12
West	9,697	1,527	0.16	68.5	664	89	753	77.7	1.13

Notes: • Effective Lighting Hours are obtained by dividing the total lighted floorspace-hours by the open-hours lighted floorspace. • Hours per week shown for each row are floorspace-weighted averages. • Table of Relative Standard Errors can be found in Appendix F. • See Appendix D for explanation of floorspace-hour computations and the Glossary for explanations of abbreviations and definitions used in this report.

Source: Energy Information Administration, Office of Energy Markets and End Use, Form EIA-871A, "Building Questionnaire" of the 1986 Nonresidential Buildings Energy Consumption Survey.

Table 4. Usage Measures by Lighting Equipment

Lamp Type	Total Lighted Floorspace (million square feet)			Operating Hours per Week	Total Weekly Lighted Floorspace-Hours (billion square foot-hours)			Effective Lighting Hours per Week	
	Open	Closed	Ratio (Closed/ Open)		Open	Closed	Total (Open + Closed)	H^e	Ratio (Effective Lighting/ Operating)
Fluorescent	37,831	6,238	0.16	68.8	2,601	377	2,978	78.7	1.14
Standard	20,700	2,810	0.14	64.4	1,332	194	1,527	73.7	1.15
Energy-Efficient	17,131	3,428	0.20	74.1	1,269	183	1,452	84.7	1.14
Incandescent	9,325	1,571	0.17	75.1	701	63	763	81.9	1.09
Standard	6,774	1,079	0.16	71.7	486	43	529	78.1	1.09
Energy-Efficient	2,551	492	0.19	84.3	215	19	234	91.9	1.09
High-Intensity Discharge . .	3,064	697	0.23	83.7	256	33	289	94.3	1.13

Notes: • Floorspace allocation by lamp type assumes the proportions of floorspace served by different lamps within a building is the same during off-hours as during operating hours. • Effective Lighting Hours are obtained by dividing the total lighted floorspace-hours by the open-hours lighted floorspace. • Hours per week shown for each row are floorspace-weighted averages. • Table of Relative Standard Errors can be found in Appendix F. • See Appendix D for explanation of floorspace-hour computations and the Glossary for explanations of abbreviations and definitions used in this report.

Source: Energy Information Administration, Office of Energy Markets and End Use, Form EIA-871A, "Building Questionnaire" of the 1986 Nonresidential Buildings Energy Consumption Survey.

Table 5. Average Assigned Illuminance Ranges by Building Characteristics

Building Characteristics	Average Assigned Illuminance Range (lumens per square foot)		
	Low	Medium	High
All Buildings	30.0	45.0	65.3
Principal Activity			
Assembly	19.1	28.6	46.9
Education	50.0	75.0	100.0
Food Sales	20.0	30.0	50.0
Food Service	10.0	15.0	20.0
Health Care	92.8	139.2	186.5
Lodging	20.0	30.0	50.0
Mercantile/Service	20.0	30.0	50.0
Office	44.6	66.9	91.0
Public Order and Safety	37.1	55.7	78.5
Warehouse	7.9	11.8	17.6
Vacant	2.0	3.0	5.0
Other	48.7	73.1	117.5
Building Size (square feet)			
1,001 to 5,000	24.4	36.5	55.0
5,001 to 10,000	24.3	36.5	54.8
10,001 to 25,000	26.7	40.0	59.5
25,001 to 50,000	28.5	42.7	61.8
50,001 to 100,000	28.6	42.9	62.7
100,001 to 200,000	33.1	49.7	69.9
200,001 to 500,000	35.4	53.1	75.3
Over 500,000	42.5	63.7	89.7
Year Constructed			
Before 1920	25.7	38.5	56.9
1920-1945	30.7	46.1	66.4
1946-1959	29.4	44.1	63.7
1960-1969	30.6	45.9	66.2
1970-1979	30.1	45.2	65.5
1980-1986	31.3	46.9	68.2
Census Region			
Northeast	29.7	44.6	64.7
Midwest	31.1	46.6	67.4
South	28.9	43.4	63.1
West	30.8	46.2	66.7

Notes: • Table of Relative Standard Errors can be found in Appendix F. • See Appendix B for explanation of the average assigned illuminances and the Glossary for explanations of abbreviations and definitions used in this report.

Sources: Adapted from Energy Information Administration, Office of Energy Markets and End Use, Form EIA-788A, "Building Form" of the 1979 Nonresidential Buildings Energy Consumption Survey; Form EIA-871A, "Building Questionnaire" of the 1986 Nonresidential Buildings Energy Consumption Survey; and Illuminating Engineering Society of North America, *IES Lighting Handbook: 1987 Application Volume.*

Table 6. Illuminance and Power Measures by Lighting Configuration

Lamp Type and Conservation Feature Present	Percent of Total Lighted Floorspace	Usage Factor (percent)	Illuminance (lumens per square foot)		Efficacy (lumens per square foot)	In-Use Lighting Power Density (watts per
			In-Use	Time-Averaged		
Standard Fluorescent	41.6	43.9	62.7	28.8	59.0	1.0
No Conservation Features	22.8	41.3	59.2	25.6	59.0	1.0
Ballast	6.6	43.6	61.5	27.3	59.0	1.0
Controls	3.3	48.1	62.7	29.4	59.0	1.1
Delamping	2.6	45.3	73.5	33.9	59.0	1.3
Ballast and Controls	2.7	54.5	61.0	34.2	59.0	1.0
Ballast and Delamping	1.5	40.5	67.6	27.6	59.0	1.1
Controls and Delamping	1.2	55.4	91.4	58.9	59.0	1.6
Ballast, Controls, and Delamping	0.9	51.2	87.2	49.2	59.0	1.4
Energy-Efficient Fluorescent	34.6	50.4	77.3	41.4	62.0	1.2
No Conservation Features	6.5	44.3	66.2	30.5	62.0	1.1
Ballast	9.5	46.7	76.8	38.0	62.0	1.1
Controls	2.6	46.2	65.9	30.9	62.0	1.1
Delamping	1.2	46.6	79.7	37.0	62.0	1.3
Ballast and Controls	4.1	62.1	83.5	54.6	62.0	1.2
Ballast and Delamping	4.2	49.5	85.4	44.6	62.0	1.3
Controls and Delamping	1.1	47.7	84.8	41.0	62.0	1.4
Ballast, Controls, and Delamping	5.4	59.8	84.0	54.3	62.0	1.3
Standard Incandescent	13.6	46.5	50.6	24.7	18.0	2.8
No Conservation Features	10.4	43.6	47.8	22.4	18.0	2.7
Controls	1.8	58.4	54.6	29.3	18.0	3.0
Delamping	0.9	45.5	63.4	29.4	18.0	3.5
Controls and Delamping	0.5	65.3	71.9	48.3	18.0	4.0
Energy-Efficient Incandescent	5.2	54.7	61.4	34.9	20.0	3.1
No Conservation Features	2.6	45.9	56.6	26.3	20.0	2.8
Controls	1.1	64.5	63.5	43.8	20.0	3.2
Delamping	0.6	52.9	70.6	36.3	20.0	3.5
Controls and Delamping	0.9	70.3	67.5	48.8	20.0	3.4
High-Intensity Discharge	6.3	56.1	51.9	31.2	69.0	0.8
No Conservation Features	3.2	52.0	42.3	20.9	69.0	0.6
Controls	1.5	65.6	62.3	45.0	69.0	0.9
Delamping	0.9	49.2	47.5	21.7	69.0	0.7
Controls and Delamping	0.7	64.1	80.7	62.3	69.0	1.2

Notes: • Ballast, Controls, and Delamping, respectively, indicate that high efficiency ballasts, any type or combination of lighting controls, and a delamping program were reported for the building containing the floorspace lit by the indicated lamp. High-efficiency ballasts, when reported, were assumed to apply only to fluorescent lamps. The illuminance or power measure for each lighting equipment configuration is the (lighted-floorspace-weighted) average of that measure across buildings. A column that represents an average product is not equal to the product of the corresponding columns. For example, for a single building, the time-averaged illuminance is the product of the usage factor and the in-use illuminance; however, the average time-averaged illuminance is not the average usage factor times the average in-use illuminance. • Table of Relative Standard Errors can be found in Appendix F. • See Appendices B, C, and D for derivations and the Glossary for explanations of abbreviations and definitions used in this report.

Sources: Percent of floorspace and usage factor from Energy Information Administration, Office of Energy Markets and End Use, Form EIA-871A, "Building Questionnaire" of the 1986 Nonresidential Buildings Energy Consumption Survey; Illuminance and efficacy derived from sources described in Appendices B and C. Lighting power density is derived from illuminance and efficacy.

Table 7. Illuminance and Power Measures by Building Characteristics

Building Characteristics	Percent of Total Lighted Floorspace 1986	Usage Factor (percent)	Illuminance (lumens per square foot)		In-Use Lighting Power Density (watts/square foot)
			In-Use	Time-Averaged	
All Buildings	100.0	47.6	65.3	32.9	1.4
Principal Activity					
Assembly	11.9	36.2	46.9	17.0	1.4
Education	14.1	36.5	100.0	36.5	1.9
Food Sales	1.3	70.0	50.0	35.0	1.1
Food Service	2.3	58.8	20.0	11.7	0.7
Health Care	4.1	91.3	186.5	170.2	3.6
Lodging	4.9	96.1	50.0	48.1	2.0
Mercantile/Service	22.9	46.4	50.0	23.2	1.0
Office	17.7	41.1	91.0	37.5	1.8
Public Order and Safety	1.2	80.5	78.5	63.2	1.9
Warehouse	13.9	44.0	17.6	7.7	0.4
Vacant	2.8	28.0	5.0	1.4	0.1
Other	3.0	58.5	117.5	68.7	2.5
Building Size (square feet)					
1,001 to 5,000	10.1	40.0	55.0	21.9	1.3
5,001 to 10,000	11.2	40.2	54.8	21.4	1.3
10,001 to 25,000	14.9	42.3	59.5	25.1	1.4
25,001 to 50,000	15.0	43.3	61.8	27.8	1.3
50,001 to 100,000	14.8	49.7	62.7	30.9	1.4
100,001 to 200,000	12.7	50.7	69.9	37.9	1.4
200,001 to 500,000	12.5	55.6	75.3	43.6	1.6
Over 500,000	8.8	62.6	89.7	63.9	1.7
Year Constructed					
Before 1920	8.3	42.3	56.9	25.0	1.5
1920-1945	13.9	44.6	66.4	31.6	1.6
1946-1959	14.5	43.5	63.7	29.4	1.4
1960-1969	20.2	47.3	66.2	31.6	1.4
1970-1979	25.5	51.6	65.5	36.9	1.3
1980-1986	17.6	50.3	68.2	36.5	1.4
Census Region					
Northeast	20.1	49.9	64.7	33.4	1.4
Midwest	26.5	47.6	67.4	34.6	1.5
South	33.9	47.0	63.1	31.7	1.4
West	19.6	46.3	66.8	32.4	1.4

Notes: • The illuminance or power measure for each building characteristic is the (lighted-floorspace-weighted) average of that measure across buildings. A column that represents an average product is not equal to the product of the corresponding columns. For example, for a single building, the time-averaged illuminance is the product of the usage factor and the in-use illuminance; however, the average time-averaged illuminance is not the average usage factor times the average in-use illuminance. • Table of Relative Standard Errors can be found in Appendix F. • See Appendices B, C, and D for derivations and the Glossary for explanations of abbreviations and definitions used in this report.

Sources: Percent of floorspace and usage factor from Energy Information Administration, Office of Energy Markets and End Use, Form EIA-871A, "Building Questionnaire" of the 1986 Nonresidential Buildings Energy Consumption Survey; Illuminance and efficacy derived from sources described in Appendices B and C. Lighting power density is derived from illuminance and efficacy.

Table 8. Lighting Energy and Intensity by Lighting Configuration

Lamp Type and Conservation Feature Present	Floorspace (million square feet)		Annual Lighting End-Use Intensity (kWh/square foot)	Annual Lighting Energy (billion kWh)
	Total Lighted	Percent of Total Lighted		
Standard Fluorescent	20,700	41.6	4.3	88.6
No Conservation Features	11,327	22.8	3.8	43.1
Ballast	3,286	6.6	4.1	13.3
Controls	1,654	3.3	4.4	7.2
Delamping	1,297	2.6	5.0	6.5
Ballast and Controls	1,322	2.7	5.1	6.7
Ballast and Delamping	739	1.5	4.1	3.0
Controls and Delamping	615	1.2	8.7	5.4
Ballast, Controls, and Delamping	460	0.9	7.3	3.4
Energy-Efficient Fluorescent	17,130	34.6	5.9	100.4
No Conservation Features	3,222	6.5	4.3	13.9
Ballast	4,702	9.5	5.4	25.3
Controls	1,286	2.6	4.4	5.6
Delamping	600	1.2	5.2	3.1
Ballast and Controls	2,042	4.1	7.7	15.8
Ballast and Delamping	2,098	4.2	6.3	13.2
Controls and Delamping	526	1.1	5.8	3.1
Ballast, Controls, and Delamping	2,654	5.4	7.7	20.4
Standard Incandescent	6,774	13.6	12.0	81.3
No Conservation Features	5,177	10.4	10.9	56.3
Controls	899	1.8	14.3	12.8
Delamping	455	0.9	14.3	6.5
Controls and Delamping	243	0.5	23.5	5.7
Energy-Efficient Incandescent	2,551	5.2	15.3	39.0
No Conservation Features	1,305	2.6	11.5	15.0
Controls	536	1.1	19.2	10.3
Delamping	279	0.6	15.9	4.5
Controls and Delamping	431	0.9	21.4	9.2
High-Intensity Discharge	3,064	6.3	3.9	12.1
No Conservation Features	1,570	3.2	2.7	4.2
Controls	722	1.5	5.7	4.1
Delamping	440	0.9	2.8	1.2
Controls and Delamping	332	0.7	7.9	Q

Q Data withheld because the Relative Standard Error (RSE) was greater than 50 percent.

Notes: • Ballast, Controls, and Delamping, respectively, indicate that high-efficiency ballasts, any type or combination of lighting controls, and a delamping program were reported for the building containing the floorspace lighted by the indicated lamp. High-efficiency ballasts, when reported, were assumed to apply only to fluorescent lamps. • Table of RSE's can be found in Appendix F. • See Appendix D for derivations and the Glossary for explanations of abbreviations and definitions in this report.

Sources: Floorspace from Energy Information Administration, Office of Energy Markets and End Use, Form EIA-871A, "Building Questionnaire" of the 1986 Nonresidential Buildings Energy Consumption Survey; Illuminance and efficacy derived from sources described in Appendices B and C. Lighting end-use intensity and energy measures derived from illuminance and efficacy.

Table 9. Lighting Energy and Intensity by Building Characteristics

Building Characteristics	Floorspace, 1986 (million square feet)			Annual Lighting End-Use Intensity (kWh/square foot)		Annual Lighting Energy (billion kWh)
	Total	Total Lighted	Percent of Total Lighted	per Total Square Feet	per Total Lighted Square Feet	
All Buildings	58,199	49,590	100.0	5.5	6.5	321.4
Principal Activity						
Assembly	7,339	5,918	11.9	3.2	4.0	23.6
Education	7,292	6,968	14.1	6.2	6.5	45.1
Food Sales	712	668	1.3	6.3	6.7	4.5
Food Service	1,281	1,133	2.3	3.2	3.7	4.2
Health Care	2,107	2,010	4.1	28.6	30.0	60.3
Lodging	2,785	2,423	4.9	14.5	16.6	40.2
Mercantile/Service	12,805	11,361	22.9	3.8	4.3	48.3
Office	9,546	8,763	17.7	6.1	6.6	58.1
Public Order and Safety	680	573	1.2	11.8	14.0	8.0
Warehouse	8,996	6,917	13.9	1.2	1.5	10.7
Vacant	2,931	1,392	2.8	0.2	0.3	0.4
Other	1,726	1,464	3.0	10.5	12.3	18.0
Building Size (square feet)						
1,001 to 5,000	6,209	5,023	10.1	3.8	4.7	23.7
5,001 to 10,000	6,861	5,545	11.2	3.7	4.6	25.2
10,001 to 25,000	9,119	7,405	14.9	4.4	5.5	40.4
25,001 to 50,000	8,661	7,451	15.0	4.7	5.5	40.7
50,001 to 100,000	8,559	7,350	14.8	5.3	6.1	45.2
100,001 to 200,000	7,161	6,275	12.7	6.4	7.3	45.6
200,001 to 500,000	6,737	6,198	12.5	7.7	8.4	52.1
Over 500,000	4,893	4,342	8.8	9.9	11.2	48.6
Year Constructed						
Before 1920	5,735	4,139	8.3	4.1	5.7	23.7
1920-1945	8,894	6,907	13.9	5.6	7.2	49.4
1946-1959	8,534	7,180	14.5	4.8	5.7	41.2
1960-1969	11,117	10,000	20.2	5.7	6.4	63.5
1970-1979	14,036	12,644	25.5	6.1	6.8	85.3
1980-1986	9,883	8,721	17.6	5.9	6.7	58.3
Census Region						
Northeast	11,830	9,963	20.1	5.7	6.8	67.3
Midwest	16,034	13,140	26.5	5.5	6.7	87.9
South	19,397	16,790	33.9	5.4	6.2	104.4
West	10,937	9,697	19.6	5.6	6.4	61.7

Notes: • Table of Relative Standard Errors can be found in Appendix F. • See Appendix D for derivations and the Glossary for explanations of abbreviations and definitions used in this report.

Sources: Floorspace from Energy Information Administration, Office of Energy Markets and End Use, Form EIA-871A, "Building Questionnaire" of the 1986 Nonresidential Buildings Energy Consumption Survey; Illuminance and efficacy derived from sources described in Appendices B and C. Lighting end-use intensity and energy measures derived from illuminance and efficacy.

Table 10. Lighting Energy Savings by Lamp Type for Various Conservation Cases, with No Illumination Reduction

(Billion Kilowatthours)

	Standard Fluorescent	Energy-Efficient Fluorescent	Standard Incandescent	Energy-Efficient Incandescent	High Intensity Discharge	Total
Base Case Energy Estimate .	88.6	100.3	81.4	39.0	12.1	321.3
REPLACEMENT SCHEME AND CONSERVATION FEATURE EFFECT (Savings Relative to Base Case)						
Comprehensive						
Modest	42.6	45.4	62.9	29.1	3.6	183.6
Optimistic	60.0	66.2	68.2	31.9	5.5	231.9
Compact Fluorescent Conversion Only						
Modest	0.0	0.0	60.8	28.1	0.0	88.9
Optimistic	0.0	0.0	62.5	28.9	0.0	91.5
Comprehensive Improvements Without Compact Fluorescent Conversions						
Modest	42.6	45.4	8.1	3.9	3.6	103.6
Optimistic	60.0	66.2	24.4	11.7	5.5	167.9

Notes: • A conservation case is defined by a replacement scheme together with an assumed effect of conservation features and reduction in illumination (delamping). • This table shows the amount of lighting energy saved for each no-delamping case, by type of lamp. • See Appendix E for savings estimation methodology and the Glossary for explanations of abbreviations and definitions used in this report.

Sources: Adapted from Energy Information Administration, Office of Energy Markets and End Use, Form EIA-871A, "Building Questionnaire" of the 1986 Nonresidential Buildings Energy Consumption Survey; and sources described in Appendices B and C.

Table 11. Lighting Energy Savings by Lamp Type for Various Conservation Cases, with No Illumination Reduction
(Percent)

	Standard Fluorescent	Energy-Efficient Fluorescent	Standard Incandescent	Energy-efficient Incandescent	High-Intensity Discharge	Total
Base Case Energy Estimate .	100.0	100.0	100.0	100.0	100.0	100.0
REPLACEMENT SCHEME AND CONSERVATION FEATURE EFFECT (Savings Relative to Base Case)						
Comprehensive						
Modest	48.0	45.3	77.3	74.8	29.9	57.1
Optimistic	67.7	66.0	83.8	82.0	45.5	72.2
Compact Fluorescent Conversion Only						
Modest	0.0	0.0	74.8	72.0	0.0	27.7
Optimistic	0.0	0.0	76.9	74.3	0.0	28.5
Comprehensive Improvements Without Compact Fluorescent Conversions						
Modest	48.0	45.3	10.0	10.0	29.9	32.2
Optimistic	67.7	66.0	30.0	30.0	45.5	52.2

Notes: • A conservation case is defined by a replacement scheme together with an assumed effect of conservation features and reduction in illumination (delamping). • This table shows the amount of lighting energy saved for each no-delamping case, by type of lamp, as a percent of the base lighting energy used by that lamp type. • See Appendix E for savings estimation methodology and the Glossary for explanations of abbreviations and definitions used in this report.

Sources: Adapted from Energy Information Administration, Office of Energy Markets and End Use, Form EIA-871A, "Building Questionnaire" of the 1986 Nonresidential Buildings Energy Consumption Survey; and sources described in Appendices B and C.

Table 12. Overall Percent Lighting Energy Savings for Various Conservation Cases

Reduction in Illuminance (Delamping)	Equipment Replacement Scheme		
	(1) Comprehensive	(2) Compact Fluorescent Conversion Only	(3) Comprehensive Improvements without Compact Fluorescent Conversions
None	57-72	28-29	32-52
Modest (10 percent)	61-75	35-36	39-75
Optimistic (25 percent)	68-79	46-46	49-64

Note: • A conservation case is defined by an equipment replacement scheme together with an assumed effect of conservation features and a reduction in illuminance (delamping). Each range given is the range of estimated savings from the modest and to the optimistic assumptions for the effect of conservation features, as described in Appendix C. The equipment replacement schemes are:

(1) Comprehensive: highest efficiency fluorescent and HID lamps and equipment; incandescent bulbs converted to compact fluorescent with reflectors; lighting controls on all lamps;

(2) Compact Fluorescent Conversion Only: incandescent bulbs converted to compact fluorescent with reflectors; no lighting controls;

(3) Comprehensive Improvements Without Compact Fluorescent Conversions: highest efficiency fluorescent, incandescent, and HID lamps and equipment; no conversions of incandescent to compact fluorescent; lighting controls on all lamps.

The figure shows the amount of lighting energy saved for each case as a percent of the base case lighting energy (321.3 billion kilowatthours). •See Appendix E for savings estimation methodology and the Glossary for explanations of abbreviations and definitions used in this report.

Sources: Adapted from Energy Information Administration, Office of Energy Markets and End Use, Form EIA-871A, "Building Questionnaire" of the 1986 Nonresidential Buildings Energy Consumption Survey; and sources described in Appendices B and C.

Appendices

A. Methodology for Computing Aggregates and Averages

B. Illuminance Assignments for CBECS Building Activity Categories

C. Equipment Technical Characteristics

D. Motivation and Computation of Lighting Measures

E. Savings Estimation Methodology

F. Relative Standard Errors for Detailed Tables

Appendix A

Methodology for Computing Aggregates and Averages

General Method of Constructing Aggregates over Sample Buildings

The CBECS is a national probability sample. Each building **b** in the data set has an associated weight $\mathbf{w_b}$, which is the number of buildings in the United States represented by that sample building.

Aggregate Totals

For any quantity **X** that is known for all buildings in the data base, the national total $\mathbf{X_T}$ is estimated as

$$\mathbf{X_T = \Sigma_b X_b w_b}. \qquad \textbf{(1)}$$

Similarly, for any subgroup **G**, such as buildings of a particular size or activity, the subgroup total is estimated as

$$\mathbf{X_G = \Sigma_{b\epsilon G} X_b w_b}. \qquad \textbf{(2)}$$

In particular, setting $\mathbf{X_b \equiv 1}$ for all buildings in the data set, the estimated number of buildings in the group is obtained as the sum of the weights:

$$\mathbf{N_G = \Sigma_{b\epsilon G} w_b}. \qquad \textbf{(3)}$$

Building-Weighted Averages

The average value of **X** over all buildings in group **G** in the population is obtained by dividing the estimated aggregate total by the estimated number of buildings:

$$\mathbf{\overline{X} = X_G/N_G} \qquad \textbf{(4)}$$

$$\mathbf{= (\Sigma_{b\epsilon G} X_b w_b)/(\Sigma_{b\epsilon G} w_b)}. \qquad \textbf{(5)}$$

Floorspace-Weighted Averages

The quantity **X** can be also be averaged over all floorspace in group **G**. Because much of the analysis presented in this report is cast in terms of floorspace, floorspace-weighted averages are the statistics generally used to represent a group. Since floorspace is isolated as one of the key factors determining total energy consumption, floorspace-weighted averages of other factors are of direct use in constructing energy estimates. The floorspace-weighted average is obtained as

$$X^{\#} = (\Sigma_{b \epsilon G} X_b S_b w_b)/(\Sigma_{b \epsilon G} S_b w_b). \quad (6)$$

The floorspace S_b used in creating the floorspace-weighted average $X^{\#}$ can be the total floorspace in the building, the floorspace lighted during usual operating hours, or the floorspace lighted by a particular type of lighting equipment during usual operating hours.

Floorspace Lighted (by lamp type)

For each building **b**, the CBECS data set has the total floorspace, S_b, the fraction q_b of that floorspace lighted during usual operating hours, and the fraction q_{Lb} of the lighted floorspace served by each type of lamp **L**. From these quantities, the building's overall lighted floorspace and floorspace lighted by each type of lamp were respectively computed as

$$S^o_b = q_b S_b \quad (7)$$

and

$$S^o_{bL} = q_{Lb} q_b S_b. \quad (8)$$

Aggregating S^o_b and S^o_{bL} over buildings **b**, as indicated above, gives the total lighted floorspace and the total floorspace lighted by each lamp type.

Within the building, the same floorspace may be lighted by more than one type of lamp. For most buildings in the CBECS sample, the sum of the lamp fractions q_{Lb} over the different lamp types **L** was 100. In some cases, though, the sum was greater than 100, indicating that some floorspace was lighted by more than one type of lamp. Any such overlapping floorspace was double-counted in the total floorspace lighted, summing over the different lighting combinations. The extent of the double counting was about 2 percent. Summing the percents across each row of Table 2 indicates the discrepancy for that subgroup.

Appendix B

Illuminance Assignments for CBECS Building Activity Categories

Illuminance ranges were adopted from the 1987 Illuminating Engineering Society (IES) Lighting Handbook. The IES illuminance ranges represent the amount of light required for certain activities that take place in various types of buildings. Illuminance is measured in either **lux** (lumens per square meter) or **footcandles** (lumens per square foot). The two measurements differ by a factor of approximately 10 (i.e., 20 lux ≈ 2 footcandles). The illuminance categories with the corresponding lux and footcandle ranges are displayed in Table B1.

Table B1. Illuminance Categories and Lux/Footcandle Ranges

Illuminance	Lux Range			Footcandle Range		
Category	Low	Medium	High	Low	Medium	High
A	20	30	50	2	3	5
B	50	75	100	5	7.5	10
C	100	150	200	10	15	20
D	200	300	500	20	30	50
E	500	750	1000	50	75	100
F	1000	1500	2000	100	150	200
G	2000	3000	5000	200	300	500
H	5000	7500	10000	50	750	1000
I	10000	15000	20000	1000	1500	2000

Source: Illuminating Engineering Society of North America, IES Lighting Handbook 1987: Application Volume.

As a first step toward attaching illuminances to the CBECS data, a category was assigned to detailed activities from the 1979 CBECS. This assignment was based on a judgment of the predominant function that would take place in a building of that activity classification. For example, education buildings from the 1979 CBECS were assigned an illuminance category corresponding to reading and writing activities. The assigned category implied an assigned low, medium, and high illuminance for each building in the 1979 CBECS data set.

The 1979 CBECS data set was used in the initial stages of the assignment process because the 1986 CBECS grouped commercial buildings into only 19 broad activity categories, whereas the 1979 CBECS had a much finer classification scheme of 181 categories. This finer breakdown of building classification simplified the assigning of illuminance categories since the IES handbook gave guidelines for very specific activities. Even with the finer classification, however, some of the CBECS building types were difficult to match to an IES activity.

The total floorspace in the detailed building configuration was also determined from the 1979 CBECS data. For each of the broader CBECS activity categories used for the 1986 data, the floorspace-weighted average of the assigned low, medium, and high illuminances were computed across the buildings in that activity category in the 1979 CBECS data set. These averages were then assigned to the 1986 CBECS building activity categories.

This approach assumes that the distribution of detailed activities within each broad category did not change substantially between 1979 and 1986. Even if changes did occur, the effect on the average illuminance ranges might be minimal, unless the detailed activities whose proportions shifted had substantially different illuminances assigned.

The activity categories used for CBECS refer to the building as a whole, whereas the IES handbook refers to separate functions taking place in the building. Hence, there were very few exact matches between the two sources. Therefore, after assigning illuminance categories to CBECS building activities that matched to IES activities exactly, the remainder of the CBECS activities were matched with the most closely corresponding IES building activity and were then assigned the respective illuminance category. Table B2 lists the detailed building activities from the 1979 CBECS and the illuminance categories assigned to each.

Changes in Illuminance Over Time

The IES recommended illuminance ranges have been reduced somewhat in recent years, so that design illuminances were somewhat higher for buildings built in the 1960's, for example, than for those built in the 1980's. On the other hand, lighting equipment efficiency tends to degrade over time, so that in-place illuminance may be about the same for buildings of different ages. A more detailed analysis would either assume higher illuminance for older buildings, with uniform equipment efficiency, or would assume lower efficiency for older buildings, with the same illuminance. Either of these approaches would result in somewhat higher derived lighting power densities for older buildings. This level of detail was not incorporated in this analysis, which assigns the same illuminance and efficacy regardless of building age.

Table B2. Illuminance Categories for the Commercial Buildings Energy Consumption Survey Building Types

Building Types	Illuminance Category
Assembly:	
Entertainment	
art gallery/museum/exhibit hall	C
coliseum/arena	D
concert hall	D
observatory/planetarium	A
nightclub	B
radio/TV station/studio	G
theater/movie house/cinema	A
Recreation	
amusement arcade	B
bowling alley	C
gymnasium/YMCA/indoor racquet sports	D
indoor pool	C
poolroom	D
skating rink	C
Religious	
chapel	D
church	D
mosque	D
synagogue	D
Social/Public/Civic	
assembly hall	D
auditorium	B
convention hall	D
funeral home	C
lecture hall	D
lodge hall	C
meeting hall	D
student union	D
town hall	D
Other Enclosed Buildings	
armory	C
passenger terminal	C
Nonenclosed/Partial Structure	
grandstand	D
stadium	D
Education:	
Preschool	E
Elementary	E
Junior High	E
Senior High	E
College/University	E
Vocational School	E
Food Sales:	
Convenience Store	D
Farmer's Market/Vegetable Stand	D
Meat/Seafood Store	D
Retail Bakery	D
Specialty Foods Store	D
Supermarket/Grocery Store	D

See footnotes at end of table.

Table B2. Illuminance Categories for the Commercial Buildings Energy Consumption Survey Building Types (Continued)

Building Types	Illuminance Category
Food Service:	
Prepared Meals	
cafeteria	C
Carry Out	
caterer	C
fast-food	C
pizza parlor	C
sandwich shop	C
Full Service	
bar	C
bar/grill	C
coffee shop	C
diner	C
full menu	C
Health Care:	
Medical Care Hospital	
chronic disease	F
ear, eyes, nose, throat	F
general medical/surgical	F
maternity	F
medical infirmary	F
orthopedic	F
tuberculosis/respiratory disease	F
Mental Facility	
metal retardation/schools	F
psychiatric	F
Rehabilitation Facility	
alcoholism	D
substance abuse	D
physical therapy	F
Veterinary Facility	
animal hospital	F
kennel	D
Dental Clinic	D
Medical Clinic	
abortion/birth control	F
ear, eyes, nose, throat	F
emergency walk-in	E
general	D
mental health/psychiatric	D
veterinary	F
Laboratory:	
Mechanical/Electrical	E
Medical/Dental	E
Agricultural	E

See footnotes at end of table.

Table B2. Illuminance Categories for the Commercial Buildings Energy Consumption Survey Building Types (Continued)

Building Types	Illuminance Category
Lodging:	
Short-Term Residence	D
convention hotel	D
hotel	D
inn	D
motel	D
shelter home	D
tourist home	D
Long-Term Residence	
boarding house	D
convent/monastery	D
dormitory/sorority/fraternity	D
orphanage	D
Mercantile/Service:	
Automotive	
automobile dealers	D
gasoline station	D
motor vehicle repair/service	E
Retail Sales	
building materials/garden supply	D
department stores/apparel stores	D
drugstores	D
furniture/home furnishings/equipment	D
multiretail establishments	D
Services	
laundry/dry cleaning/car wash	D
multiservice establishment	D
personal services	D
post office	D
shopping mall	D
strip shopping center	D
wholesale goods	D
Office:	
Data Processing	
computer center	E
Financial Office Buildings	
bank	D
brokerage firm	D
insurance	D
real estate	D
securities	D
Professional Office Buildings	
administration	D
consulting	D
corporate	D
engineering	D
law	D
management	D
medical	D
mixed professional	D

See footnotes at end of table.

Table B2. Illuminance Categories for the Commercial Buildings Energy Consumption Survey Building Types (Continued)

Building Types	Illuminance Category
Other:	
Crematorium	C
Hangar	D
Parking Garage	C
Public Restrooms/Showers	C
Telephone Exchange	C
Public Order and Safety:	
Courthouse	E
Fire Station	D
Jail/Prison	D
Penitentiary	D
Police Station	E
Reformatory	D
Sheriff's Office	E
Residential Care:	
Skilled Nursing	
homes for the aged	D
nursing homes	D
Warehouse:	
Refrigerated Warehouse	C
Non-refrigerated Storage	C
Vacant:	A

Sources: Energy Information Administration, Office of Energy Markets and End Use, Nonresidential Buildings Energy Consumption Survey: *Characteristics of Commercial Buildings 1979* and Illuminating Engineering Society of North America, *IES Lighting Handbook: 1987 Application Volume.*

Appendix C

Equipment Technical Characteristics

For this analysis, technical ratings were developed for broad categories of common lighting equipment. Exotic technologies and elaborate reconfigurations of lighting systems were not considered. The general framework developed here could be used to analyze other technologies, given the necessary technology specifications.

Lamps

For the present implementation of the framework, seven types of lamps with four different conservation features define the possible lighting categories. For each lamp type **L**, the base efficacy $\mathbf{Q_L}$, absent any special conservation features, was determined from the literature.

The lamp types considered and efficacies assigned are given in Table C1. The efficacies for most lamps and lamp/ballast combinations were taken directly or derived from the ALTAG series.[2] This series consists of several pamphlets reporting data on different types of lighting equipment.

There was no ALTAG pamphlet for incandescent bulbs, but the efficacy of the standard incandescent bulb was reported in the "Conventional Shape Tungsten Halogen Lamps" pamphlet as 18 lumens per watt. The New York State energy Research and Development Authority (NYSERDA) reported that the energy-efficient incandescent bulb reduces electricity use by 10 percent.[13] This reduction corresponds roughly to replacement of a 75-watt bulb by a 70-watt energy-efficient bulb, or a 60-watt by a 55-watt. Applying the 10 percent factor, the efficacy for the energy-efficient incandescent bulb was obtained by adding 10 percent to the efficacy of the standard incandescent bulb.

The ALTAG series did contain a pamphlet on compact fluorescent lamps. The efficacy for the compact fluorescent lamp was taken directly from that pamphlet.

Determining the efficacy for full-size fluorescent lamps was somewhat problematic in that the data on the full-size fluorescent lamps given in the ALTAG "Full-Size Fluorescent Lamps" pamphlet referred to fluorescent lamps using magnetic ballasts. These are the current minimum standard under California law. However, magnetic ballasts are not likely to be the standard equipment in newer buildings in other parts of the country.

For this report it was assumed that the standard ballast for fluorescent lamps would be the standard core-coil ballast. The ALTAG "Full-Size Fluorescent Lamps" pamphlet did report that the magnetic (or "energy- efficient") ballast would cause the lamp/ballast system to draw approximately 10 percent fewer watts than the core-coil ballast (96 watts for the core-coil versus 86 for the magnetic). Using that information, the efficacy ratings obtained from the ALTAG pamphlet were adjusted to represent the fluorescent lamps with core-coil ballasts. This adjustment was done by taking the efficacy of the lamp/magnetic ballast system and subtracting the 10 percent difference.

The ALTAG series also does not give efficacies for high-intensity discharge (HID) lamps. Efficacies for metal halide and high-pressure sodium HID lamps were taken from tables prepared by the LBL Lighting Research Group. The CBECS data do not specify the type of HID lamp used. The analysis assumes that HID lamps currently in place are all metal halide, and uses high-pressure sodium as a conservation conversion option.

Table C1. Lamp Types and Efficacies

Lamp Type	Percent of Lighted Floorspace (1986)	Efficacy (lumens/watt)
Fluorescent		
Standard	41.7	59
Compact	0.0[1]	52
Energy-Efficient	34.5	62
Very High Efficiency	0.0[1]	68
Incandescent		
Standard	13.7	18
Energy-Efficient	5.1	20
High-Intensity Discharge		
Metal Halide	6.2[1]	69
High-Pressure Sodium	0.0[1]	88

[1] Assumed for the analysis. The 1986 Commercial Buildings Energy Consumption Survey collected no data on the presence of this equipment or feature. This analysis assumes the current floorspace for each of these categories is zero, except that metal halide lamps are assumed to be the only type of high-intensity discharge lamps currently in place.

Note: See the Glossary for explanations of abbreviations and definitions used in this report.

Sources: Energy Information Administration, Office of Energy Markets and End Use, Nonresidential Buildings Energy Consumption Survey: *Characteristics of Commercial Buildings 1986*; California Energy Commission, *Advanced Lighting Technologies Application Guidelines*; and Lawrence Berkeley Laboratory Lighting Research Group, personal communication, Barbara Atkinson.

Table C2. Conservation Features and Deflation Factors

Conservation Feature	Percent of Lighted Floorspace in Buildings with Feature[1]	Assumed Deflation Factor	
		Optimistic	Modest
No Features	45.6	1.00	1.00
Lighting Controls	27.7	0.70	0.90
Fluorescent Lamp Features			
High-Efficiency Ballast	34.9	0.80	0.92
Reflector	0.0	0.67	0.73
Delamping	22.5	0.75	0.90

[1] Percent of lighted floorspace that was in buildings where the indicated feature was present. The 1986 Commercial Buildings Energy Consumption Survey collected no data on the presence of reflectors.

Note: See the Glossary for explanations of abbreviations and definitions used in this report.

Sources: Energy Information Administration, Office of Energy Markets and End Use, Nonresidential Buildings Energy Consumption Survey: *Characteristics of Commercial Buildings 1986*; Lawrence Berkeley Laboratory Lighting Research Group, personal communication, Barbara Atkinson and Francis Rubinstein; California Energy Commission, *Advanced Lighting Technologies Application Guidelines*; New York State Energy Research and Development Authority, *The Potential for Electricity Conservation in New York State*; Goldstein and Watson, *Deriving and Testing Power Budgets for Energy Efficient Lighting in Nonresidential Buildings*; Piette et. al., *Technology Assessment: Energy-Efficient Commercial Lighting*; Lighting Research Center, *Commercial Lighting Efficiency Resource Book*; and Dubin et. al., *How to Save Energy and Cut Costs in Existing Industrial and Commercial Buildings.*

Conservation Features

Four types of conservation features are considered: controls, high-efficiency ballasts, reflectors, and delamping. Controls include occupancy sensors, daylight sensors, timers, and any other controls that could be used to turn lights off at times when they are not needed. High-efficiency ballasts are assumed to apply only to non-compact fluorescent lamps. Reflectors are assumed to apply only to fluorescent lamps, either compact or standard dimension.

Delamping as defined for the 1986 CBECS refers to the removal of lamps and disconnecting associated ballasts. This process is often associated with installation of more efficient lighting equipment efficiency, so that the original lighting levels are maintained. However, the CBECS did not determine the context in which any reported delamping occurred. For purposes of the savings analysis, delamping means a reduction in illuminance, as discussed further below.

For each of the conservation features **f**, a modest (high) and an optimistic (low) deflation factor $\mathbf{d_f}$ was obtained from the literature. The deflation factor is the fraction of the base energy the lamp would use if the conservation feature were added. Estimates of the effects of the different features vary, in part because the applications of these features are not as standard as the energy requirements of different types of lamps. To account for the range of possible effects, a high and a low deflation factor $\mathbf{d_f}$ were considered for each feature (Table C2).

The deflation factor represents an average over all the floorspace the feature applies to. Thus, the factor is applied uniformly to all applicable space in the building.

Controls

A wide range of lighting control devices and strategies is available for commercial buildings. The 1986 CBECS collected information on the presence of daylighting controls and on the presence of other lighting controls. For this analysis, controls are grouped together as one broad category. It is assumed that a building where controls are present may have a variety of different types of controls in place in different areas, depending on the use and location of the space.

Because the effectiveness and applicability of each type of lighting control is site-specific, the estimates of how much these devices can save varies widely. The ALTAG pamphlet on "Lighting Design Practice" states that a 10-percent reduction can be achieved by daylight controls, 15 to 30 percent by occupancy sensors. NYSERDA report a range of savings for various control systems, from 9 to 57 percent.[14] Included in the range is are estimates of 50 to 60 percent savings for occupancy sensors, 10 to 30 percent for daylight sensors. An earlier NYSERDA report indicated a savings of 40 to 55 percent for daylighting, 50 percent for occupancy sensors where installed.[13]

The deflation factor used here represents an average over all lighted floorspace in a building where lighting controls are assumed. Even in the optimistic case, reductions of 50 percent are not assumed to be achievable as an overall average. The modest effect is set at a 10 percent reduction (0.9 deflation factor), and the optimistic effect at 30 percent reduction (0.7 deflation factor).

High-Efficiency Ballasts

High-efficiency ballasts constituted one category of lighting conservation features identified on the 1986 CBECS. When this feature was reported for a building, however, it was not clear whether it was understood as a magnetic ballast or as an electronic ballast. The ALTAG series indicates efficacies of 60 l/w for a standard core coil, 65 l/w for magnetic, and 75 l/w for an electronic ballast of "A" rating (low hum). These efficacies give deflation factors of 60/65 = 0.92 or 60/75 = 0.80 relative to the standard core coil. Goldstein and Watson also indicate that electronic ballasts can save 20 percent.[10] For this feature, 0.80 and 0.92 are taken as the optimistic and modest deflation factors, respectively.

Reflectors

Piette et al.[15] report a 27-percent improvement in efficacy when a specular reflector is added to a 4-lamp fluorescent fixture. NYSERDA [13] indicate an efficacy improvement of 50 percent, which would imply a deflation factor of 1/1.5 = 0.67. The Lighting Research Center [12] states that reflectors reduce energy requirements by 50 percent, with a loss of illumination of 25 to 40 percent, implying deflation factors of 0.5/0.75 = 0.83 to 0.5/0.6 = 0.67. Rubinstein [17] suggests 0.73 as a moderate deflation factor for typical applications. For the savings analysis presented here, the optimistic and modest deflation factors for reflectors are set at 0.67 and 0.73, respectively.

Delamping

Delamping in the context of the savings analysis refers to reducing illumination levels. That is, the analysis is not concerned with the number of fixtures in place, but with the lumens per square foot and the efficacy of the equipment providing that illumination. Implicitly, it is assumed that if lamps and/or fixtures are replaced by more efficient equipment, the illumination level is retained and the number of fixtures required are reduced. For example, if the efficacy is improved by one-third, an average of one in four fixtures would be disconnected. This implied reduction in fixtures is accounted for in the analysis by the efficacy improvement, and is not represented as a delamping effect.

The delamping conservation cases implicitly assume that illuminances in place are unnecessarily high for the functions in place. The extent to which existing floorspace is currently overly lighted is difficult to determine.

In practice, illuminance reductions in many places would be linked to lumen maintenance strategies, which are not explicitly addressed here. Lighting installations generally call for higher than necessary illuminance to provide tolerance for lighting loss as equipment degrades over time. Goldstein and Watson report that typical lighting systems are overdesigned by 43 percent to allow for equipment degradation.[10] Piette et al. indicate overdesign at 20 to 40 percent, and suggest a possible savings of 10 to 15 percent with lumen maintenance.[15] Dubin et al.[3] cite examples of savings of 28 percent and 50 percent by reducing lighting levels.[3]

For this analysis, 10-percent savings (deflation factor of 0.90) is taken as the modest delamping effect. A savings of 25 percent (deflation factor of 0.75) is the optimistic case. This level of delamping corresponds to disconnecting one fixture in every four.

Appendix D

Motivation and Computation of Lighting Measures

Floorspace by Lighting Equipment Configuration

As described in Appendix A, for each building **b**, the CBECS data set has the total floorspace, $\mathbf{S_b}$, the fraction $\mathbf{q_b}$ of that floorspace lighted during usual operating hours, and the fraction $\mathbf{q_{Lb}}$ of the lighted floorspace served by each type of lamp **L**. These are used to estimate the amount of floorspace lighted by each lamp type, for various population subgroups **G**.

A further step is to estimate the amount of floorspace lighted by lighting configurations, defined by a combination of a lamp type with a set of lighting conservation features. For this step, the CBECS buildings were partitioned according to the combination of lighting conservation features present and absent in the building. For a lighting configuration **c** defined by a lamp **L** together with a combination **f** of conservation features, the floorspace served by that lighting configuration was computed as:

$$\mathbf{S_{Lf} = \Sigma_{b \varepsilon GLf}\, s_b\, q_b\, q_{Lb}\, w_b}\ , \qquad \mathbf{(9)}$$

where **GLf** is the group of CBECS buildings that have the combination **f** of conservation features associated with lamps of type **L**. For each lamp type **L**, each building in the data set was assigned to only one group **GLf** of conservation features.

As indicated in Table 1 of the Detailed Tables, the lamp types identified by the CBECS include five of the seven considered in this analysis; compact fluorescents and very-high efficiency fluorescents are the two types not separately identified. These would have been reported as standard or energy-efficient fluorescents, or as "other," depending on the respondents' interpretation. The floorspace currently lighted by these types is assumed to be negligible and set at zero.

Floorspace currently under reflectors is similarly assumed to be zero; no CBECS data are available on reflectors. The 1986 CBECS does have data on the presence in the building of daylight sensors, other lighting controls, and high-efficiency ballasts, and on whether delamping has been performed in the building.

As noted, data were not collected on which lamps or how much floorspace each of these features was associated with. The configuration floorspace estimate $\mathbf{S_{Lf}}$ given above represents the total floorspace to which the collection of features **f** could be applied, in buildings where those features are present. For high-efficiency ballasts, that floorspace is the total floorspace lighted by fluorescent lamps in buildings that have high-efficiency ballasts. For controls and delamping, all lighted floorspace in buildings that have those features is included.

The fact that the penetration of a particular feature may be less than 100 percent even within a building where it is present is accounted for in the deflation factor assumed for each feature. This factor represents the average effect of the feature over all applicable floorspace in buildings where the feature is present. Higher penetration within those buildings is represented by a lower (more optimistic) deflation factor.

Effective Lighting Hours and Floorspace-Hours

One measure of the amount of use of the floorspace that is lighted during operating hours is the number of operating hours during a typical week. To account for the floorspace lighted during off hours, the "effective lighting hours" is computed. The effective lighting hours represents the number of hours per week the building would have to be open for the same amount of lighting use if no floorspace were lighted during off hours.

While the total hours of use of different types of equipment cannot be determined directly, the CBECS data do provide the floorspace $\mathbf{S^o}$ lighted during operating hours and the floorspace $\mathbf{S^n}$ lighted when closed, as indicated in Appendix A. Combining these with the typical operating hours $\mathbf{H^o}$ per week gives the total weekly lighted floorspace-hours $\mathbf{(SH)^T}$**,** as given in Table 3:

$$\mathbf{(SH)^T = S^o\, H^o + S^n(168 - H^o).} \quad \mathbf{(10)}$$

Dividing this total by the floorspace lighted during operating hours gives the effective hours $\mathbf{H^e}$ of lighting for that floorspace:

$$\mathbf{H^e = (SH)^T/S^o.} \quad \mathbf{(11)}$$

$$\mathbf{= H^o + (S^n/S^o)\, H^n.} \quad \mathbf{(12)}$$

The floorspace-hours $\mathbf{(SH)^T}$ and effective hours $\mathbf{H^e}$ can be computed for each building **b** within a group. Summing floorspace-hours over buildings gives the total floorspace hours for the group. Dividing by the total lighted floorspace for the group gives the floorspace-weighted average effective hours for the group. An advantage of using the effective lighting hours is that this quantity incorporates the percent of floorspace lighted during off hours as an adjustment to the assumed hours of lighting. As a result, the remainder of the analysis only needs to consider the amount of floorspace lighted during operating hours.

With the floorspace lighted during off hours taken into account, the effective lighting hours are 13 percent higher on average than the usual operating hours, as indicated in the text. Thus, considering only operating-hours usage could result in substantial understatement of lighting demand.

The magnitude of the potential understatement varies considerably with building activity. For buildings that tend to be open almost all the time, including health care, lodging, and public order and safety buildings, the ratio of effective lighting to operating hours is close to 1.0. These buildings types have more than half as much floorspace lighted during off hours as during usual operating hours, but the off-hours are so few that the effective lighting hours are still only slightly large than the operating hours.

For office, mercantile, education, and vacant buildings, all of which have fewer than 60 operating hours per week, the effective lighting hours are 17 to 30 percent higher than the usual operating hours. For all these building types, the floorspace lighted during off hours was 15 percent or less of the floorspace lighted during usual operating hours.

In general, higher ratios of effective lighting to operating hours would be expected with higher ratios of floorspace lighted during off hours to floorspace lighted during usual operating hours. However, higher fractions of floorspace lighted off hours tend to go with fewer off hours; the trends in the two factors tend to balance out. For example, both weekly operating hours and the ratio of off-hours to operating-hours lighted floorspace tend to increase with building size, and also with building construction year. (See Table 3 of the Detailed Tables.) The net effect is that the ratio of effective lighting to operating hours shows little variation with building size or age.

Time-Averaged Illuminance

Multiplying the in-use illuminance (in lumens per square foot, l/sf) by the hours of use per week gives the weekly lighting service intensity, in lumen-hours per square foot. Dividing by 168 (the number of hours in a week) gives the time-averaged illuminance. For this analysis, the in-use illuminance is known only in terms of the assigned values based on activity, and the hours of use is approximated by the effective hours. Using these proxy measures, the time-averaged illuminance is given by :

$$\mathbf{T} = \mathbf{I\ H^e/168} \tag{13}$$

$$= \mathbf{U\ I.} \tag{14}$$

Thus, the time-averaged illuminance is affected both by the illuminance **I** and by the effective lighting hours $\mathbf{H^e}$. Reducing the lighting energy requirement by reducing the lighting service provided, either through the illuminance or the hours, reduces the time-averaged illuminance **T**.

The in-use illuminance **I** is assigned based on the principal building activity. The effective lighting hours are computed as described above. The resulting time-averaged illuminance is assumed to apply to all equipment and lighted floorspace in the building.

Usage and in-use illuminance are equally important in determining lighting energy consumption. The time-averaged illuminance measures their combined effect. For example, education buildings have twice the in-use illuminance of food sales buildings but a usage factor half as large. The two building types have about the same time-averaged illuminance, and about the same lighting end-use intensity.

Lodging buildings and mercantile buildings show the opposite effect. The two types have about the same in-use illuminance, but lodging buildings have twice the usage factor, hence about twice the time-averaged illuminance.

The value of examining the average combined illuminance and usage is that combining the separate averages does not always give an accurate measure of their combined effect for a group. For buildings over 500,000 square feet, the (floorspace-weighted) average time-averaged illuminance $\mathbf{T^\#}$ is 14 percent higher than the corresponding average in-use illuminance $\mathbf{I^\#}$ times the average usage factor $\mathbf{U^\#}$. This discrepancy could translate directly into a corresponding error in the energy estimate that would be obtained by combining average illuminance, average usage, and average efficiency.

Energy Intensity and Floorspace-Weighted Illuminance by Lamp Type

The end-use lighting intensity **EUI** depends on the illuminance **I**, the hours of use **H**, and the equipment efficacy **Q**. For a building **b**, the floorspace lighted by lighting configuration **c** has annual energy intensity

$$\mathbf{EUI_{bc}} = \mathbf{(8760/168)\ I_b\ H^e_b\ /\ Q_c.} \tag{15}$$

The factor 8760/168 is the ratio of the total hours in a year to the total hours in a week. The **EUI** can also be expressed as:

$$\mathbf{EUI_{bc}} = \mathbf{8760\ U_b\ I_b\ /\ Q_c} \tag{16}$$

$$= \mathbf{8760\ T_b\ /\ Q_c.} \tag{17}$$

In reality, illuminance **I** and hours $\mathbf{H_e}$ are likely to be different for different lighting configurations within building **b**. There being no way of estimating these differences, the building's overall value is assigned to all configurations **c**.

Multiplying the intensity $\mathbf{EUI_{bc}}$ by the floorspace $\mathbf{S_{bc}}$ served by configuration **c** in building **b** gives the energy consumed by that configuration in the building. Summing over buildings gives the total energy used by the configuration. Dividing by the total floorspace under the configuration gives the **EUI** for that configuration:

$$\mathbf{EUI_c} = 8760 \; \frac{\Sigma_b \, w_b \, S_{bc} \, T_b \, / \, Q_c}{\Sigma_b \, w_b \, S_{bc}} \qquad (18)$$

$$= 8760 \;\; T^{\#}_c \, / \, Q_c, \qquad (19)$$

where $\mathbf{T^{\#}_c}$ is the floorspace-weighted average of the time-averaged illuminance for configuration **c**.

Alternatively, the **EUI** for the configuration can be thought of as the floorspace-weighted average over buildings of the **EUI** for the floorspace lighted by that configuration within each building:

$$\mathbf{EUI_c} = \Sigma_b \, S_{bc} \, EUI_{bc} \, w_b \, / \, \Sigma_b \, S_{bc} \, w_b. \qquad (20)$$

Energy Estimate Incorporating Conservation Effects

The base case energy estimate assumes that the lighting conservation features currently present have negligible effect, as an average over all the floorspace in buildings where they are present. An alternate calculation was performed, assuming a modest effect for the features currently present.

The different classes of conservation features considered in this analysis affect different components of lighting energy. High-efficiency ballasts and reflectors increase the equipment efficacy **Q**. Delamping decreases the illuminance **I**. Lighting controls operate in various ways, some of which might be considered to affect the average hours of lighting use, others that are better thought of as affecting the electrically provided illuminance.

For the savings estimates, the deflation factors assumed for the different conservation features are combined into one overall deflation factor, which is applied to the base energy estimate. This procedure is described in Appendix E. This approach gives correct savings estimates under the given set of assumptions, but does not indicate the effect of the features on the different components.

For the alternate energy calculation, the conservation effects are applied separately to the corresponding components. The efficacy **Q** is divided by the deflation factor $\mathbf{d_{HEB}}$ for high-efficiency ballasts. Illuminance **I** is multiplied by the deflation factor $\mathbf{d_{DEL}}$ for delamping, and also by the deflation factor $\mathbf{d_{CTL}}$ for lighting controls (Tables D1 and D2). From the resulting alternate efficacy and illuminance, alternate lighting power density, end-use intensity, and energy use are derived. These are then aggregated by lighting configuration (Table D3) and by building characteristics (Table D4), just as the original base-case estimates are.

Table D1. Alternate Illuminance and Power Measures by Lighting Configuration

Lamp Type and Conservation Feature Present	Percent of Total Lighted Floorspace	Usage Factor (percent)	Illuminance (lumens per square foot) In-Use	Illuminance (lumens per square foot) Time-Averaged	Efficacy (lumens per watt)	In-Use Lighting Power Density (watts per square foot)
Standard Fluorescent	41.6	43.9	62.7	27.5	60.4	1.0
No Conservation Features	22.8	41.3	59.2	25.6	59.0	1.0
Ballast	6.6	43.6	61.5	27.3	64.1	1.0
Controls	3.3	48.1	62.7	26.5	59.0	1.1
Delamping	2.6	45.3	73.5	30.5	59.0	1.3
Ballast and Controls	2.7	54.5	61.0	30.7	64.1	1.0
Ballast and Delamping	1.5	40.5	67.6	24.8	64.1	1.1
Controls and Delamping	1.2	55.4	91.4	47.7	59.0	1.6
Ballast, Controls, and Delamping	0.9	51.2	87.2	39.9	64.1	1.4
Energy-Efficient Fluorescent	34.6	50.4	77.3	38.0	65.6	1.2
No Conservation Features	6.5	44.3	66.2	30.5	62.0	1.1
Ballast	9.5	46.7	76.8	38.0	67.4	1.1
Controls	2.6	46.2	65.9	27.8	62.0	1.1
Delamping	1.2	46.6	79.7	33.3	62.0	1.3
Ballast and Controls	4.1	62.1	83.5	49.1	67.4	1.2
Ballast and Delamping	4.2	49.5	85.4	40.1	67.4	1.3
Controls and Delamping	1.1	47.7	84.8	33.2	62.0	1.4
Ballast, Controls, and Delamping	5.4	59.8	84.0	44.0	67.4	1.3
Standard Incandescent	13.6	46.5	50.6	23.8	18.0	2.8
No Conservation Features	10.4	43.6	47.8	22.4	18.0	2.7
Controls	1.8	58.4	54.6	26.4	18.0	3.0
Delamping	0.9	45.5	63.4	26.4	18.0	3.5
Controls and Delamping	0.5	65.3	71.9	39.1	18.0	4.0
Energy-Efficient Incandescent	5.2	54.7	61.4	32.0	20.0	3.1
No Conservation Features	2.6	45.9	56.6	26.3	20.0	2.8
Controls	1.1	64.5	63.5	39.4	20.0	3.2
Delamping	0.6	52.9	70.6	32.7	20.0	3.5
Controls and Delamping	0.9	70.3	67.5	39.5	20.0	3.5
High-Intensity Discharge	6.3	56.1	51.9	28.5	69.0	0.8
No Conservation Features	3.2	52.0	42.3	20.9	69.0	0.6
Controls	1.5	65.6	62.3	40.5	69.0	0.9
Delamping	0.9	49.2	47.5	19.6	69.0	0.7
Controls and Delamping	0.7	64.1	80.7	50.5	69.0	1.2

Notes: • Ballast, Controls, and Delamping, respectively, indicate that high efficiency ballasts, any type or combination of lighting controls, and a delamping program were reported for the building containing the floorspace lighted by the indicated lamp. High-efficiency ballasts, when reported, were assumed to apply only to fluorescent lamps. • The illuminance and power density in this table are adjusted for conservation features present, assuming the modest effect for each feature. • The illuminance or power measure for each lighting equipment configuration is the (lighted-floorspace-weighted) average of that measure across buildings. A column that represents an average product is not equal to the product of the corresponding columns. For example, for a single building, the time-averaged illuminance is the product of the usage factor and the in-use illuminance; however, the average time-averaged illuminance is not the average usage factor times the average in-use illuminance. • Table of Relative Standard Errors can be found in Appendix F. • See the Glossary for explanations of abbreviations and definitions used in this report.

Sources: Percent of floorspace and usage factor from Energy Information Administration, Office of Energy Markets and End Use, Form EIA-871A, "Building Questionnaire" of the 1986 Nonresidential Buildings Energy Consumption Survey; Illuminance and efficacy derived from sources described in Appendices B and C. Lighting power density is derived from illuminance and efficacy.

Table D2. Alternate Illuminance and Power Measures by Building Characteristics

Building Characteristics	Percent of Total Lighted Floorspace 1986	Usage Factor (percent)	Illuminance (lumens per square foot)		In-Use Lighting Power Density (watts/square foot)
			In-Use	Time-Averaged	
All Buildings	100.0	47.6	65.3	30.8	1.4
Principal Activity					
Assembly	11.9	36.2	46.9	16.1	1.4
Education	14.1	36.5	100.0	34.4	1.9
Food Sales	1.3	70.0	50.0	33.2	1.1
Food Service	2.3	58.8	20.0	11.2	0.7
Health Care	4.1	91.3	186.5	154.0	3.6
Lodging	4.9	96.1	50.0	45.4	2.0
Mercantile/Service	22.9	46.4	50.0	22.1	1.0
Office	17.7	41.1	91.0	35.0	1.8
Public Order and Safety	1.2	80.5	78.5	60.0	1.9
Warehouse	13.9	44.0	17.6	7.5	0.4
Vacant	2.8	28.0	5.0	1.4	0.1
Other	3.0	58.5	117.5	65.0	2.5
Building Size (square feet)					
1,001 to 5,000	10.1	40.0	55.0	21.4	1.3
5,001 to 10,000	11.2	40.2	54.8	20.8	1.3
10,001 to 25,000	14.9	42.3	59.5	24.2	1.4
25,001 to 50,000	15.0	43.3	61.8	26.6	1.3
50,001 to 100,000	14.8	49.7	62.7	29.3	1.4
100,001 to 200,000	12.7	50.7	69.9	35.5	1.4
200,001 to 500,000	12.5	55.6	75.3	40.3	1.6
Over 500,000	8.8	62.6	89.7	55.7	1.7
Year Constructed					
Before 1920	8.3	42.3	56.9	24.2	1.5
1920-1945	13.9	44.6	66.4	30.3	1.6
1946-1959	14.5	43.5	63.7	28.1	1.4
1960-1969	20.2	47.3	66.2	29.8	1.4
1970-1979	25.5	51.6	65.5	34.0	1.3
1980-1986	17.6	50.3	68.2	33.3	1.4
Census Region					
Northeast	20.1	49.9	64.7	31.2	1.4
Midwest	26.5	47.6	67.4	32.7	1.5
South	33.9	47.0	63.1	29.5	1.4
West	19.6	46.3	66.8	30.3	1.4

Notes: • The illuminance and power density in this table are adjusted for conservation features present, assuming the modest effect for each feature. • The illuminance or power measure for each building characteristic is the (lighted-floorspace-weighted) average of that measure across buildings. A column that represents an average product is not equal to the product of the corresponding columns. For example, for a single building, the time-averaged illuminance is the product of the usage factor and the in-use illuminance; however, the average time-averaged illuminance is not the average usage factor times the average in-use illuminance. • Table of Relative Standard Errors can be found in Appendix F. • See Appendices B, C, and D for derivations and the Glossary for explanations of abbreviations and definitions used in this report.

Sources: Percent of floorspace and usage factor from Energy Information Administration, Office of Energy Markets and End Use, Form EIA-871A, "Building Questionnaire" of the Nonresidential Buildings Energy Consumption Survey; Illuminance and efficacy derived from sources described in Appendices B and C. Lighting power density is derived from illuminance and efficacy.

Table D3. Alternate Lighting Energy and Intensity Estimates by Lighting Configuration

Lamp Type and Conservation Feature Present	Floorspace (million square feet)		Annual Lighting End-Use Intensity (kWh/square foot)	Annual Lighting Energy (billion kWh)
	Total Lighted	Percent of Total Lighted		
Standard Fluorescent	20,700	41.6	4.0	82.7
No Conservation Features	11,327	22.8	3.8	43.1
Ballast	3,286	6.6	3.7	12.2
Controls	1,654	3.3	3.9	6.5
Delamping	1,297	2.6	4.5	5.9
Ballast and Controls	1,322	2.7	4.2	5.6
Ballast and Delamping	739	1.5	3.4	2.5
Controls and Delamping	615	1.2	7.1	4.4
Ballast, Controls, and Delamping	460	0.9	5.5	2.5
Energy-Efficient Fluorescent	17,130	34.6	5.1	86.6
No Conservation Features	3,222	6.5	4.3	13.9
Ballast	4,702	9.5	4.9	23.2
Controls	1,286	2.6	3.9	5.1
Delamping	600	1.2	4.7	2.8
Ballast and Controls	2,042	4.1	6.4	13.0
Ballast and Delamping	2,098	4.2	5.2	10.9
Controls and Delamping	526	1.1	4.7	2.5
Ballast, Controls, and Delamping	2,654	5.4	5.7	15.2
Standard Incandescent	6,774	13.6	11.6	78.3
No Conservation Features	5,177	10.4	10.9	56.3
Controls	899	1.8	12.8	11.5
Delamping	455	0.9	12.9	5.9
Controls and Delamping	243	0.5	19.0	4.6
Energy-Efficient Incandescent	2,551	5.2	14.0	35.8
No Conservation Features	1,305	2.6	11.5	15.0
Controls	536	1.1	17.3	9.3
Delamping	279	0.6	14.3	4.0
Controls and Delamping	431	0.9	17.3	7.5
High-Intensity Discharge	3,064	6.3	3.6	11.1
No Conservation Features	1,570	3.2	2.7	4.2
Controls	722	1.5	5.1	3.7
Delamping	440	0.9	2.5	1.1
Controls and Delamping	332	0.7	6.4	Q

Q Data withheld because the Relative Standard Error (RSE) was greater than 50 percent.

Notes: • Ballast, Controls, and Delamping, respectively, indicate that high-efficiency ballasts, any type or combination of lighting controls, and a delamping program were reported for the building containing the floorspace lighted by the indicated lamp. High-efficiency ballasts, when reported, were assumed to apply only to fluorescent lamps. • The energy and intensity in this table are adjusted for conservation features present, assuming the modest effect for each feature. • Table of RSE's can be found in Appendix F. • See the Glossary for explanations of abbreviations and definitions used in this report.

Sources: Floorspace from Energy Information Administration, Office of Energy Markets and End Use, Form EIA-871A, "Building Questionnaire" of the 1986 Nonresidential Buildings Energy Consumption Survey; Illuminance and efficacy derived from sources described in Appendices B and C. Lighting end-use intensity and energy measures are derived from illuminance and efficacy.

Table D4. Alternate Lighting Energy and Intensity Estimates by Building Characteristics

Building Characteristics	Floorspace, 1986 (million square feet)			Annual Lighting End-Use Intensity (kWh/square foot)		Annual Lighting Energy (billion kWh)
	Total	Total Lighted	Percent of Total Lighted	per Total Square Feet	per Total Lighted Square Feet	
All Buildings	58,199	49,590	100.0	5.1	5.9	294.5
Principal Activity						
Assembly	7,339	5,918	11.9	3.0	3.7	22.2
Education	7,292	6,968	14.1	5.7	5.9	41.2
Food Sales	712	668	1.3	5.9	6.3	4.2
Food Service	1,281	1,133	2.3	3.1	3.5	3.9
Health Care	2,107	2,010	4.1	24.9	26.1	52.4
Lodging	2,785	2,423	4.9	13.6	15.6	37.8
Mercantile/Service	12,805	11,361	22.9	3.5	4.0	45.0
Office	9,546	8,763	17.7	5.5	6.0	52.9
Public Order and Safety	680	573	1.2	11.1	13.2	7.5
Warehouse	8,996	6,917	13.9	1.1	1.5	10.2
Vacant	2,931	1,392	2.8	0.1	0.3	0.4
Other	1,726	1,464	3.0	9.7	11.4	16.8
Building Size (square feet)						
1,001 to 5,000	6,209	5,023	10.1	3.7	4.6	23.0
5,001 to 10,000	6,861	5,545	11.2	3.5	4.4	24.2
10,001 to 25,000	9,119	7,405	14.9	4.2	5.2	38.4
25,001 to 50,000	8,661	7,451	15.0	4.4	5.1	38.1
50,001 to 100,000	8,559	7,350	14.8	4.9	5.7	41.9
100,001 to 200,000	7,161	6,275	12.7	5.8	6.6	41.5
200,001 to 500,000	6,737	6,198	12.5	6.9	7.5	46.4
Over 500,000	4,893	4,342	8.8	8.4	9.4	40.9
Year Constructed						
Before 1920	5,735	4,139	8.3	4.0	5.5	22.8
1920-1945	8,894	6,907	13.9	5.3	6.8	46.7
1946-1959	8,534	7,180	14.5	4.5	5.4	38.5
1960-1969	11,117	10,000	20.2	5.3	5.9	58.5
1970-1979	14,036	12,644	25.5	5.4	6.0	76.4
1980-1986	9,883	8,721	17.6	5.2	5.9	51.6
Census Region						
Northeast	11,830	9,963	20.1	5.2	6.2	61.5
Midwest	16,034	13,140	26.5	5.1	6.2	81.1
South	19,397	16,790	33.9	4.9	5.7	95.1
West	10,937	9,697	19.6	5.2	5.9	56.8

Notes: • The energy and intensity in this table are adjusted for conservation features present, assuming the modest effect for each feature. • Table of Relative Standard Errors can be found in Appendix F. • See the Glossary for explanations of abbreviations and definitions used in this report.

Sources: Floorspace from Energy Information Administration, Office of Energy Markets and End Use, Form EIA-871A, "Building Questionnaire" of the 1986 Nonresidential Buildings Energy Consumption Survey; Illuminance and efficacy derived from sources described in Appendices B and C. Lighting end-use intensity and energy measures are derived from illuminance and efficacy.

Appendix E

Savings Estimation Methodology

Savings are estimated for several conservation cases. Each conservation case is defined by an equipment replacement scheme together with the assumed effects of conservation features and extent of delamping (reduction in illuminance).

Each equipment replacement scheme defines the lamp types **L*** and conservation features **f*** that are to be adopted. A different collection of equipment replacements is assumed for each lighting configuration currently in place.

For each current lighting configuration **c** (defined by a lamp type **L** together with conservation features **f**) the base estimate of energy consumption is adjusted by an overall deflation factor. The overall deflation factor $\mathbf{d_{c/c*}}$ is obtained as the product of deflation factors for each of the lamp replacements or conservation feature adoptions under the scheme. Thus,

$$\mathbf{d_{c/c*}} = \frac{\mathbf{Q_L}}{\mathbf{Q_{L*}}} \; \frac{\mathbf{d_{CTL(c*)}}}{\mathbf{d_{CTL(c)}}} \; \frac{\mathbf{d_{HEB(c*)}}}{\mathbf{d_{HEB(c)}}} \; \frac{\mathbf{d_{RFL(c*)}}}{\mathbf{d_{RFL(c)}}} \; \frac{\mathbf{d_{DEL(c*)}}}{\mathbf{d_{DEL(c)}}} \qquad \mathbf{(21)}$$

where **CTL**, **HEB**, **RFL**, and **DEL**, respectively, refer to lighting controls, high-efficiency ballasts, reflectors, and delamping, and $\mathbf{d_{f(c)}}$ indicates the assumed effect of feature **f** for configuration **c**.

This general formulation allows each conservation feature **f** to have different assumed effects depending on the lighting configuration considered. The feature could also have different assumed effect before and after the replacement is implemented, for example, if the replacement assumes greater penetration within buildings where the feature is already in place. If feature **f** is assumed not to be adopted or to have negligible effect, $\mathbf{d_{f(c)}}$ is set equal to 1.

For the base case energy calculation, the effect of all conservation features currently in place is assumed to be negligible, as an average over all floorspace that might be affected. Thus, for the savings calculations presented, the overall deflation factors are computed as:

$$\mathbf{d_{c/c*}} = \frac{\mathbf{Q_L}}{\mathbf{Q_{L*}}} \; \mathbf{d_{CTL(c*)}} \; \mathbf{d_{HEB(c*)}} \; \mathbf{d_{RFL(c*)}} \; \mathbf{d_{DEL(c*)}}. \qquad \mathbf{(22)}$$

This expression can also be written as:

$$\mathbf{d_{c/c*}} = \mathbf{(Q_L/Q_{L*})\ [d_{CTL}]\ [d_{HEB}]\ [d_{RFL}]\ [d_{DEL}],} \qquad \mathbf{(23)}$$

where the square brackets indicate that the deflation factor $\mathbf{d_f}$ is included in the product only if feature **f** is adopted for current configuration c under the replacement scheme.

Because the presence of controls, high-efficiency ballasts, and delamping are ignored in the base case, configurations are distinguished only by lamp type currently in place. Thus, only five different deflation factors are required for each conservation case examined here, one for each of the lamp types identified as currently in place.

The overall deflation factor $\mathbf{d_{c/c*}}$ is applied to the base case energy estimate $\mathbf{E_c}$ for lighting configuration **c** to give the after-replacement energy estimate $\mathbf{E_{c*}}$ for that configuration. Subtracting from the base case estimate gives the savings.

$$\mathbf{SV_c = E_c - E_{c*}} \quad \mathbf{(24)}$$

$$\mathbf{= E_c - d_{c/c*}\, E_c} \quad \mathbf{(25)}$$

$$\mathbf{= (1 - d_{c/c*})\, E_c.} \quad \mathbf{(26)}$$

Summing savings over configurations gives total lighting energy savings for that case.

$$\mathbf{SV_T = \Sigma_c\, SV_c.} \quad \mathbf{(27)}$$

The percent savings for a particular lighting configuration is obtained directly from the overall deflation factor as

$$\mathbf{SV\%_c = 100\ (1 - d_{c/c*}).} \quad \mathbf{(28)}$$

For the commercial buildings population as a whole, the percent savings is obtained by dividing the total after-replacement energy estimate by the base case estimate of total lighting energy:

$$\mathbf{SV\%_T = 100\ (1 - E_{T*} / E_T).} \quad \mathbf{(29)}$$

The overall percent savings can also be expressed as the weighted average of the savings for the individual configurations:

$$\mathbf{SV\%_T = \Sigma_c\, SV\%_c\ (E_c / E_T).} \quad \mathbf{(30)}$$

Alternate Savings Estimate: A Sensitivity Check

The least verifiable component of the energy and savings computations is the illuminance **I** assigned to the building. If the illuminances assumed are too high or too low by a consistent factor, the resulting savings estimates would be off by that factor in absolute terms, but would be unaffected in percentage terms. However, if the errors in the illuminance assignments are inconsistent across building types, even the percent savings estimates could be distorted.

To test the sensitivity of the estimated percent savings to the relative illuminances assumed, the computations are repeated assuming that the time-averaged illuminance **T** is independent of the type of equipment or building. The independence assumption does not require that lighting levels and hours of use be the same for all buildings, only that the differences among buildings be unrelated to the types of equipment. Realistically, though, certain types of lighting equipment are more likely to be used in certain applications, depending in part on the hours of use and lighting levels.

Re-expressing the total percent savings formula above gives

$$\mathbf{SV\%_T} = \frac{\Sigma_c\ \mathbf{SV\%_c\ S_c\ I_c\ U_c\ /\ Q_L}}{\Sigma_c\ \mathbf{S_c\ I_c\ U_c\ /\ Q_L}}\ . \qquad \mathbf{(31)}$$

With a constant assumed for the illuminance **I** and usage factor **U**, this formula becomes simply

$$\mathbf{SV\%_T} = \frac{\Sigma_c\ \mathbf{SV\%_c\ S_c\ /\ Q_L}}{\Sigma_c\ \mathbf{S_c\ /\ Q_L}}\ . \qquad \mathbf{(32)}$$

Thus, with differences in illuminance and hours ignored, the percent savings can be estimated knowing for each lighting configuration only the deflation factor $\mathbf{d_c}$, efficacy $\mathbf{Q_c}$, and floorspace served $\mathbf{S_c}$. In fact, the efficacy does not need to be known in absolute terms, only relative to some standard. This was the approach used in an earlier stage of this analysis.[9]

As discussed in the text, the results of the alternate savings estimate indicated that ignoring differences in **T** resulted in an overstatement of the potential savings, on the order of 5 to 10 percent of the savings estimate that incorporated these differences.

Appendix F

Relative Standard Errors for the Lighting Profile Tables

The CBECS is a probability sample. The statistics that are calculated from the reported CBECS data are subject to random variation, as a result of the random sampling procedure. The random uncertainty associated with these statistics is represented by the standard error. The standard error is the root mean square difference between the estimate based on the CBECS sample and the value that would be computed if the entire population of commercial buildings were included in the data base. The relative standard error (RSE) is the standard error expressed as a percent of the estimate.

The uncertainty of the estimates presented in this report stems from many sources. A crucial source of uncertainty is the assumptions made to derive many of the technical characteristics presented. The analysis has attempted to assess the sensitivity of results to a range of plausible assumptions.

The RSE indicates the uncertainty derived from the sampling only, treating the technical assumptions as known for each sampled building. For quantities involving reported CBECS items only, such as floorspace and hours, this random error is the principal source of uncertainty. For derived quantities based on technical assumptions, the uncertainty of assumptions is generally much greater than the sampling error.

For each of the tables of statistics developed in for the "Commercial Lighting Energy Profile" (Tables 1 through 9 and D1 through D4), a corresponding table of RSE's appears in this appendix. In general, the RSE's are small enough that the comparisons presented among the broad categories tabulated are valid, subject to the acceptability of the engineering assumptions, and the sensitivity of the results to those assumptions.

No RSE's are presented for the savings estimates developed in section on "Lighting Energy Conservation Potential" (Tables 10 through 12). The savings estimates are heavily assumption driven. Their uncertainties are best characterized by the range or estimates under varying assumptions. In fact, for a particular lamp type, the percent savings is completely determined by the assumed deflation factors, which are treated as known quantities; thus, the RSE, which measures the uncertainty due to random sampling, is zero.

Table F1. Relative Standard Errors for Table 1

Building Characteristics	Type of Lamp: Fluorescent Standard	Fluorescent Energy-Efficient	Fluorescent Total	Incandescent Standard	Incandescent Energy-Efficient	Incandescent Total	High Intensity Discharge	Total Lighted Floorspace	Total Floorspace
All Buildings	4.1	5.4	3.4	4.7	7.7	4.5	12.4	3.2	3.0
Principal Activity									
Assembly	12.6	13.2	9.1	11.3	18.3	10.5	19.4	7.8	5.3
Education	9.2	10.7	7.1	14.8	25.0	13.9	27.7	7.2	4.1
Food Sales	18.7	26.9	16.2	21.8	55.2	21.4	57.9	15.0	6.8
Food Service	14.9	22.0	11.7	19.1	33.3	17.0	51.7	12.0	14.4
Health Care	22.1	21.8	17.0	22.0	28.7	18.7	75.9	18.2	4.1
Lodging	13.6	25.0	14.3	12.6	24.7	12.3	66.5	10.5	5.3
Mercantile/Service	5.6	13.1	7.4	13.3	19.6	11.7	17.4	7.1	3.4
Office	8.7	8.8	6.4	12.3	15.7	11.0	23.0	6.3	2.7
Public Order and Safety	19.4	30.9	19.6	60.9	62.2	56.5	55.8	19.6	9.6
Warehouse	12.4	14.1	10.9	11.7	26.7	11.3	21.0	10.1	6.5
Vacant	12.2	32.8	14.2	30.1	48.4	24.1	37.4	11.9	20.7
Other	14.5	27.1	16.3	33.7	38.5	26.1	47.6	17.8	8.3
Building Size (square feet)									
1,001 to 5,000	6.0	7.4	5.3	8.5	17.5	8.0	23.2	5.5	3.9
5,001 to 10,000	5.7	9.6	5.1	8.0	18.0	7.4	18.7	4.6	4.1
10,001 to 25,000	7.3	9.9	5.8	9.2	14.6	7.8	20.4	5.1	5.8
25,001 to 50,000	7.7	10.7	6.6	11.1	19.5	9.7	27.6	6.0	5.7
50,001 to 100,000	10.8	10.2	7.8	15.5	20.7	12.1	21.1	7.3	6.7
100,001 to 200,000	12.7	10.7	8.6	21.0	22.1	16.1	18.5	8.2	7.6
200,001 to 500,000	16.0	13.4	9.9	25.9	23.6	19.1	33.3	10.0	7.8
Over 500,000	25.6	20.9	16.4	31.0	22.9	19.2	40.1	16.0	16.0
Year Constructed									
Before 1920	14.0	14.9	10.8	13.0	27.1	12.4	32.7	9.7	10.6
1920-1945	10.4	11.9	8.2	11.7	21.3	10.9	15.5	7.3	9.5
1946-1959	9.2	9.6	7.8	11.0	20.7	11.0	30.7	7.7	7.5
1960-1969	8.2	10.4	6.9	11.6	20.4	12.2	29.8	6.4	5.1
1970-1979	7.3	9.7	6.4	13.5	16.5	11.2	20.0	6.2	7.2
1980-1986	10.6	12.6	10.1	12.5	16.2	11.1	19.1	9.0	11.0
Census Region									
Northeast	6.6	11.8	5.8	13.4	14.1	10.4	39.4	6.5	5.4
Midwest	7.6	10.7	6.6	9.7	15.2	8.8	17.1	5.7	6.9
South	6.7	9.1	6.4	6.8	15.0	7.8	18.7	6.0	7.7
West	15.3	10.5	9.9	11.7	16.7	10.9	23.7	9.2	7.1

Source: Energy Information Administration, Office of Energy Markets and End Use, Form EIA-871A, "Building Questionnaire" of the 1986 Nonresidential Buildings Energy Consumption Survey.

Table F2. Relative Standard Errors for Table 2

Building Characteristics	Type of Lamp: Fluorescent Standard	Fluorescent Energy-Efficient	Fluorescent Total	Incandescent Standard	Incandescent Energy-Efficient	Incandescent Total	High Intensity Discharge	Total Lighted Floorspace
All Buildings	3.3	3.8	1.2	4.2	7.0	3.8	11.0	0.0
Principal Activity								
Assembly	8.7	11.3	3.9	9.7	14.7	7.4	18.9	0.0
Education	7.6	6.7	1.3	13.0	22.6	11.1	25.7	0.0
Food Sales	15.6	19.2	5.6	18.9	46.6	14.9	54.8	0.0
Food Service	14.7	16.2	7.1	11.5	29.5	8.3	50.3	0.0
Health Care	21.3	8.1	2.0	21.5	26.8	17.1	55.7	0.0
Lodging	11.0	19.8	7.9	9.2	19.9	5.8	67.1	0.0
Mercantile/Service	4.2	7.6	1.3	10.8	18.8	9.3	16.2	0.0
Office	6.3	5.9	1.2	10.4	14.5	8.9	23.4	0.0
Public Order and Safety	22.0	18.8	11.4	49.4	56.1	44.3	51.1	0.0
Warehouse	8.3	8.7	4.7	10.7	26.5	10.4	16.2	0.0
Vacant	10.0	27.7	7.5	25.9	48.4	20.4	38.7	0.0
Other	16.8	17.8	10.4	30.0	37.6	21.7	34.6	0.0
Building Size (square feet)								
1,001 to 5,000	2.8	5.9	1.6	5.8	15.5	4.8	22.5	0.0
5,001 to 10,000	3.7	7.7	1.9	6.4	16.9	5.3	18.0	0.0
10,001 to 25,000	5.1	8.1	2.1	8.4	15.4	7.6	18.7	0.0
25,001 to 50,000	5.3	8.5	2.7	11.0	18.7	9.3	25.3	0.0
50,001 to 100,000	7.6	7.6	2.7	15.3	18.9	10.8	18.6	0.0
100,001 to 200,000	8.2	9.1	3.3	18.4	22.9	14.3	16.4	0.0
200,001 to 500,000	14.0	9.5	4.5	23.4	21.8	16.0	26.6	0.0
Over 500,000	24.1	11.0	4.4	33.3	22.2	20.7	31.8	0.0
Year Constructed								
Before 1920	8.7	12.4	4.0	9.8	24.3	8.2	34.3	0.0
1920-1945	7.3	8.9	3.0	9.5	19.6	8.1	16.7	0.0
1946-1959	5.3	6.7	3.0	8.8	19.2	8.6	27.0	0.0
1960-1969	5.8	7.9	2.8	9.5	18.4	9.7	30.1	0.0
1970-1979	5.3	6.8	2.2	13.7	16.5	11.3	16.4	0.0
1980-1986	7.2	6.5	3.1	13.4	14.9	10.8	16.7	0.0
Census Region								
Northeast	9.5	6.7	2.8	11.4	12.4	7.7	35.5	0.0
Midwest	5.2	8.3	2.5	8.0	13.7	6.6	16.4	0.0
South	4.0	5.5	1.8	7.2	13.8	7.4	14.9	0.0
West	8.8	8.5	2.4	9.5	15.4	8.7	20.9	0.0

Source: Energy Information Administration, Office of Energy Markets and End Use, Form EIA-871A, "Building Questionnaire" of the 1986 Nonresidential Buildings Energy Consumption Survey.

Table F3. Relative Standard Errors for Table 3

Building Characteristics	Total Lighted Floorspace (million square feet) Open	Total Lighted Floorspace Closed	Total Lighted Floorspace Ratio (Closed/ Open)	Operating Hours per Week	Total Weekly Lighted Floorspace-Hours (billion square foot-hours) Open	Total Weekly Lighted Floorspace-Hours Closed	Total Weekly Lighted Floorspace-Hours Total (Open + Closed)	Effective Lighting Hours per Week H^e	Effective Lighting Hours per Week Ratio (Effective Lighting/ Operating)
All Buildings	3.2	7.1	5.7	2.0	4.4	4.9	4.1	1.8	0.6
Principal Activity									
Assembly	7.8	20.0	17.6	7.3	11.0	18.6	10.8	6.7	1.6
Education	7.2	10.7	10.3	3.6	8.2	10.8	7.6	3.1	1.7
Food Sales	15.0	23.7	16.7	5.8	15.1	27.5	15.3	5.1	2.8
Food Service	12.0	22.4	16.8	9.0	19.0	19.3	18.0	7.9	1.5
Health Care	18.2	23.1	8.8	2.9	19.6	27.0	19.5	2.8	0.1
Lodging	10.5	14.2	8.9	1.6	11.0	41.8	10.9	1.5	0.3
Mercantile/Service	7.1	9.8	5.7	1.5	7.4	10.9	7.7	1.8	0.9
Office	6.3	13.0	11.3	2.9	5.9	13.7	6.6	3.0	2.5
Public Order and Safety . . .	19.6	28.7	15.4	7.4	22.9	43.6	22.2	6.2	2.7
Warehouse	10.1	20.6	17.4	5.9	12.6	16.7	12.2	5.5	1.7
Vacant	11.9	32.2	30.0	17.8	21.3	34.6	19.6	15.7	8.2
Other	17.8	24.1	14.8	10.8	22.3	23.0	20.6	9.0	2.9
Building Size (square feet)									
1,001 to 5,000	5.5	8.9	7.4	2.9	6.1	9.3	5.9	2.6	1.0
5,001 to 10,000	4.6	9.9	9.0	2.8	4.4	9.3	4.5	2.7	0.8
10,001 to 25,000	5.1	10.2	9.5	2.7	5.2	9.9	5.1	2.6	1.0
25,001 to 50,000	6.0	9.2	8.7	3.3	6.9	12.1	6.5	3.0	1.5
50,001 to 100,000	7.3	15.2	11.9	5.6	9.9	12.8	9.5	5.1	1.4
100,001 to 200,000	8.2	12.0	8.7	4.5	8.4	16.9	8.3	4.1	2.1
200,001 to 500,000	10.0	13.1	12.7	6.1	10.7	15.7	10.0	5.1	2.0
Over 500,000	16.0	26.0	15.4	8.9	21.2	24.3	19.6	6.5	3.5
Year Constructed									
Before 1920	9.7	23.6	19.9	7.0	11.4	18.8	11.5	6.1	2.3
1920-1945	7.3	15.1	12.4	5.5	10.5	10.4	9.6	4.8	1.5
1946-1959	7.7	12.4	9.7	3.5	8.6	11.8	8.4	3.0	1.2
1960-1969	6.4	11.4	8.9	3.7	7.9	16.4	7.8	3.4	1.9
1970-1979	6.2	9.3	7.3	3.1	7.4	9.6	6.8	2.6	1.4
1980-1986	9.0	18.3	12.6	4.8	11.8	12.5	11.4	4.1	1.1
Census Region									
Northeast	6.5	8.4	9.5	2.5	6.9	7.6	6.2	2.1	1.2
Midwest	5.7	11.1	8.7	3.1	6.5	15.0	6.7	3.2	1.7
South	6.0	14.5	10.4	4.4	9.5	7.1	8.7	3.7	1.1
West	9.2	11.5	8.5	3.0	9.1	12.3	8.9	2.7	1.2

Source: Energy Information Administration, Office of Energy Markets and End Use, Form EIA-871A, "Building Questionnaire" of the 1986 Nonresidential Buildings Energy Consumption Survey.

Table F4. Relative Standard Errors for Table 4

Lamp Type	Total Lighted Floorspace (million square feet)			Operating Hours per Week	Total Weekly Lighted Floorspace-Hours (billion square foot-hours)			Effective Lighting Hours per Week	
	Open	Closed	Ratio (Closed/ Open)		Open	Closed	Total (Open + Closed)	H^e	Ratio (Effective Lighting/ Operating)
Fluorescent	3.4	7.3	5.6	1.9	4.3	5.9	4.1	1.7	0.7
Standard	4.1	8.4	6.7	1.8	4.7	7.3	4.4	1.7	1.0
Energy-Efficient	5.4	9.5	7.6	3.0	6.3	10.0	6.2	2.6	1.2
Incandescent	4.5	10.7	9.1	3.8	6.2	5.9	5.9	3.5	0.6
Standard	4.7	12.4	10.4	4.3	6.5	7.5	6.1	3.9	0.7
Energy-Efficient	7.7	12.7	11.3	6.6	10.9	10.8	10.1	5.8	1.2
High-Intensity Discharge	12.4	20.7	14.5	7.6	17.5	17.2	15.9	6.4	2.4

Source: Energy Information Administration, Office of Energy Markets and End Use, Form EIA-871A, "Building Questionnaire" of the 1986 Nonresidential Buildings Energy Consumption Survey.

Table F5. Relative Standard Errors for Table 5

Building Characteristics	Average Assigned Illuminance Range (lumens per square foot)		
	Low	Medium	High
All Buildings	2.58	2.58	2.29
Principal Activity			
Assembly	0.00	0.00	0.00
Education	0.00	0.00	0.00
Food Sales	0.00	0.00	0.00
Food Service	0.00	0.00	0.00
Health Care	0.00	0.00	0.00
Lodging	0.00	0.00	0.00
Mercantile/Service	0.00	0.00	0.00
Office	0.00	0.00	0.00
Public Order & Safety	0.00	0.00	0.00
Warehouse	0.00	0.00	0.00
Vacant	0.00	0.00	0.00
Other	0.00	0.00	0.00
Building Size (square feet)			
1,001 to 5,000	1.43	1.43	1.26
5,001 to 10,000	2.58	2.58	2.16
10,001 to 25,000	2.41	2.41	2.08
25,001 to 50,000	3.65	3.65	3.39
50,001 to 100,000	3.46	3.46	3.11
100,001 to 200,000	5.86	5.86	5.30
200,001 to 500,000	6.97	6.97	6.40
Over 500,000	10.75	10.75	10.00
Year Constructed			
Before 1920	5.05	5.05	4.24
1920-1945	4.91	4.91	4.26
1946-1959	4.92	4.92	4.40
1960-1969	4.13	4.13	3.54
1970-1979	3.92	3.92	3.56
1980-1986	6.88	6.88	6.11
Census Region			
Northeast	3.74	3.74	3.21
Midwest	4.10	4.10	3.67
South	4.62	4.62	3.98
West	4.85	4.85	4.37

Sources: Adapted from Energy Information Administration, Office of Energy Markets and End Use, Form EIA-788A, "Building Form" of the 1979 Nonresidential Buildings Energy Consumption Survey; Form EIA-871A, "Building Questionnaire" of the 1986 Nonresidential Buildings Energy Consumption Survey; and Illuminating Engineering Society of North America, *IES Lighting Handbook: 1987 Application Volume.*

Table F6. Relative Standard Errors for Table 6

Lamp Type and Conservation Feature Present	Percent of Total Lighted Floorspace	Usage Factor (percent)	Illuminance (lumens per square foot) In-Use Average	Illuminance (lumens per square foot) Time-Averaged	Efficacy (lumens per square foot)	In-Use Lighting Power Density (watts per
Standard Fluorescent	4.1	1.7	2.0	3.1	0.0	2.0
No Conservation Features	5.4	2.6	3.1	5.2	0.0	3.1
Ballast	8.7	4.2	3.7	5.5	0.0	3.7
Controls	11.6	7.0	4.8	7.6	0.0	4.8
Delamping	18.0	5.4	6.8	10.1	0.0	6.8
Ballast and Controls	14.5	6.6	5.0	7.7	0.0	5.0
Ballast and Delamping	16.8	8.4	9.4	10.4	0.0	9.4
Controls and Delamping	33.2	10.0	15.9	29.2	0.0	15.9
Ballast, Controls, and Delamping	25.8	10.4	8.6	17.1	0.0	8.6
Energy-Efficient Fluorescent	5.4	2.6	3.1	6.2	0.0	3.1
No Conservation Features	9.1	4.0	5.7	8.3	0.0	5.7
Ballast	8.0	5.8	4.9	9.0	0.0	4.9
Controls	18.4	5.2	6.3	6.8	0.0	6.3
Delamping	12.2	6.8	7.6	11.9	0.0	7.6
Ballast and Controls	12.3	7.1	10.1	18.6	0.0	10.1
Ballast and Delamping	14.4	5.2	3.1	7.2	0.0	3.1
Controls and Delamping	26.0	9.8	3.9	10.8	0.0	3.9
Ballast, Controls, and Delamping	16.1	6.0	10.9	20.0	0.0	10.9
Standard Incandescent	4.7	3.9	2.9	4.4	0.0	2.9
No Conservation Features	5.9	5.1	2.6	6.0	0.0	2.6
Controls	13.1	9.5	5.9	7.4	0.0	5.9
Delamping	25.2	8.6	14.2	11.3	0.0	14.2
Controls and Delamping	17.2	7.3	12.0	17.9	0.0	12.0
Energy-Efficient Incandescent	7.7	5.8	4.3	6.8	0.0	4.3
No Conservation Features	9.6	8.2	5.7	8.2	0.0	5.7
Controls	14.1	8.8	9.3	14.5	0.0	9.3
Delamping	20.6	9.3	6.6	9.0	0.0	6.6
Controls and Delamping	20.7	7.8	11.4	12.8	0.0	11.4
High-Intensity Discharge	12.4	6.4	12.2	21.6	0.0	12.2
No Conservation Features	14.6	8.6	9.1	8.1	0.0	9.1
Controls	21.6	9.4	14.6	23.9	0.0	14.6
Delamping	28.6	9.9	22.3	17.2	0.0	22.3
Controls and Delamping	26.2	10.7	23.6	35.0	0.0	23.6

Sources: Percent of floorspace and usage factor from Energy Information Administration, Office of Energy Markets and End Use, Form EIA-871A, "Building Questionnaire" of the 1986 Nonresidential Buildings Energy Consumption Survey; Illuminance and efficacy derived from sources described in Appendices B and C. Lighting power density is derived from illuminance and efficacy.

Table F7. Relative Standard Errors for Table 7

Building Characteristics	Percent of Total Lighted Floorspace 1986	Usage Factor (percent)	Illuminance (lumens per square foot)		In-Use Lighting Power Density (watts/square foot)
			In-Use	Time-Averaged	
All Buildings	3.2	1.8	2.3	4.3	N/A
Principal Activity					
Assembly	7.8	6.7	0.0	6.7	N/A
Education	7.2	3.1	0.0	3.1	N/A
Food Sales	15.0	5.1	0.0	5.1	N/A
Food Service	12.0	7.9	0.0	7.9	N/A
Health Care	18.2	2.8	0.0	2.8	N/A
Lodging	10.5	1.5	0.0	1.5	N/A
Mercantile/Service	7.1	1.8	0.0	1.8	N/A
Office	6.3	3.0	0.0	3.0	N/A
Public Order and Safety	19.6	6.2	0.0	6.2	N/A
Warehouse	10.1	5.5	0.0	5.5	N/A
Vacant	11.9	15.7	0.0	15.8	N/A
Other	17.8	9.0	0.0	9.0	N/A
Building Size (square feet)					
1,001 to 5,000	5.5	2.6	1.3	3.0	N/A
5,001 to 10,000	4.6	2.7	2.2	3.1	N/A
10,001 to 25,000	5.1	2.6	2.1	3.8	N/A
25,001 to 50,000	6.0	3.0	3.4	5.9	N/A
50,001 to 100,000	7.3	5.1	3.1	5.5	N/A
100,001 to 200,000	8.2	4.1	5.3	7.6	N/A
200,001 to 500,000	10.0	5.1	6.4	7.9	N/A
Over 500,000	16.0	6.5	10.0	17.0	N/A
Year Constructed					
Before 1920	9.7	6.1	4.2	9.1	N/A
1920-1945	7.3	4.8	4.3	8.0	N/A
1946-1959	7.7	3.0	4.4	6.9	N/A
1960-1969	6.4	3.4	3.5	4.8	N/A
1970-1979	6.2	2.6	3.6	6.6	N/A
1980-1986	9.0	4.1	6.1	13.4	N/A
Census Region					
Northeast	6.5	2.1	3.2	4.2	N/A
Midwest	5.7	3.2	3.7	6.6	N/A
South	6.0	3.7	4.0	9.3	N/A
West	9.2	2.7	4.4	6.2	N/A

N/A This statistic was created using a composite of data from Table 6 and the relative standard errors are unavailable.

Sources: Percent of floorspace and usage factor from Energy Information Administration, Office of Energy Markets and End Use, Form EIA-871A, "Building Questionnaire" of the 1986 Nonresidential Buildings Energy Consumption Survey; Illuminance and efficacy derived from sources described in Appendices B and C. Lighting power density is derived from illuminance and efficacy.

Table F8. Relative Standard Errors for Table 8

Lamp Type and Conservation Feature Present	Floorspace, 1986 (million square feet) Total Lighted	Percent of Total Lighted	Annual Lighting End-Use Intensity (kWh/square foot)	Annual Lighting Energy (billion kWh)
Standard Fluorescent	4.1	4.1	6.2	5.5
No Conservation Features	5.4	5.4	5.2	7.0
Ballast	8.7	8.7	5.5	10.7
Controls	11.6	11.6	7.6	15.4
Delamping	18.0	18.0	10.1	23.4
Ballast and Controls	14.5	14.5	7.7	15.7
Ballast and Delamping	16.8	16.8	10.4	19.8
Controls and Delamping	33.2	33.2	29.2	38.2
Ballast, Controls, and Delamping	25.8	25.8	17.1	24.1
Energy-Efficient Fluorescent	5.4	5.4	6.2	8.2
No Conservation Features	9.1	9.1	8.3	12.4
Ballast	8.0	8.0	9.0	11.4
Controls	18.4	18.4	6.8	16.8
Delamping	12.2	12.2	11.9	15.0
Ballast and Controls	12.3	12.3	18.6	23.5
Ballast and Delamping	14.4	14.4	7.2	16.6
Controls and Delamping	26.0	26.0	10.8	23.1
Ballast, Controls, and Delamping	16.1	16.1	20.0	28.6
Standard Incandescent	4.7	4.7	4.4	6.5
No Conservation Features	5.9	5.9	6.0	8.3
Controls	13.1	13.1	7.4	12.3
Delamping	25.2	25.2	11.3	21.1
Controls and Delamping	17.2	17.2	17.9	23.4
Energy-Efficient Incandescent	7.7	7.7	6.8	9.0
No Conservation Features	9.6	9.6	8.2	9.3
Controls	14.1	14.1	14.5	21.9
Delamping	20.6	20.6	9.0	20.6
Controls and Delamping	20.7	20.7	12.8	14.2
High-Intensity Discharge	12.4	12.4	21.6	29.0
No Conservation	14.6	14.6	8.1	15.3
Controls	21.6	21.6	23.9	46.5
Delamping	28.6	28.6	17.2	21.1
Controls and Delamping	26.2	26.2	35.0	59.4

Sources: Floorspace from Energy Information Administration, Office of Energy Markets and End Use, Form EIA-871A, "Building Questionnaire" of the Nonresidential Buildings Energy Consumption Survey; Illuminance and efficacy derived from sources described in Appendices B and C. Lighting end-use intensity and energy measures are derived from illuminance and efficacy.

Table F9. Relative Standard Errors for Table 9

Building Characteristics	Floorspace, 1986 (million square feet)			Annual Lighting End-Use Intensity (kWh/square foot)		Annual Lighting Energy (billion kWh)
	Total	Total Lighted	Percent of Total Lighted	per Total Square Feet	per Total Lighted Square Feet	
All Buildings	3.01	3.20	3.20	3.57	3.36	5.04
Principal Activity						
Assembly	7.08	7.81	7.81	5.29	5.22	9.11
Education	7.01	7.21	7.21	4.10	4.13	8.30
Food Sales	14.44	15.04	15.04	6.82	6.45	14.59
Food Service	10.12	12.04	12.04	14.35	12.15	21.91
Health Care	17.36	18.21	18.21	4.05	4.07	17.71
Lodging	9.84	10.52	10.52	5.33	4.20	12.01
Mercantile/Service	7.02	7.10	7.10	3.36	2.46	7.95
Office	6.18	6.26	6.26	2.72	2.42	6.26
Public Order and Safety	18.54	19.60	19.60	19.64	19.61	32.92
Warehouse	8.61	10.12	10.12	6.49	5.20	10.45
Vacant	9.59	11.92	11.92	20.69	17.80	20.02
Other	16.69	17.84	17.84	8.25	7.49	18.14
Building Size (square feet)						
1,001 to 5,000	5.16	5.47	5.47	3.92	3.29	6.71
5,001 to 10,000	4.54	4.62	4.62	4.10	3.83	5.42
10,001 to 25,000	4.80	5.07	5.07	5.78	5.76	6.48
25,001 to 50,000	5.78	6.01	6.01	5.66	5.64	7.50
50,001 to 100,000	6.90	7.32	7.32	6.67	6.23	9.19
100,001 to 200,000	8.54	8.19	8.19	7.59	7.71	10.37
200,001 to 500,000	9.96	10.02	10.02	7.82	7.57	11.03
Over 500,000	15.06	16.02	16.02	16.00	14.62	23.59
Year Constructed						
Before 1920	8.97	9.68	9.68	10.59	8.62	12.44
1920-1945	6.32	7.27	7.27	9.47	8.96	12.78
1946-1959	7.65	7.68	7.68	7.49	6.76	8.67
1960-1969	6.16	6.42	6.42	5.13	5.08	8.29
1970-1979	5.71	6.24	6.24	7.23	7.05	8.58
1980-1986	8.32	9.00	9.00	11.03	10.62	16.11
Census Region						
Northeast	6.96	6.46	6.46	5.36	4.95	5.09
Midwest	5.08	5.71	5.71	6.92	6.34	9.37
South	5.47	6.00	6.00	7.73	6.99	10.94
West	9.59	9.19	9.19	7.10	7.28	9.34

Sources: Floorspace from Energy Information Administration, Office of Energy Markets and End Use, Form EIA-871A, "Building Questionnaire" of the 1986 Nonresidential Buildings Energy Consumption Survey; Illuminance and efficacy derived from sources described in Appendices B and C. Lighting end-use intensity and energy measures are derived from illuminance and efficacy.

Table F10. Relative Standard Errors for Table D1

Lamp Type and Conservation Feature Present	Percent of Total Lighted Floorspace	Usage Factor (percent)	Illuminance (lumens per square foot) In-Use	Illuminance (lumens per square foot) Time-Averaged	Efficacy (lumens per watt)	In-Use Lighting Power Density (watts per square foot)
Standard Fluorescent	4.1	1.7	2.0	3.1	0.0	2.0
No Conservation Features	5.4	2.6	3.1	5.2	0.0	3.1
Ballast	8.7	4.2	3.7	5.5	0.0	3.7
Controls	11.6	7.0	4.8	7.6	0.0	4.8
Delamping	18.0	5.4	6.8	10.1	0.0	6.8
Ballast and Controls	14.5	6.6	5.0	7.7	0.0	5.0
Ballast and Delamping	16.8	8.4	9.4	10.4	0.0	9.4
Controls and Delamping	33.2	10.0	15.9	29.2	0.0	15.9
Ballast, Controls, and Delamping	25.8	10.4	8.6	17.1	0.0	8.6
Energy-Efficient Fluorescent	5.4	2.6	3.1	5.9	0.0	3.1
No Conservation Features	9.1	4.0	5.7	8.3	0.0	5.7
Ballast	8.0	5.8	4.9	9.0	0.0	4.9
Controls	18.4	5.2	6.3	6.8	0.0	6.3
Delamping	12.2	6.8	7.6	11.9	0.0	7.6
Ballast and Controls	12.3	7.1	10.1	18.6	0.0	10.1
Ballast and Delamping	14.4	5.2	3.1	7.2	0.0	3.1
Controls and Delamping	26.0	9.8	3.9	10.8	0.0	3.9
Ballast, Controls, and Delamping	16.1	6.0	10.9	20.0	0.0	10.9
Standard Incandescent	4.7	3.9	2.9	4.4	0.0	2.9
No Conservation Features	5.9	5.1	2.6	6.0	0.0	2.6
Controls	13.1	9.5	5.9	7.4	0.0	5.9
Delamping	25.2	8.6	14.2	11.3	0.0	14.2
Controls and Delamping	17.2	7.3	12.0	17.9	0.0	12.0
Energy-Efficient Incandescent	7.7	5.8	4.3	6.6	0.0	4.3
No Conservation Features	9.6	8.2	5.7	8.2	0.0	5.7
Controls	14.1	8.8	9.3	14.5	0.0	9.3
Delamping	20.6	9.3	6.6	9.0	0.0	6.6
Controls and Delamping	20.7	7.8	11.4	12.8	0.0	11.4
High-Intensity Discharge	12.4	6.4	12.2	19.9	0.0	12.2
No Conservation Features	14.6	8.6	9.1	8.1	0.0	9.1
Controls	21.6	9.4	14.6	23.9	0.0	14.6
Delamping	28.6	9.9	22.3	17.2	0.0	22.3
Controls and Delamping	26.2	10.7	23.6	35.0	0.0	23.6

Sources: Percent of floorspace and usage factor from Energy Information Administration, Office of Energy Markets and End Use, Form EIA-871A, "Building Questionnaire" of the 1986 Nonresidential Buildings Energy Consumption Survey; Illuminance and efficacy derived from sources described in Appendices B and C. Lighting power density is derived from illuminance and efficacy.

Table F11. Relative Standard Errors for Table D2

Building Characteristics	Percent of Total Lighted Floorspace 1986	Usage Factor (percent)	Illuminance (lumens per square foot)		In-Use Lighting Power Density (watts/square foot)
			In-Use	Time-Averaged	
All Buildings	3.20	1.8	2.3	3.96	N/A
Principal Activity					
Assembly	7.81	6.7	0.0	6.43	N/A
Education	7.21	3.1	0.0	3.12	N/A
Food Sales	15.04	5.1	0.0	5.29	N/A
Food Service	12.04	7.9	0.0	7.25	N/A
Health Care	18.21	2.8	0.0	2.81	N/A
Lodging	10.52	1.5	0.0	1.6	N/A
Mercantile/Service	7.10	1.8	0.0	1.51	N/A
Office	6.26	3.0	0.0	2.96	N/A
Public Order and Safety	19.60	6.2	0.0	6.19	N/A
Warehouse	10.12	5.5	0.0	5.32	N/A
Vacant	11.92	15.7	0.0	15.61	N/A
Other	17.84	9.0	0.0	8.65	N/A
Building Size (square feet)					
1,001 to 5,000	5.47	2.6	1.3	2.89	N/A
5,001 to 10,000	4.62	2.7	2.2	3.1	N/A
10,001 to 25,000	5.07	2.6	2.1	3.75	N/A
25,001 to 50,000	6.01	3.0	3.4	5.91	N/A
50,001 to 100,000	7.32	5.1	3.1	5.62	N/A
100,001 to 200,000	8.19	4.1	5.3	8.05	N/A
200,001 to 500,000	10.02	5.1	6.4	8.01	N/A
Over 500,000	16.02	6.5	10.0	16.18	N/A
Year Constructed					
Before 1920	9.68	6.1	4.2	9.29	N/A
1920-1945	7.27	4.8	4.3	8.28	N/A
1946-1959	7.68	3.0	4.4	6.99	N/A
1960-1969	6.42	3.4	3.5	4.81	N/A
1970-1979	6.24	2.6	3.6	6.47	N/A
1980-1986	9.00	4.1	6.1	11.9	N/A
Census Region					
Northeast	6.46	2.1	3.2	4.45	N/A
Midwest	5.71	3.2	3.7	6.52	N/A
South	6.00	3.7	4.0	8.17	N/A
West	9.19	2.7	4.4	6.42	N/A

N/A: This statistic was created using a composite of data from Table D1 and the relative standard errors are unavailable.

Sources: Percent of floorspace and usage factor from Energy Information Administration, Office of Energy Markets and End Use, Form EIA-871A, "Building Questionnaire" of the 1986 Nonresidential Buildings Energy Consumption Survey; Illuminance and efficacy derived from sources described in Appendices B and C. Lighting power density is derived from illuminance and efficacy.

Table F12. Relative Standard Errors for Table D3

Lamp Type and Conservation Feature Present	Floorspace (million square feet) Total Lighted	Percent of Total Lighted	Annual Lighting End-Use Intensity (kWh/square foot)	Annual Lighting Energy (billion kWh)
Standard Fluorescent	4.1	4.1	3.1	5.5
No Conservation Features	5.4	5.4	5.2	7.0
Ballast	8.7	8.7	5.5	10.7
Controls	11.6	11.6	7.6	15.4
Delamping	18.0	18.0	10.1	23.4
Ballast and Controls	14.5	14.5	7.7	15.7
Ballast and Delamping	16.8	16.8	10.4	19.8
Controls and Delamping	33.2	33.2	29.2	38.2
Ballast, Controls, and Delamping	25.8	25.8	17.1	24.1
Energy-Efficient Fluorescent	5.4	5.4	5.8	7.8
No Conservation Features	9.1	9.1	8.3	12.4
Ballast	8.0	8.0	9.0	11.4
Controls	18.4	18.4	6.8	16.8
Delamping	12.2	12.2	11.9	15.0
Ballast and Controls	12.3	12.3	18.6	23.5
Ballast and Delamping	14.4	14.4	7.2	16.6
Controls and Delamping	26.0	26.0	10.8	23.1
Ballast, Controls, and Delamping	16.1	16.1	20.0	28.6
Standard Incandescent	4.7	4.7	4.4	6.5
No Conservation Features	5.9	5.9	6.0	8.3
Controls	13.1	13.1	7.4	12.3
Delamping	25.2	25.2	11.3	21.1
Controls and Delamping	17.2	17.2	17.9	23.4
Energy-Efficient Incandescent	7.7	7.7	6.6	8.8
No Conservation Features	9.6	9.6	8.2	9.3
Controls	14.1	14.1	14.5	21.9
Delamping	20.6	20.6	9.0	20.6
Controls and Delamping	20.7	20.7	12.8	14.2
High-Intensity Discharge	12.4	12.4	19.9	27.4
No Conservation Features	14.6	14.6	8.1	15.3
Controls	21.6	21.6	23.9	46.5
Delamping	28.6	28.6	17.2	21.1
Controls and Delamping	26.2	26.2	35.0	59.4

Sources: Floorspace from Energy Information Administration, Office of Energy Markets and End Use, Form EIA-871A, "Building Questionnaire" of the 1986 Nonresidential Buildings Energy Consumption Survey; Illuminance and efficacy derived from sources described in Appendices B and C. Lighting end-use intensity and energy measures are derived from illuminance and efficacy.

Table F13. Relative Standard Errors for Table D4

Building Characteristics	Floorspace, 1986 (million square feet) Total	Total Lighted	Percent of Total Lighted	Annual Lighting End-Use Intensity (kWh/square foot) per Total Square Feet	per Total Lighted Square Feet	Annual Lighting Energy (billion kWh)
All Buildings	3.0	3.2	3.2	3.3	3.2	4.8
Principal Activity						
Assembly	7.1	7.8	7.8	5.3	5.2	8.7
Education	7.0	7.2	7.2	4.2	4.2	8.5
Food Sales	14.4	15.0	15.0	7.5	7.1	14.7
Food Service	10.1	12.0	12.0	13.4	11.3	20.9
Health Care	17.4	18.2	18.2	4.5	4.7	16.8
Lodging	9.8	10.5	10.5	5.0	4.2	11.5
Mercantile/Service	7.0	7.1	7.1	3.4	2.6	7.7
Office	6.2	6.3	6.3	2.8	2.4	6.3
Public Order and Safety	18.5	19.6	19.6	21.3	21.3	34.3
Warehouse	8.6	10.1	10.1	6.4	5.1	10.4
Vacant	9.6	11.9	11.9	20.4	17.2	19.9
Other	16.7	17.8	17.8	8.2	7.6	17.8
Building Size (square feet)						
1,001 to 5,000	5.2	5.5	5.5	3.9	3.3	6.7
5,001 to 10,000	4.5	4.6	4.6	4.2	3.9	5.5
10,001 to 25,000	4.8	5.1	5.1	5.8	5.8	6.5
25,001 to 50,000	5.8	6.0	6.0	5.7	5.6	7.6
50,001 to 100,000	6.9	7.3	7.3	6.9	6.4	9.2
100,001 to 200,000	8.5	8.2	8.2	8.0	8.1	10.9
200,001 to 500,000	10.0	10.0	10.0	7.9	7.7	11.0
Over 500,000	15.1	16.0	16.0	15.3	13.9	22.6
Year Constructed						
Before 1920	9.0	9.7	9.7	10.9	8.9	12.6
1920-1945	6.3	7.3	7.3	9.8	9.4	13.1
1946-1959	7.7	7.7	7.7	7.6	6.9	8.8
1960-1969	6.2	6.4	6.4	5.2	5.2	8.3
1970-1979	5.7	6.2	6.2	6.8	6.7	8.3
1980-1986	8.3	9.0	9.0	9.6	9.3	14.6
Census Region						
Northeast	7.0	6.5	6.5	5.6	5.4	5.5
Midwest	5.1	5.7	5.7	6.8	6.2	9.2
South	5.5	6.0	6.0	6.9	6.1	10.0
West	9.6	9.2	9.2	7.3	7.6	9.6

Sources: Floorspace from Energy Information Administration, Office of Energy Markets and End Use, Form EIA-871A, "Building Questionnaire" of the 1986 Nonresidential Buildings Energy Consumption Survey; Illuminance and efficacy derived from sources described in Appendices B and C. Lighting end-use intensity and energy measures are derived from illuminance and efficacy.

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Notation

E Annual lighting energy (kWh)

EUI End-use intensity for lighting (kWh/sf)

$\mathbf{d_f}$ Deflation factor for lighting conservation feature **f**

H Hours

$\mathbf{H^e}$ Effective lighting hours per week

$\mathbf{H^o}$ Weekly operating hours

$\mathbf{H^n}$ Weekly off hours (assumed = 168 - $\mathbf{H^o}$).

I In-use illuminance (l/sf)

P Lighting power density (w/sf)

S Lighted floorspace (sf)

$\mathbf{S^o}$ Floorspace lighted during usual operating hours (sf)

$\mathbf{S^n}$ Floorspace lighted during off hours (sf)

SH Lighted floorspace-hours per week (sf-hr)

Q Efficacy (l/w)

T Time-averaged illuminance (l/sf)

U Usage factor ($\mathbf{H^e}$/168)

Subscripts

***** after conservation replacement scheme is adopted

b building

c lighting configuration (lamp type and conservation features)

CTL controls

DEL delamping

f conservation feature

HEB high-efficiency ballast

L lamp type

RFL reflector

T total

Glossary

Ballast: See **High-Efficiency Ballast**.

Btu: British thermal unit. A unit quantity of energy consumed by or delivered to a building. A Btu is defined as the amount of energy required to increase the temperature of 1 pound of water by 1 degree Fahrenheit, at normal atmospheric pressure. The term is used in this report to help with the comparison of consumption among fuels that are measured in different units. The conversion factor for electricity for the CBECS is 3,412 Btu/kWh.

Building (b): For the CBECS, a structure totally enclosed by walls extending from the foundation to the roof, containing over 1,000 square feet of floorspace, and intended for human occupancy. Structures that were included in the survey as a specific exception were parking garages not totally enclosed by walls and a roof, as well as structures erected on pillars to elevate the first fully enclosed level, but leaving the sides at ground level open.

Census Region: A geographic area consisting of several States defined by the U.S. Department of Commerce, Bureau of the Census. The states are grouped into four regions:

Region	States
Northeast	Connecticut, Maine, Massachusetts, New Hampshire, Vermont, Rhode Island, New Jersey, New York, and Pennsylvania
Midwest	Illinois, Indiana, Michigan, Ohio, Wisconsin, Iowa, Kansas, Minnesota, Missouri, Nebraska, North Dakota, and South Dakota
South	Delaware, the District of Columbia, Florida, Georgia, Maryland, North Carolina, South Carolina, Virginia, West Virginia, Alabama, Kentucky, Mississippi, Tennessee, Arkansas, Louisiana, Oklahoma, and Texas
West	Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, Wyoming, Alaska, California, Hawaii, Oregon, and Washington

Commercial: Neither residential, manufacturing, nor agricultural.

Commercial Building: A building with more than 50 percent of its floorspace used for commercial activities. Commercial buildings include, but are not limited to, stores, offices, schools, churches, gymnasiums, libraries, museums, hospitals, clinics, warehouses, and jails. Government buildings were included except for buildings on site with restricted access, such as some military bases or reservations. Farms and buildings located on farms (such as silos, grain elevators and barns) were excluded from the CBECS.

Conservation Case: An equipment replacement scheme together with assumed deflation factors for conservation feature effects and extent of delamping. (See **Deflation Factor** and **Delamping**.)

Conservation Feature (f): A feature in the building designed to reduce the usage of electricity for lighting.

Controls (CTL): A lighting conservation feature, consisting of any lighting control equipment, including occupancy sensors, timers, and daylight controls. (See **Conservation Feature**.)

Deflation Factor (d): A factor less than one representing the assumed ratio of energy used by equipment with a particular conservation feature present to the energy that would be used without that feature. (See **Conservation Feature**.)

Delamping (DEL): In this report, reduction in illuminance while maintaining equipment efficacy, typically by disconnecting some fixtures. More generally, delamping refers to the removal of lamps and the associated ballasts.

Effective Lighting Hours (H^e): The average number of hours per week of lighting use for the floorspace that is lighted during usual operating hours. (See **Usual Operating Hours** and Appendix D).

Efficacy (Q): The amount of light produced by a lamp per unit of energy used.

End-Use Intensity (EUI): Energy consumption for a particular end use per unit of floorspace. In this report, lighting is the only end use for which end-use intensities are considered.

Energy-Efficient Lamp or Bulb: A fluorescent lamp or incandescent bulb that uses less energy for the same or nearly the same light output as a standard lamp or bulb of the same dimensions.

Floorspace-Weighted Average: A weighted average, using lighted floorspace as the weighting factor. (See **Lighted Floorspace** and Appendix A.)

Fluorescent Lamp: A lamp made of a glass tube coated on the inside with fluorescent material. The lamp produces light by passing electricity through mercury vapor, which causes the fluorescent coating to glow or fluoresce.

High-Efficiency Ballast (HEB): A lighting conservation feature consisting of an energy-efficient version of a conventional electromagnetic ballast. The ballast is the transformer for fluorescent and HID lamps, which provides the necessary current, voltage, and wave-form conditions to operate the lamp. A high-efficiency ballast requires lower power input than a conventional ballast to operate HID and fluorescent lamps. (See **Fluorescent Lamp**, **High-Intensity Discharge (HID) Lamp**, and **Conservation Feature**.)

High-Intensity Discharge (HID) Lamp: A lamp that produces light by passing electricity through gas, which causes the gas to glow. Examples of HID lamps are mercury vapor lamps, metal halide lamps, and high-pressure sodium lamps.

Illuminance: A measure of the amount of light in a space. In this report, expressed in units of lumens per square foot. (See **In-Use Illuminance** and **Time-Averaged Illuminance**.)

Incandescent bulb: A lamp that produces light by electrically heating a filament so that it glows. Included in this category are the familiar household light bulbs which screw into sockets, as well as energy-efficient incandescent bulbs such as Tungsten Halogen (spotlights), Reflector or R-Lamps (accent and task lighting), Parabolic Aluminized Reflector (PAR) lamps (flood and spot lighting), and Ellipsoidal Reflector (ER) lamps (recessed lighting).

In-Use Illuminance (I): The illuminance during periods when the lights are on. In this report, illuminances were assigned based on the principal building activity, using engineering guidelines. (See **Illuminance**, **Principal Building Activity**, and Appendix B.)

Lamp (L): A term generally used to describe a manmade source of light. The term is often used when referring to a "bulb" or "tube". The CBECS collects data only about lamps using electricity.

Lighting Equipment Configuration (c): A combination of a type of lamp with various lighting energy conservation features. (See **Lamp**, and **Conservation Features**.)

Lighting Power Density (P): The lighting energy per unit of lighted floorspace during periods when the lights are on. In this report, the lighting power density was computed from the assigned in-use illuminance and the assumed equipment efficacy. (See **Lighted Floorspace**, **In-Use Illuminance**, and **Efficacy**).

Lighted Floorspace (S): The total amount of floorspace within commercial buildings that was lighted electrically. In this report, the lighted floorspace was computed by multiplying each building's total floorspace by the reported percent lighted, divided by 100. The floorspace lighted by each type of lamp in the building was computed by multiplying the lighted floorspace by the report percent of lighted floorspace lighted by that type of lamp, divided by 100.

Lighted Floorspace-Hours (SH): For an individual building, the product of lighted floorspace and effective lighting hours. For a group of buildings, the sum of lighted floorspace hours for the individual buildings. (See **Lighted Floorspace**, and **Effective Lighting Hours**.)

Lighting Hours: (See **Effective Lighting Hours**.)

Modest: Achieving less conservation. Two possible values are assumed in this report for the quantitative effects of a given conservation feature. The modest level corresponds to less conservation, implying that either the feature is less effective or its penetration is less. (See **Optimistic** and Appendix C.)

Off hours (H^n): Hours other than the weekly operating hours. For this report, the off hours are computed as 168 minus the usual weekly operating hours. (See **Operating Hours**.)

Operating Hours (H^o): The typical number of hours per week the building is in use.

Optimistic: Achieving more conservation. Two possible values are assumed in this report for the quantitative effect of a given conservation feature. The optimistic level corresponds to more conservation, implying that either the feature is more effective or its penetration is greater. (See **Modest** and Appendix C.)

Power: Energy consumption per unit time.

Principal Building Activity: The activity or function occupying the most floorspace in the building. The categories were designed to group buildings that have similar patterns of energy consumption. Examples of various types of principal activity include office, health care, lodging, and mercantile and service.

Reflector (RFL): In this report, a lighting conservation feature consisting of a reflective surface or panel attached to a fluorescent lamp to direct a greater fraction of the lamp's light into the room. (See **conservation Feature**.)

Savings (SV): The lighting energy savings estimated to result from a conservation case. (See **Conservation Case**.)

Time-Averaged Illuminance (T): The illuminance averaged over all hours in the week. In this report, the time-averaged illuminance is computed as the in-use illuminance multiplied by the effective lighting hours, divided by 168 (the number of hours in a week). (See **In-Use Illuminance**, and **Effective lighting Hours**.)

Usage Factor (U): The fraction of time lighting equipment is in use, computed as the ratio of effective lighting hours to 168 hours per week.

Year Constructed: The year in which the major part or the largest portion of a building was constructed.