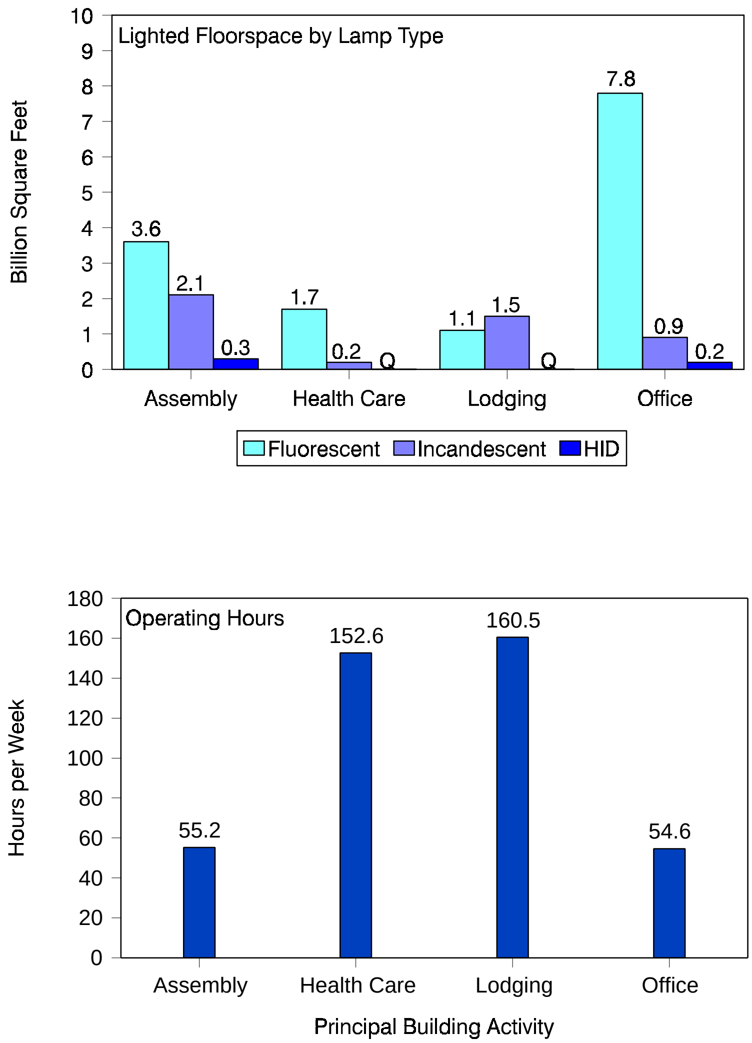
Commercial Lighting Energy Profile

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

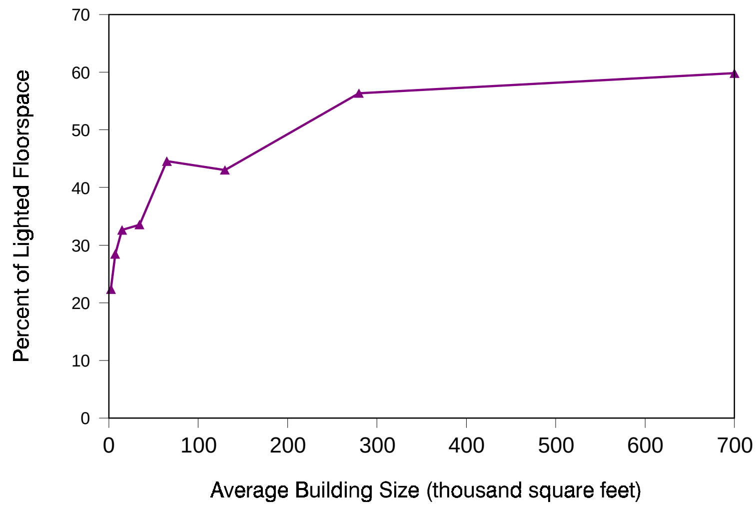
A more comprehensive measure of lighting usage than floorspace alone is the total lighted floorspace-hours. This usage measure complements the lighting power density in determining the total lighting energy requirement. Even without knowing lighting power densities, health care, lodging, and food buildings 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

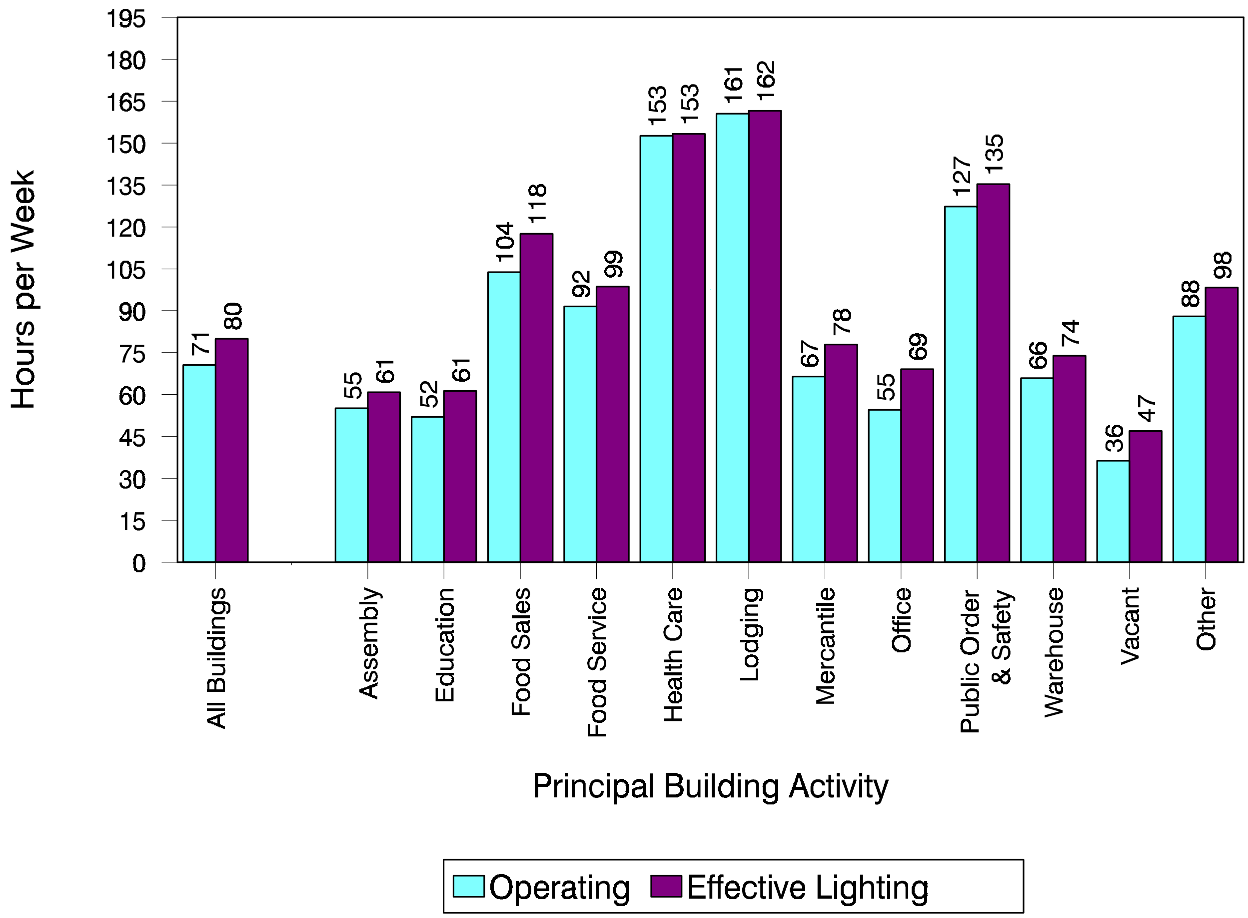
$$\mathbf{H^e = H^o + (S^n/S^o)\,H^n,}$$

where $\mathbf{H^o}$ and $\mathbf{H^n}$, respectively, are the weekly operating and nonoperating hours, and $\mathbf{S^o}$ and $\mathbf{S^n}$, respectively, are the amounts of floorspace lighted during operating and nonoperating hours. With this formulation of the effective lighting hours, the floorspace $\mathbf{S^o}$ is assumed lighted for more than the weekly operating hours. Specifically, additional usage is attributed to $\mathbf{S^o}$ 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

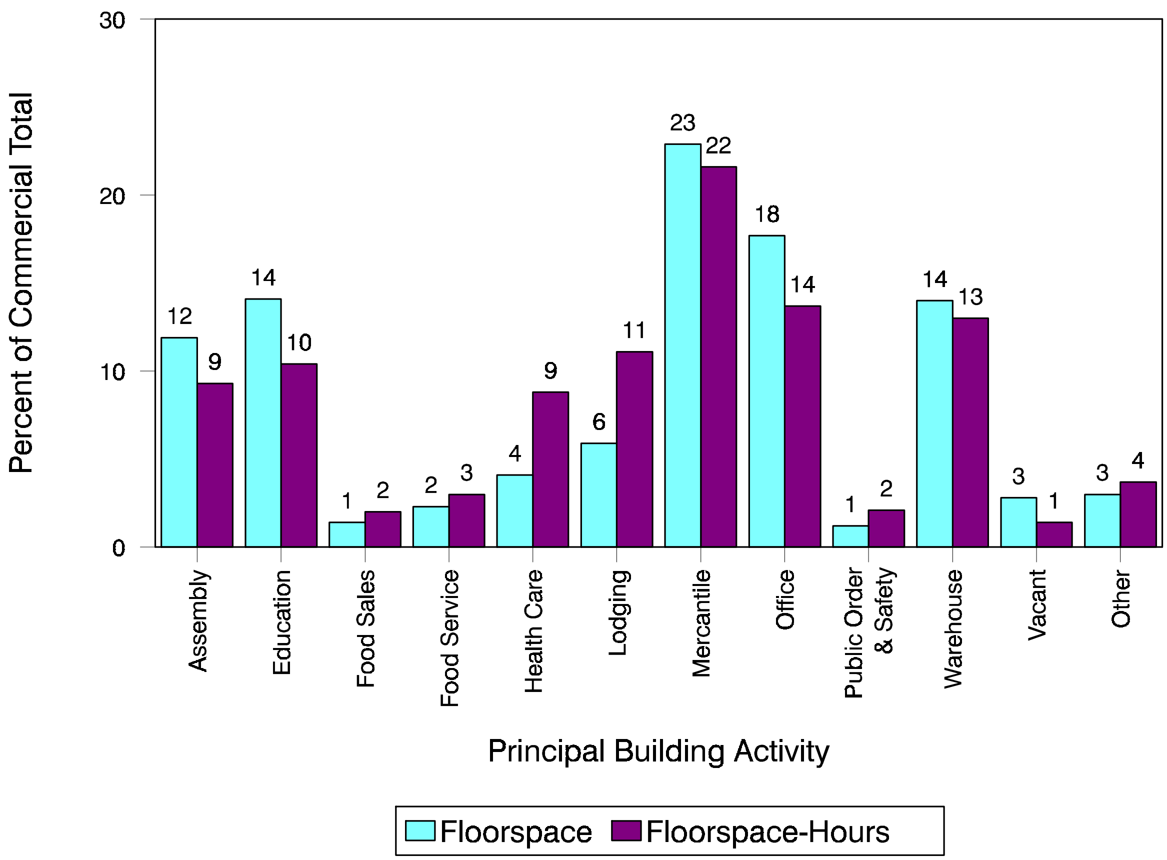
Combining the lighted floorspace with the effective lighting hours for that floorspace gives the total lighted floorspace-hours. This quantity complements the installed lighting power density, in watts per square foot, as a measure of lighting requirements.

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



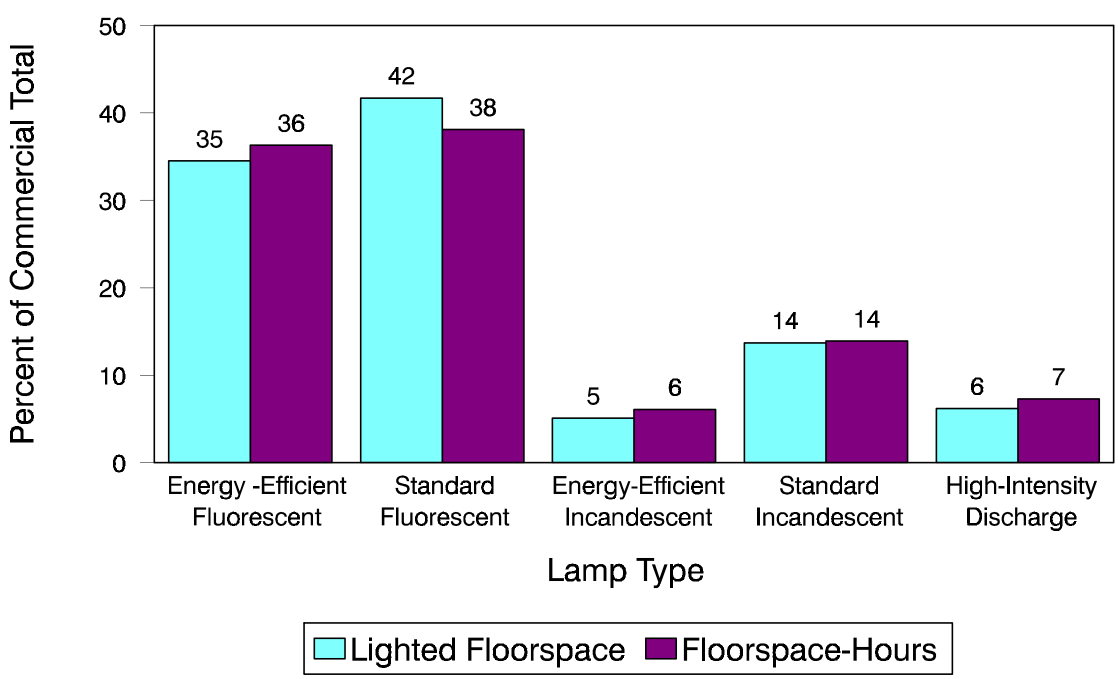
Note: Percent of lighted floorspace and lighted floorspace-hours for each building activity category are computed as percents of the commercial total lighted floorspace (49.59 billion square feet) and total lighted floorspace-hours (3.5 trillion square foot-hours).
Source: Energy Information Administration, 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.

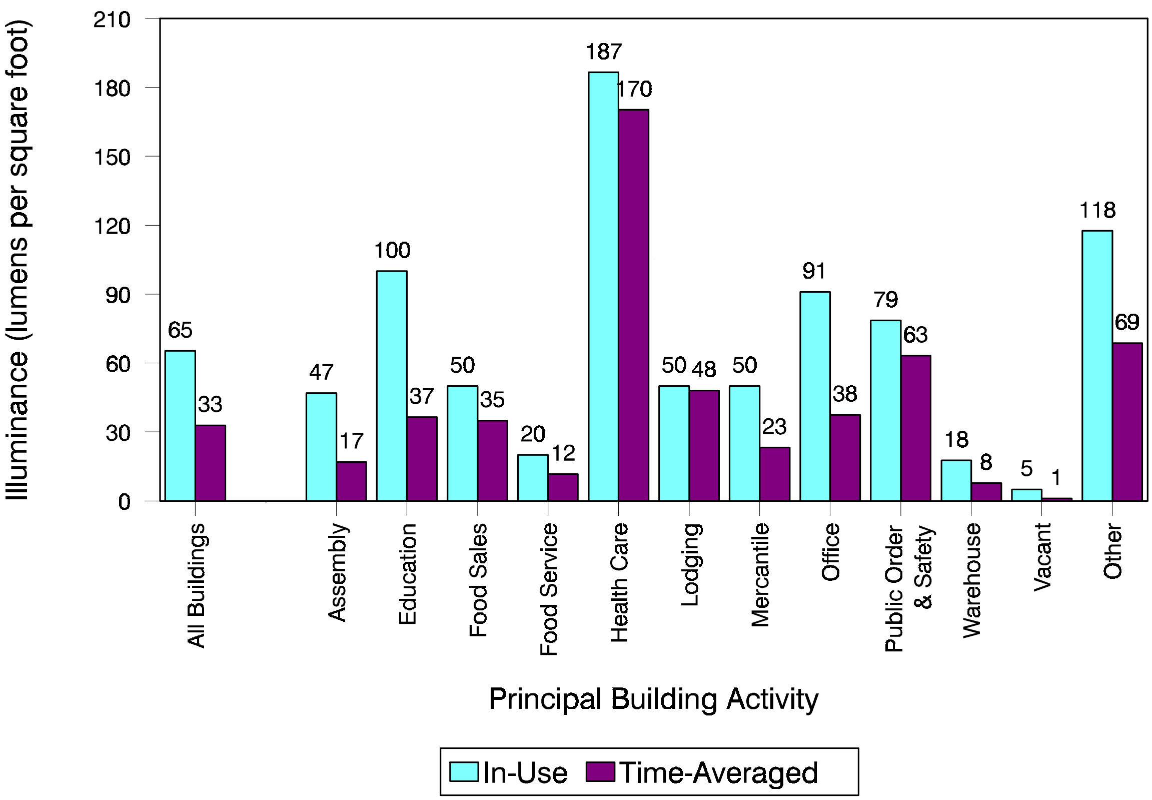
Illumination Levels

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



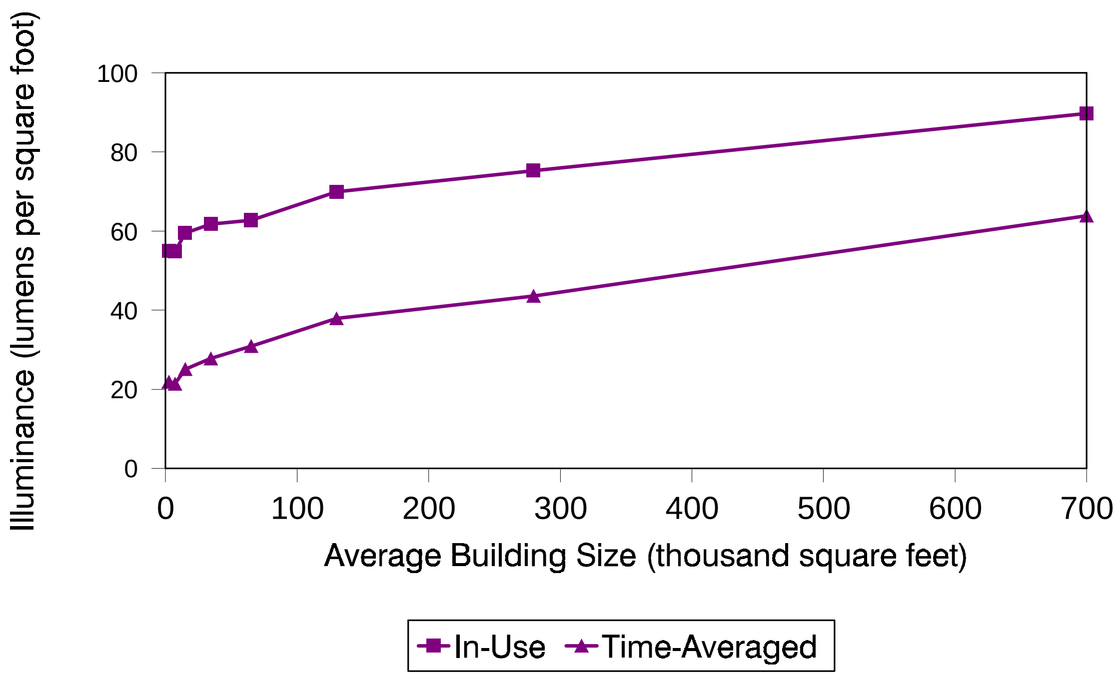
Notes: • In-use illuminances are average assigned values based on IES recommended categories. • Time-averaged illuminance is in-use illuminance adjusted by the usage factor, that is, the estimated proportion of time the lighting is in use.

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.)

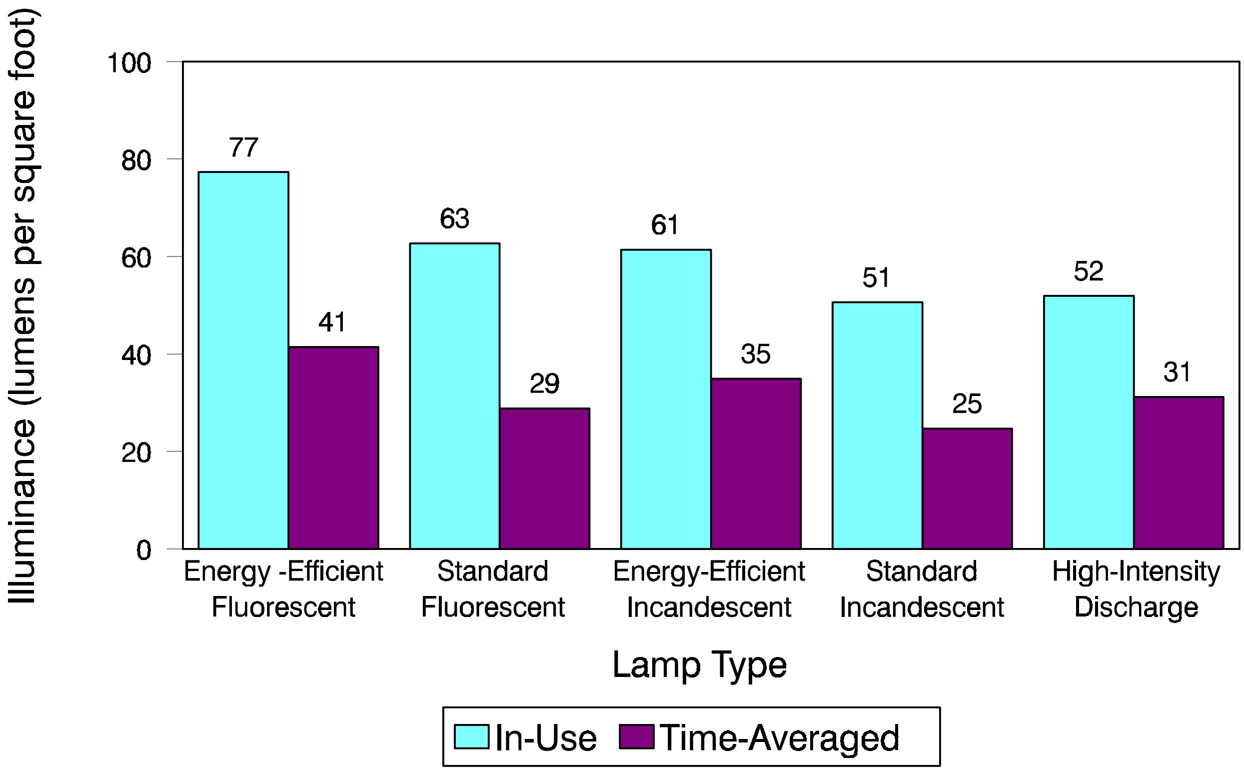
Although several simplifying assumptions went into the estimates of the average illuminances associated with different lighting equipment, these estimates at least offer qualitative comparisons of the amount of lighting service provided by the different equipment. To derive comparative energy requirements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

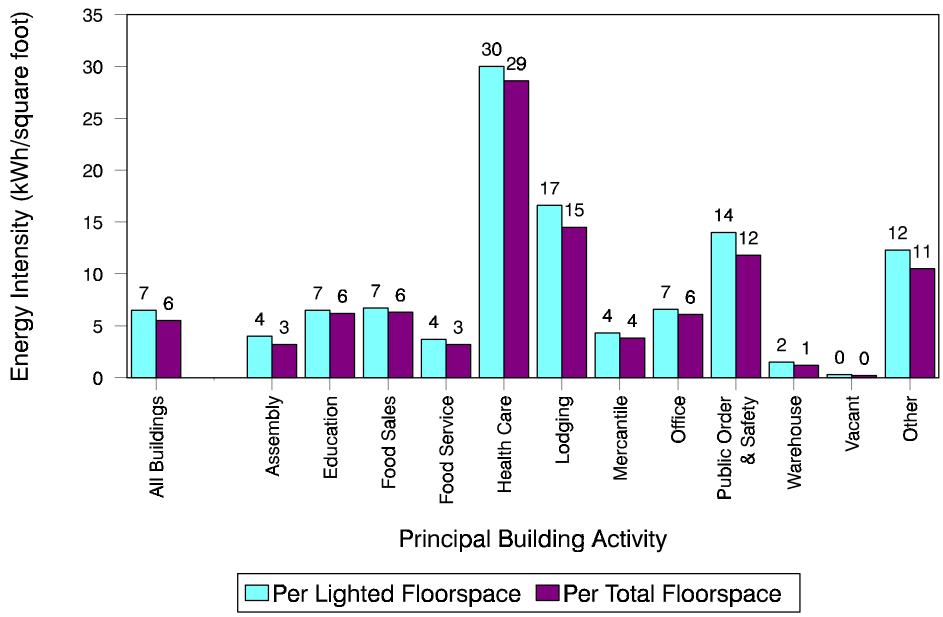
For nonvacant buildings, the estimated EUI's range from 1.5 kWh/sf for warehouses to 30 kWh/sf for health care buildings, with an overall average of 6.5 kWh/sf (Figure 9). These EUI's are computed relative to the lighted floorspace only. Using the total floorspace as a base, the EUI's are 10 to 20 percent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

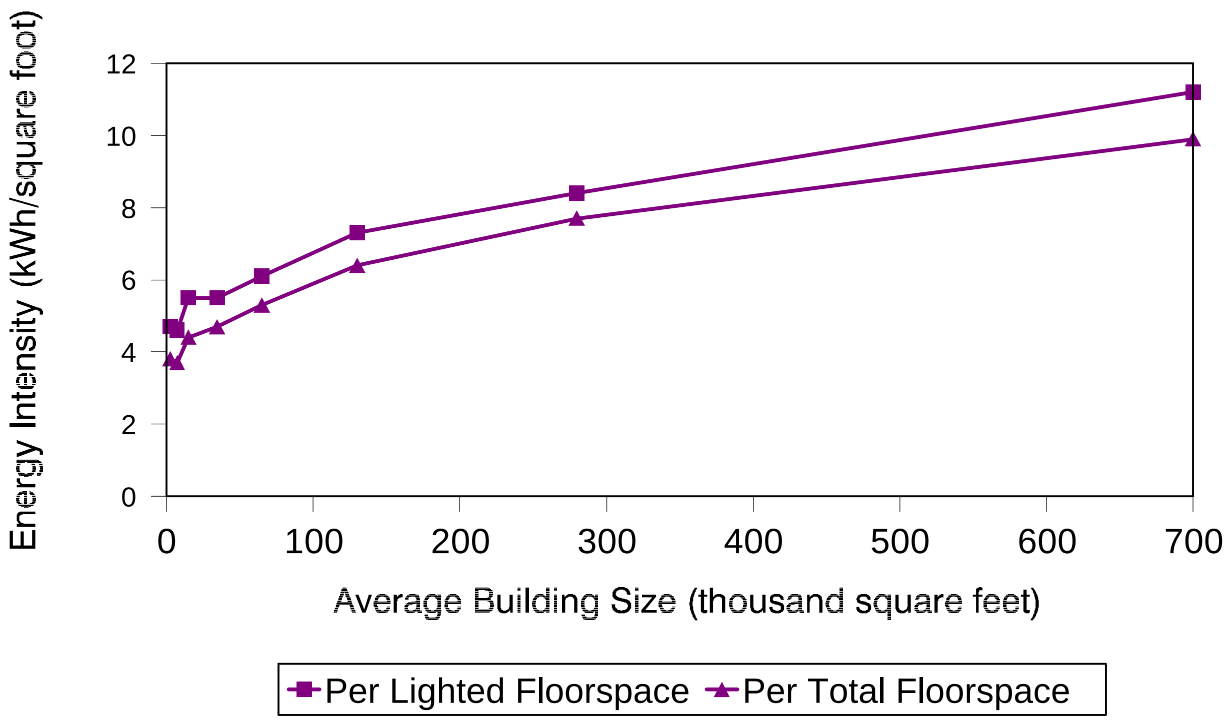
Lighting Energy Consumption

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



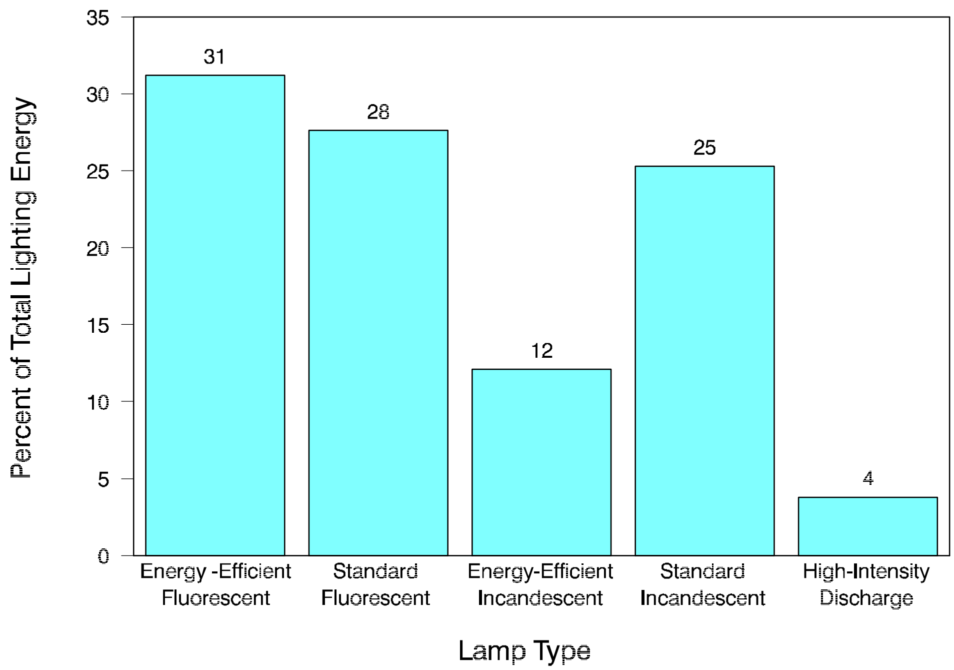
Notes: • For each building size category, lighting energy intensity per lighted floorspace (per total floorspace) is the estimated lighting energy divided by the lighted floorspace (total floorspace) in the category. • For each size category, the energy intensities are plotted at a horizontal position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

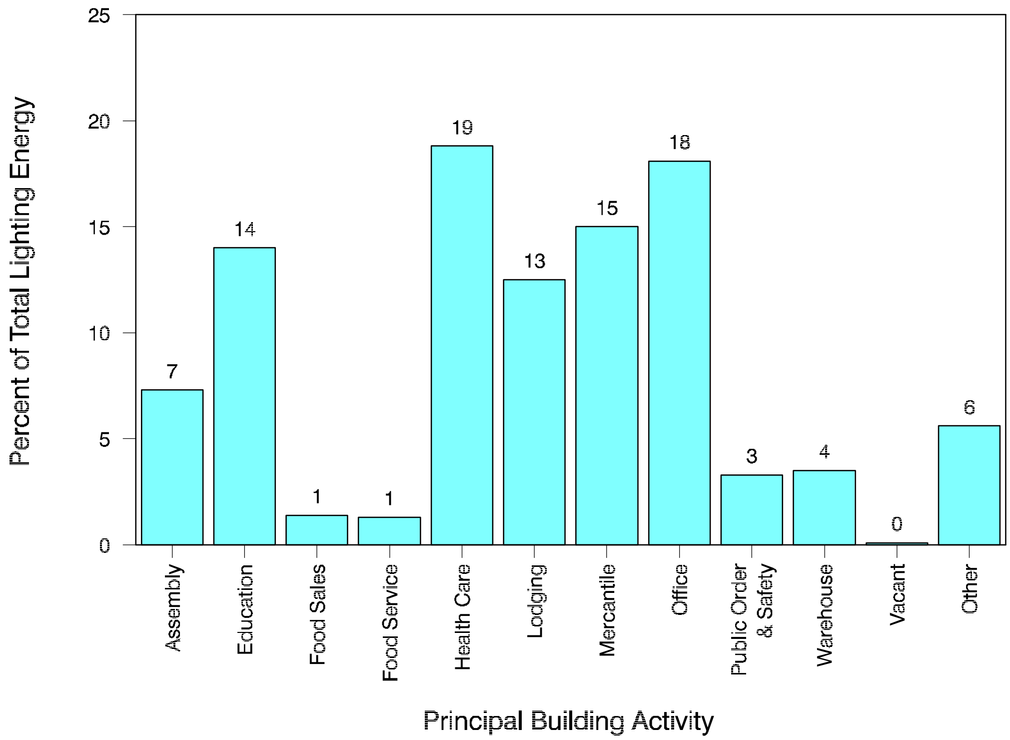
Because of the uncertainty and simplifications at each step of the lighting energy computation, the resulting estimates are only approximate. To gauge the possible errors introduced by some of the assumptions made, overall commercial lighting energy was recomputed under some alternate assumptions.

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.