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Impact Assessment and Performance Targets for Lighting and Envelope Systems

R. Sullivan, E.S. Lee, and S. Selkowitz

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Energy and Environment Division
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Executive Summary

Electric lighting loads and cooling from solar heat gains and from lights are the two largest components of peak demand in commercial buildings. The most cost effective demand side management solutions are generally those that directly reduce or eliminate these loads. Existing technologies can provide modest reductions, however they are typically applied an a piecemeal manner that yields less than optimal results. The full potential of existing technologies will be realized when they are commercially available in an integrated package easily specifiable by architects and engineers. Emerging technologies can also be developed to provide even greater savings and extend the savings over a greater portion of the building floor area.

This report assesses achievable energy and peak demand performance in California commercial buildings with technologies available today and in the future. We characterize energy performance over a large range of building envelope and lighting conditions, both through computer simulation models and through case study measured data, and subsequently determine reasonable energy targets if building design were further optimized with integrated systems of current or new technologies. Energy targets are derived from the study after consideration of industry priorities, design constraints, market forces, energy code influence, and the state of current building stock.

The study included the following tasks:

- Determination of achievable energy performance for a prototypical commercial building using computer simulations. A matrix of envelope and lighting technologies was examined through parametric performance simulations using the DOE-2 building energy simulation program.
- Characterization of the performance of existing building stock and identification of the influence of energy codes on performance. Determination of the range of performance actually achieved in existing buildings.
- Development of "Performance Targets" currently achievable and technically achievable in 2-5 years and in 10-15 years.

Using advanced envelope and lighting technologies, it is possible to reduce the total electricity consumption of typical commercial office buildings 25% by 1995 and by 48% by 2005. Peak demand can be reduced by 22% by 1995 and by 40% by 2005. These figures imply a reduction in lighting power density from a current level of 1.50 W/ft^2 to 1.25 W/ft^2 in 1995 and 0.50 W/ft^2 in 2005 with a corresponding increased use of daylighting control. Fenestration system efficacy, defined as the ratio of properties that correspond to daylight induced lighting energy savings and solar gain induced cooling energy penalties increases by 50% by 1995 and by 200% by 2005, stemming from the use of advanced glazing products that substantially reduce solar heat gain without limiting visible daylighting savings.

Commercial office building floor area is projected to represent 26% of the total California commercial floor area stock in 2005 (CEC, 1991). Total electric demand for commercial office buildings in California in the year 2005 can be reduced from a projected 6.0 GW to 4.8 GW (20% change) if all new construction and 10% of the building retrofits in 1995 and 30% of the retrofits in 2005 utilize the strategies recommended in this report.

1. Introduction

Electrical source energy use in California accounts for over 55% of all primary energy use in the building sector (CEC, 1990). In the commercial building sector, 38% of electric energy consumption is directly attributable to lighting and 19% for cooling. These two major interrelated building subsystems, electric lighting and cooling from the building envelope, also account for more than half of typical peak demand in California buildings. The exterior envelope of the building, primarily the glazing, is a major source of peak cooling demand and of annual cooling load; it is also a potential source of daylight that may be exploited to offset electric lighting loads. Despite improvements in lighting technology, especially new lamps and ballasts, lighting remains a key contributor to energy use, load shape, and peak demand. Lighting controls, integrated with daylighting, afford the opportunity to significantly reduce lighting requirements and cooling loads.

We present in this document an assessment of achievable energy and peak demand performance in California commercial buildings with an emphasis on building envelope and lighting technologies available today and in the future. After first characterizing energy performance over a large range of building envelope and lighting conditions, both through computer simulation models and through case study measured data, we subsequently determine reasonable energy targets if building design were further optimized with integrated systems of current or new technologies.

2. Building Energy Simulations

The analysis of the commercial building energy performance is conveniently facilitated by numerical simulation using computers. The DOE-2 Building Energy Simulation Program (Simulation Research Group, 1985) is the de facto standard computer program for such purposes and is used by many industry and research organizations. DOE-2 provides sophisticated, yet simple, input descriptions for buildings and their associated HVAC equipment. Load and energy use output can be obtained at the zone or building level for various time periods.

To better understand the factors affecting envelope and lighting system performance and assist in developing performance targets for future systems, we followed a series of steps that represent the distillation of LBL parametric performance studies that has been evolving over many years, i.e.:

- Define a representative commercial office building module. The module, which is described below, allows us to isolate perimeter and core zone energy performance as a function of many different envelope and lighting system parameters.
- Create a database of DOE-2 simulations for varying building configuration properties. The database included parametric variation of lighting system characteristics and fenestration parameters.
- Perform a regression analysis of the DOE-2 database. The regression analysis yields a simplified algebraic expression that can be used to investigate the performance of any arbitrary configuration.

This section of the report documents these procedures and also discusses the fenestration and lighting system interactions that affect overall building energy performance.

Model Description

We created a large database of DOE-2 annual simulations of a prototypical floor in a commercial office building (Figure 2.1) in Los Angeles, Sacramento, and San Francisco. The module has four perimeter zones consisting of ten offices, each 15ft (4.57m) deep by 10ft (3.05m) wide, surrounding a central core zone of 10,000 ft^2 (929 m^2) floor area. Floor-to-ceiling height is 8.5ft (2.59m) with a plenum of 3.5ft (1.07m) height. The exterior wall resistance was fixed at R11. Window and lighting system variables were varied parametrically to facilitate an understanding of their effects on energy performance.

Continuous strip windows were used in the exterior wall of each perimeter zone. Glazing area was varied at 0%, 15%, 30%, 50%, and 70% of the floor-to-floor wall area. The 70% floor-to-floor value is equivalent to 100% floor-to-ceiling. Five glazing types (Table 2.1) were simulated. These glazings covered a range of U-value (0.22 - 1.1

Btu/hr-ft^2•F, 1.25 - 6.08 W/m^2•C), shading coefficient (0.20 - 0.95), and visible transmittance (0.10 - 0.88) levels that are representative of currently available products in the marketplace.

We simulated the daylighting performance of each perimeter zone using continuous dimming and single-step switching control for changing lighting levels. The desired illuminance was varied from 20 fc (215 lux) to 80 fc (861 lux) and the installed lighting power density was varied from 0.30 W/ft^2 (3.22 W/m^2) to 2.7 W/ft^2 (29.1 W/m^2). Daylighting levels were calculated at two reference points in each perimeter zone at a height above the floor of 2.5ft (8.76m) and at depths of 5ft (1.52m) and 10ft (3.05m).

DOE-2 runs were completed with and without interior shading. The shading device, which is representative of a diffusing shade, was deployed when the quantity of transmitted solar radiation exceeded 30 Btu/hr-ft^2 (94.5 W/m^2). When deployed, the fenestration system shading coefficient was reduced by 40% and the visible transmittance by 65%.

We also simulated overhangs, fins, and adjacent building obstructions to better understand the nature of exterior shading on performance. Overhangs were fixed at an overhang width-to-window height ratio of 0.6. Past studies performed at LBL indicates that this is a realistic limiting value and overhang solar gain reduction performance approaches an asymptote. Fins were fixed at a fin-width to window-width value of 0.3. Full and partial adjacent building obstructions were simulated by assuming a continuous wall of buildings, eight stories (96ft, 29.3m) high. The full obstruction was one city block wide (500ft, 152.4m) and located across the street (100ft, 30.5m), while the partial obstruction was three city blocks (1500ft, 457.2m) wide and located one city block (500ft, 152.4m) away.

System coil loads were calculated for each perimeter zone. To isolate zone loads from the building/system interactions, a separate single-zone constant-volume system was assigned to each zone. A constant heating system efficiency (0.6) and cooling system coefficient of performance (3.0) converted these loads to energy usage values that formed the database for electric and fuel usage.

We also performed a sensitivity study to examine the effects of office equipment electric load due to the use of computers and other equipment. Loads between 0.5 W/ft^2 (5.38 W/m^2) and 1.5 W/ft^2 (16.1 W/m^2) were simulated. Other sensitivity studies analyzed the effects of exterior wall insulation levels (R11 to R30) and wall mass.

Regression Analysis Method

To facilitate an examination of any arbitrary value of a window and/or lighting variable, we performed a regression analysis of the DOE-2 simulation database and developed simplified expressions that accurately reproduced the simulated results. Multiple regression is an analytical technique for determining the best mathematical fit for a dependent variable as a function of many independent variables. The performance or dependent variables included three energy-related quantities: annual electricity use (cooling, lighting, fan), annual fuel use (heating), and peak electric demand. The independent variables included window size, conductance, shading coefficient, visible transmittance, lighting power density, desired lighting level, and equipment power density.

The regression expression used to predict these quantities is:

$$E_i = \beta_{1i} \cdot U_g \cdot A_g + \beta_{2i} \cdot SC \cdot A_g + \beta_{3i} \cdot k_d \cdot L \cdot A_f + \beta_{4i} \cdot E \cdot A_f + \beta_{5i} \cdot A_f \qquad (2.1)$$

where E is the energy quantity of interest for the ith zone (i = N, E, S, or W orientation). The regression coefficients are denoted by β, and the equation has five components chosen to contain the effects from a particular building component: glazing conduction ($U_g \cdot A_g$), glazing solar radiation ($S_g \cdot A_g$), lighting ($k_d \cdot L \cdot A_f$), and equipment ($E \cdot A_f$). The last term contains contributions due to occupants, infiltration, etc. U_g is the overall conductance of the glazing, SC is the shading coefficient, k_d is a daylighting correction term, which is discussed below, L is the lighting power density, E is the electric equipment power density. A_g and A_f represent the window and floor area, respectively. A unique equation such as this has been derived for each geographic location as well as each of the variations in interior and exterior shading and exterior wall thermal mass. Table 2.2 shows regression coefficients for data from Los Angeles.

The daylighting correction factor (k_d) is exponential and varies between 0 and 1. It is determined by a regression analysis and is a function of visible transmittance (Tv), desired lighting level (C), and effective aperture (A_e) which is the product of window-to-wall ratio and visible transmittance. The following equation was used:

$$k_d = 1.0 - [\, \Phi_{1i} + \Phi_{2i} \cdot (C/Tv) \,] \cdot [\, 1.0 - e^{(\Phi_{3i} + \Phi_{4i} \cdot C)\, A_e} \,] \tag{2.2}$$

where the Φ's are the regression coefficients.

Figure 2.2 shows a comparison of DOE-2 simulation results and the regression prediction for cooling and heating energy use in Los Angeles for the non-daylit portion of the parametric set in the four perimeter zones. The correlation between predicted and actual data is very good (r^2=0.998 for cooling and 0.964 for heating; a value of 1.0 would indicate perfect correlation). Heating correlation is lower because of the relatively small amount of heating required in Los Angeles. Peak cooling demand correlation was r^2=0.996. Daylight, k_d, correlation was on the order of 0.960.

Core zone performance was predicted using the installed lighting power and equipment power density as independent variables. In addition, perimeter zone performance was included to account for heat transfer through partition walls (E_i).

$$E_c = \beta_1 \cdot L \cdot A_f + \beta_2 \cdot E \cdot A_f + \beta_3 \cdot A_f + \Sigma\, \beta_i \cdot E_i \tag{2.3}$$

We calculated total building electric energy use by summing the individual zone components, assuming a cooling COP of 3.0. This enabled analysis of arbitrary floor plans and areas. Peak electricity demand was determined by correlation to annual electricity use.

Discussion

We will first focus on typical energy use and peak demand patterns associated with changing envelope and lighting strategies. This provides a firm foundation for a later discussion dealing with arbitrary configuration changes that eventually leads to several key findings. Our primary concern is with the interactions between the following parameters:

Fenestration System	Lighting System
Orientation	Lighting control strategy
Size	Lighting power density
Shading coefficient	Desired lighting level
Visible transmittance	
Interior shading	
Exterior shading	

The fenestration system affects the cooling electricity use and peak electric demand of a building through control of solar gain by the fenestration system's orientation, size, and shading characteristics. The fenestration, however, can also affect electric lighting requirements through control of daylight availability by the visible transmittance of the fenestration system. The lighting system affects electricity use and peak demand through the variation of lighting power density and, if daylighting is being utilized, by the selected daylight control strategy and desired lighting level. However, the lighting system also influences the cooling requirements of a building through the sensible heat gain of the lighting system into the conditioned spaces.

To better understand these interactions, we first show in Figure 2.3 the total electricity consumption for the prototypical office building module located in Los Angeles as a function of the building window-to-wall ratio. Results are shown for five glazing types without daylighting controls. The total electricity consumption includes core and perimeter zone components due to cooling, fan energy, lighting at 1.5 W/ft^2, and an internal equipment load of 0.5 W/ft^2. The core zone contribution is about 80 MWh or about 61% of the total module energy use without windows.

As expected, the curves increase monotonically with increasing window-to-wall ratio and the overall performance at a particular window size is a function of the window shading coefficient. In fact, if we define a new parameter called the *solar aperture* as the product of shading coefficient and window-to-wall ratio, we are able to define incremental electricity consumption performance due to solar gain through the use of a single curve as shown on Figure 2.4. A similar relationship exists for peak demand variations with solar aperture. Changing the lighting level to a value higher or lower than the 1.5 W/ft^2 yields parallel sets of data; i.e. electricity consumption increases 2.8 kWh/ft^2 per W/ft^2 of lighting (an additional 0.3 kWh/ft^2 per W/ft^2 of lighting would be the cooling effect of the lights) ; whereas, peak demand increases by 1.1 W/ft^2 per W/ft^2 of lighting. Such values would be typical of most commercial office buildings with a lighting schedule similar to our prototypical module.

Figure 2.4 presents the performance for the complete set of data on Figure 2.3 and are whole building incremental values. Similar results are obtained if we analyzed each perimeter zone independently, although the level of use and demand would be different. The same is true also if we presented data for a configuration that did not use shade management or if we implemented external shading devices such as overhangs or fins on the windows. In using such a presentation, we are thus able to define the fenestration system solar gain performance across a broad spectrum of configurations and immediately observe the effect of particular glazings and/or window sizes.

The effect of daylighting on electricity consumption for the above fenestration systems is presented on Figure 2.5. The data are for a continuous dimming system at a desired lighting level of 50 footcandles. Daylighted offices can have consumption and peak demand that are lower than those of an opaque wall. Daylighting is best understood by realizing that the perimeter zone electric lighting requirements are directly influenced by the fenestration system's *effective aperture* which is the product of the visible transmittance and window-to-wall ratio. Figure 2.6 shows the incremental electricity consumption due to daylighting for the data presented on Figure 2.5 as a function of this effective aperture. As the effective aperture increases initially from zero, there is an abrupt reduction in lighting. As apertures continue to increase to moderate levels, daylight saturation is approached. Such a relationship also exists for peak demand variations with effective aperture. Perimeter zone lighting consumption can be reduced by close to 73% using daylighting. This corresponds to about 26% of the total building electric lighting for our module. Again, as in the case above on solar gain, we have reduced the data to a single performance curve with the effective aperture as the single performance measure.

We have now shown how fenestration and lighting system performance are individually obtained. Optimum performance requires finding the solar and effective aperture values that minimize consumption and peak. This can best be done by combining the data presented on Figures 2.4 and 2.6 into performance tables such as is illustrated on Table 2.3. Annual electricity consumption is shown for a matrix of solar and effective apertures. We are able to show performance for any arbitrary value of shading coefficient, visible transmittance, and window-to-wall ratio because of the regression analysis of the DOE-2 database discussed in the previous section of this report. These procedures were used to assist in the development of the performance targets that are described below.

3. Impact Assessment

This section compares the DOE-2 building simulation results to the "actual performance" of existing, current practice, and energy efficient office building stock in California and other locations. The simulated energy consumption and peak demand performance is compared on an annual, monthly, and hourly basis to measured performance of real world buildings. A concluding subsection discusses the impact of these comparisons on the projected savings due to the proposed building envelope and lighting technologies.

Comparison of our DOE-2 building energy simulations to real world buildings representative of the California office building stock

- places the simulation results within the context of the wide range of performance achieved by actual buildings,

- quantifies the amount of energy savings due to the proposed envelope and lighting systems relative to the various types of building stock in existence or currently being built today, and
- permits study of how effectively the proposed envelope and lighting systems can meet the demand side management strategies of load shifting and load reduction.

Initially, utilities in California emphasized identifying potential energy saving opportunities using simulation and engineering estimates. A new focus, primarily due to recent regulatory decisions in California, is on evaluating and verifying actual energy savings using measured performance data. Long standing efforts of utilities to quantify typical energy performance of the actual building stock have been complicated by variables such as climate, type of occupancy, and building construction, age, and geometry. These efforts have been further complicated by the difficulty of obtaining detailed and accurate measured data for a representative sample of buildings at reasonable costs.

The studies used for comparison in this section typically have either a small sample size but have employed relatively accurate means to obtain energy performance data or, have a larger sample size but have employed engineering estimates to disaggregate total energy use into various end uses. Due to the limited number of studies and the evolving nature of measurement protocol and calibration, these comparisons serve as a rough guide to the potential performance of the proposed envelope and lighting systems. Full-scale demonstration in real buildings will yield a more accurate and detailed estimate of the reliability and persistence of savings resulting from these measures given real world operation, climate, and other less predictable variables such as occupant comfort and satisfaction. An exhaustive reconciliation of the various studies and our own simulation results was well beyond the scope of this project. Rather, the comparison provides useful benchmarks, reassurances and cautions regarding any effort to generate and compare predictive results to real world data.

Method

The DOE-2 building energy simulations were used as the primary means of evaluating the relative benefits of various technologies and to study the trends and interactions between building envelope and lighting parameters. A large range of building characteristics as described in Section 2 were simulated in order to sufficiently describe the range of performance exhibited by actual buildings. In order to make absolute comparisons between these results and real world building performance however, a single "typical" building configuration must be defined. Using building characteristics compiled from reviewed studies, a subset of typical characteristics was selected for the DOE-2 building module to provide a base-line and range for comparison with real world data. Comparisons were made between the simulated performance and the measured energy performance of existing buildings, existing "energy efficient" buildings, and current state energy code allowances. Performance data associated with the DOE-2 building energy simulations made in Section 2 above, are hereafter referred to as the ELS (Envelope and Lighting Systems) results.

Studies Reviewed. The methods used to evaluate actual building performance often determine the sample size and the comprehensiveness of the study. Table 3.1 provides a summary of the studies reviewed. Most of the reviewed surveys tend to use utility bills to determine whole building performance and then use engineering estimates based on building characteristics, occupancy, and limited submetered data to disaggregate the annual energy consumption into end uses. There are many such studies with sufficient sample size representing existing building stock performance such as the Nonresidential Building Energy Consumption Survey (NBECS) conducted on the national scale by the Energy Information Administration (1986) and California surveys conducted by utilities such as Pacific Gas and Electric (McCollister, 1985; Schultz, 1984), Southern California Edison (SRC, 1987; Ignelzi and Train, 1984), and San Diego Gas and Electric (McCollister and Turiel, 1987). The BECA studies, conducted by LBL, surveys the performance of a smaller number of specific commercial buildings designed to exceed the typical energy efficiency requirements of the building code (BECA-CNational and CALifomia-BECA, Piette and Riley, 1986).

The ELCAP survey conducted by Bonneville Power Administration in the Seattle City Light territory (Taylor and Pratt, 1989) is a unique study that provides a detailed database of submetered end use energy consumption on an hourly basis. This study was deemed important due to the accuracy and comprehensiveness of the data to warrant comparison despite the drawbacks of its Northwest location and small sample size (N=16). Other field studies involving submetered end use data on an hourly basis in the California region are in progress and the results were not available at this time (SCE and PG&E).

A recent study by LBL, representing one of the first attempts to combine simulation analysis with load data, disaggregates whole building performance data into hourly load shapes for forecasting electricity demand (Akbari et al, 1989). A DOE-2 prototype was developed using mail and on-site surveys to create preliminary energy performance data. The data were then reconciled using weather data and 15 minute load research billing account data from 314 large office buildings in the Southern California Edison territory to produce average hourly load shapes for various end uses.

The energy performance of current practice was determined using the 1985 California Title 24 Nonresidential Energy Conservation Standards. These data are presented in terms of annual energy budgets for various climate zones and building sizes.

ELS Prototype Characteristics. Similarities between the building characteristics of the surveys and the ELS prototype determines comparability of performance data. Table 3.2 gives the building characteristics of the reviewed surveys and the range of parameters used for the ELS building simulation work completed in Section 2. More detailed information available from the NBECS national survey is given in Tables 3.3 and 3.4 (EIA, 1986). Several spatial and geometric characteristics of the ELS prototype may be incomparable since it was developed not as a whole building but as a typical floor with adiabatic ceiling and floor surfaces. The thermodynamic behavior of the prototype, however, is comparable. Every effort has been made to ensure consistency of parameter definitions between surveys. Characteristics for the Akbari (AKB) study, however, represent preliminary simulated characteristics, not the final characteristics for the reconciled load shapes; e.g., the lighting power density for non-reconciled load shapes is 1.48 W/ft^2, and 2.4 W/ft^2 for reconciled load shapes.

Balancing the survey characteristics against our estimates for specific envelope and lighting characteristics, we selected an ELS minimum, maximum, and "base case" configuration. The base case configuration is representative of what is currently achievable today given existing conventional efficient technologies: perimeter-to-core floor area ratio = 0.60; COP = 3.5; window-to-wall ratio = 0.30; lighting power density = 1.50 W/ft^2; Heat Mirror glazing; and no daylighting controls. The ELS mechanical system choice, which may have an impact on energy use, was selected because it made it possible to more easily examine impacts by orientation.

The minimum/maximum range is defined by variations in envelope and lighting parameters only: window-to-wall ratio (0.0 and 0.7), glazing type (no minimum since WWR=0 and maximum of single pane clear), and lighting power density (0.3 and 2.7 W/ft^2). Therefore, other parameters may define a larger range of performance than that defined as the ELS "maximum"; e.g., lower COP, higher equipment loads, or no active shade management by the occupant. Equipment loads may have increased due to large computer equipment (0.18 - 0.23 W/ft^2) and personal computers (0.27 - 0.64 W/ft^2) but may decrease in the future given new display technology or other electronic advances (Pratt et al, 1990). Hence, despite the agreement between the reviewed surveys and the ELS equipment load of 0.5 W/ft^2, this value may not reflect the latest trends in high equipment loads and may lead to lower estimates of electricity use than actual measured building data. Estimates of how these non- envelope and lighting parameters affect projected energy use are given in the following sub-section.

Discussion

The type of survey data dictates how comparisons can be made. If the survey held sufficient similarities to warrant a fair comparison, the projected energy savings are discussed. Most of these direct comparisons are made for the Los Angeles coastal climate. Comparisons with reviewed surveys with dissimilar building characteristics or climate are made in a less comprehensive manner to provide additional context.

Total Electricity Use/Peak Demand. The ELS base case total annual electricity use of 8.5 kWh/ft^2-yr agrees well with building code energy allowances (10.35 kWh/ft^2-yr), and is consistently lower, as expected, when compared to existing stock performance of 20 kWh/ft^2-yr and energy efficient stock performance (16.0 kWh/ft^2). See Figure 3.1.

Monthly load shapes show general agreement between the ELS performance and the ELCAP study during summer months (Figure 3.4). Winter months are not comparable since the ELCAP Seattle buildings were in a substantially different climate and used electric space heating, while the ELS used gas. Hourly load shapes also show general agreement between the ELS and the AKB and ELCAP existing stock studies except during unoccupied hours due to differences in the lighting schedule (discussed later). See Figure 3.7. Comparisons with the electricity peak demand show good agreement with the AKB study and the California energy efficient survey, CAL-BECA, and generally lower values than the national energy efficient survey, BECA-CN (Figure 3.3).

Lighting Energy. The lighting energy use for non-daylit buildings is determined by two parameters: the lighting schedule of operation and the lighting power density. The lighting power density of both the AKB study, 4.2 W/ft^2 (reconciled), and the SCE 1987 study, 2.0 W/ft^2, is greater than the ELS "currently achievable," energy efficient value of 1.5 W/ft^2 (Table 3.2). This difference partially accounts for the lower ELS annual lighting energy use of 4.2 kWh/ft^2-yr, versus AKB estimates of 5.5 to 11.9 kWh/ft^2-yr (Figure 3.2a). Comparisons with the SDG&E and ELCAP (annual and monthly, Figure 3.5) data show good to fair agreement with the ELS base case and range. Further comparisons with the AKB hourly load shapes indicate higher nighttime lighting usage from 8:00 PM to 7:00 AM (Figure 3.8). Akbari has noted that significant differences were found between the AKB preliminary lighting energy use and previous study estimates by the California Energy Commission (Akbari, 1989). In addition, the AKB lighting load shapes were found to be quite different from other studies and detailed comparisons were difficult to make. Even though the focus of this study was on daytime daylighting impact, nighttime energy use in retrofits can certainly be reduced if time controls and occupancy sensors are used.

Cooling Energy. Annual cooling energy for the SCE 1984 and SDG&E 1985/1987 existing stock studies fall within the higher end of the ELS range as expected (Figure 3.2b). The differences between the ELS and the NBECS and PG&E existing stock studies may be due to the differences in climate, cooling system type, and operational details; e.g., setpoint temperatures. The large lighting estimates given by the AKB study may contribute to the large cooling estimate. In addition, the difference between the ELS and the AKB study may be due to differences in COP, HVAC equipment, or estimates of internal loads. For example, the ELS base case cooling can be increased 52% from 1.54 to 2.34 kWh/ft^2-yr if the equipment load, E, is increased to 1.5 W/ft^2 and the COP is decreased to 3.0. For the same changes, the ELS maximum can be extended 37% from 2.82 to 3.85 kWh/ft^2,-yr (E = 1.5 W/ft^2 COP = 3.0). These ELS estimates now approach the AKB estimate of 3.93 kWh/ft^2-yr for large offices. Monthly load shapes given for SDG&E and PG&E show good agreement. The SDG&E large office monthly peak value of 0.40 kWh/ft^2,-month matches the ELS maximum range value of 0.40 kWh/ft^2-month indicating, as expected, the lesser efficient performance of the existing stock (Figure 3.6). Comparisons between the ELS and the AKB hourly load shapes show fair agreement. These load shapes also clearly illustrate the smoothing effect of averaging data from many buildings versus the ELS single building load shape. A distinct valley at the noon hour of the ELS prototype can be noted due to the assumed occupancy and cooling schedule (Figure 3.9).

Overall Energy and Demand Savings. The results of this analysis demonstrate that the performance of the ELS model is consistent with the performance range set by the real world. Differences in energy performance may be attributed to the large range of building variables such as construction, vintage, occupancy, and climate, and/or to the large range in energy related variables such as survey techniques, definitions of energy parameters, and sample size. Given all the unknowns and uncertainties in the various measured building data sets, we believe the ELS model adequately represents what is achievable today with currently available technologies and proper building operation. Compared to the various building stock types, the ELS base case model may use 18% less total annual electricity than current building code allowances, roughly 47% less than existing energy efficient stock, and roughly 58% less than existing stock.

4. Performance Targets

We developed performance targets to provide an overall estimate of the energy, load shape, and peak demand benefits to be achieved as a result of implementing strategies that incorporate innovative lighting system and envelope strategies. We present performance targets applicable for current building designs and future designs for the 1995 and 2005 time periods. For current designs, the targets are based on available technology, which does not necessarily imply use of the best or optimum currently available technology as assumed in Section 3. In the year 1995, the targets are based on proper use of the best technologies readily available today. In the year 2005, the targets are based on improved technology that is not necessarily currently available or in use. The 2005 targets are conservative with respect to daylighting controls. Additional savings can be achieved given more sophisticated daylighting control strategies or through the use of core daylighting (projected savings in this report assess daylighting savings to only a 15 foot depth from the window wall). These daylighting strategies will be further explored in future work. At present, the 2005 targets reflect savings primarily due to improvements in lighting, ballast, and fixture technologies and due to development of glazings with improved solar gain control and daylighting potential. All targets are given as a function of whole building floor area.

Certain configuration variables were held constant for each of the time periods so that we could focus on strategies that have a more direct bearing on lighting and envelope (glazing) options: (1) perimeter-to-core floor area ratio = 0.60; (2) window-to-wall ratio = 0.30; and (3) desired lighting level = 50 footcandles. Changing these parameters would also change the targets. We selected two relatively simple parameters to define the targets: the lighting power density and glazing system efficacy. Based on our simulation results and expert judgement, we developed the following criteria:

Variable	Current	1995	2005
Lighting Power Density (W/ft^2)	1.50	1.25	0.50
Glazing Efficacy (K_e=T_{vis}/SC)	1.00	1.50	3.00
Daylighting Controls	No	Yes	Yes

The glazing efficacy has not been mentioned previously. It is the ratio of visible transmittance of the glazing to the shading coefficient and is a measure of both daylighting potential (visible transmittance) and cooling load impact (shading coefficient). We use this parameter to eliminate the need to specify a particular type of glazing. Glazings can have the same efficacy, but different visible transmittances and shading coefficients. Glazing efficacy is not a sufficient parameter to determine energy impacts; absolute values of the components and window area are also important. But given architectural design decisions that drive window area, and the need for a relatively high visible transmittance (to facilitate daylighting), "efficacy" becomes a useful single parameter to explore as a criteria. The effects of additional future glazing technologies such as opical switching material will be considered in future work.

Annual Lighting Performance Targets

Figure 4.1 shows lighting performance targets for the lighting power density over time. Data are shown with and without the use of daylighting controls and these results are valid for the three geographic locations of interest in this study. In the following tables, intermediate targets with and without the use of daylighting controls (DLC) are given for the respective lighting power density values to isolate the savings due to each technology. The lighting power density criteria is largely a function of technology options, lighting design criteria, and standards. The energy use intensities (EUI) are a function of lighting power density and the use of daylighting controls. The currently achievable lighting EUI is calculated without daylighting; whereas, the future EUIs assume the use of daylighting. The target values are also tabulated below.

Lighting Performance Targets (kWh/ft^2-yr):

Location	Case	Current	1995	2005
	LPD (W/ft^2):	1.50	1.25	0.50
All	No DLC	4.2	3.5	1.4
All	DLC	3.2	2.6	1.1
All	Final Criteria	4.2	2.6	1.1

By 1995, we foresee a possible reduction of 1.6 kWh/ft^2-yr; 40% is due to reducing the lighting power density from 1.5 W/ft^2 to 1.25 W/ft^2 and 60% due to the implementation of daylighting. By the year 2005, the reduction would be 3.1 kWh/ft^2-yr; 70% due to reducing the lighting power density from 1.5 W/ft^2 to 0.5 W/ft^2 and 30% due to daylighting controls.

Annual Cooling Performance Targets

Cooling performance targets are shown for both the lighting and solar gain components of cooling loads. The lighting component is presented in Figure 4.2 for Los Angeles, Sacramento, and San Francisco. These vary from 10% to 20% of the lighting performance target components above, with the lower values prevalent in San Francisco due to that city's smaller number of hours during which cooling is required.

Cooling Due to Lighting Performance Targets (kWh/ft^2-yr):

Location	Case	Current	1995	2005
	LPD (W/ft^2):	1.50	1.25	0.50
Los Angeles	No DLC	0.75	0.63	0.25
	DLC	0.53	0.44	0.18
	Final Criteria	0.75	0.44	0.18
Sacramento	No DLC	0.60	0.50	0.20
	DLC	0.43	0.36	0.15
	Final Criteria	0.60	0.36	0.15
San Francisco	No DLC	0.38	0.32	0.13
	DLC	0.24	0.20	0.09
	All Criteria	0.38	0.20	0.09

The performance targets for cooling due to solar gain are shown on Figure 4.3 as a function of glazing efficacy. The values are of the same order of magnitude as the cooling due to lighting targets.

Cooling Due to Solar Radiation Performance Targets (kWh/ft^2-yr):

Location	Current	1995	2005
Los Angeles	0.75	0.50	0.25
Sacramento	0.63	0.42	0.21
San Francisco	0.41	0.27	0.14

The targets represent a 33% reduction by 1995 and a 66% reduction by 2005, corresponding to the increased efficacy values, mostly due to decreasing the shading coefficient of the glazing.

Summed Annual Performance Targets

The summed annual lighting and cooling performance targets are shown below. The summed cooling energy consists of the cooling due to solar radiation and the cooling due to lighting components only and hence, does not represent the total cooling energy for the building; i.e. cooling due to equipment, occupants, conductive gains, etc. The 1995 values are 38% below current levels and the 2005 values are 73% below current levels; thus indicating a potential for major annual energy use savings.

Summed Lighting and Cooling Performance Targets (kWh/ft^2-yr):

Location	Current	1995	2005
Los Angeles	5.70	3.54	1.53
Sacramento	5.43	3.38	1.46
San Francisco	4.99	3.07	1.33

Annual whole building numbers are presented on Figure 4.4.

Peak Demand Performance Targets

Peak electricity use targets are shown superimposed on several hourly load shape curves on Figure 4.5. The targets are based on simulation results, tempered by expert judgement as to available technology and appropriate design trends. Target values for all locations for the year 2005, correspond to about a 40% reduction from current values. These values are not currently achievable without further advances in glazing and lighting technology and subsequent incorporation into an integrated design solution.

Peak Electricity Performance Targets (W/ft^2-yr):

Location	Current	1995	2005
Los Angeles	3.70	2.90	2.17
Sacramento	3.66	2.83	2.11
San Francisco	3.24	2.50	1.83

Demand Projection for California

An estimate of the total state-wide demand reduction was made by summing the product of the total square footage of office space and the peak demand for each climate zone. The total demand reduction figure will provide a rough estimate of the impact the proposed envelope and lighting energy conservation measures may have on California.

Figure 4.6 and Table 4.1 show potential state-wide demand savings in 1995 and 2005. Three scenarios were investigated for various combinations of new growth estimates and retrofits to existing office buildings:

- New office buildings will meet the performance targets and no retrofits will meet the performance targets for both 1995 and 2005.
- New office buildings plus 10% of the retrofits will meet the performance targets for both 1995 and 2005.
- New office buildings plus 10% of the retrofits will meet the targets in 1995 and all new office buildings plus 30% of the retrofits will meet the targets in 2005.

The percentages of retrofits per time period are based solely on engineering estimates. The total demand reduction has been roughly translated into the number of deferred power plants using building site energy of 1.0 GW per power plant. The market sector size for office buildings was determined in two parts using the office stock square footage data from the California Energy Commission Commercial Sector Forecasting Model (CEC, 1991):

1) The DOE-2 analysis of the single floor building module used the California Climate Zone Weather File Inventory available in the DOE-2 library for the Los Angeles metropolitan area (CTZ09), the San Francisco Bay Area (CTZ03), and the Sacramento Central Zone (CTZ12). These CTZ defined areas correspond roughly to the CEC forecast climate zones (CZ) of Los Angeles: SCE CZ8 & CZ9, LADWP CZ11 & CZ12, and BGP CZ16; Sacramento: PG&E CZ2 and SMUD CZ6; and San Francisco: PG&E CZ5. The CEC projected floor areas were summed for target years 1991, 1995 and 2005. The summed floor areas represent 69% of the total office building stock in California represented by the CEC planning areas of PG&E, SMUD, SCE, LADWP, SDG&E, BGP, and Other (Mount Shasta and Norton AFB). These floor areas per city were then multiplied by their respective peak demand performance targets given in Section 4 of this discussion to obtain a demand reduction figure for these three climate zones.

2) For the balance of office floor areas in California not included in the climate zones analyzed by our DOE-2 simulation, we applied an average peak performance target value. The demand reduction figure calculated for this remaining balance was then added to the above demand reduction figure to obtain a total demand reduction figure for the state of California. These figures are given in Table 4.1.

For comparison, Table 4.2 gives the market sector size from a second data source, the Gas Research Institute Cogeneration Market Assessment Model (Huang et al, 1990) as well as the CEC data. The GRI data represents a compilation of two sets of county-level data from Dodge (Building Stock, 1989, and Building Starts, 1989) and the NBECS (Nonresidential Buildings Energy Consumption Survey, 1983). The building stock square footage, growth rate and demolition rate are provided for large offices (> 60,000 ft^2) for the metropolitan areas of Los Angeles, San Francisco, and San Diego. The demand reduction figures presented for the GRI model represent the large offices in metropolitan areas only, whereas the demand reduction figures presented for the CEC model represent all commercial offices in the major utility districts. Hence, the total demand reduction presented in Figure 4.6 reflects data from the CEC model.

5. Summary and Conclusions

In this study, we have completed an impact assessment for the performance of a wide range of envelope and lighting technologies. We used these results, tempered with expert judgement, to develop performance targets for our integrated technology systems in the short, mid and long term. We discussed the simulation method that was used to define achievable energy and demand, characterized this performance in terms of existing building stock using published surveys of commercial building energy performance data, and defined energy and peak demand performance targets ranging from what is achievable using today's technologies and what we expect to be achievable with technologies likely to be available in the years 1995 and 2005. All of our studies in this task were limited to an office building type.

The performance targets are based on assumptions regarding lighting power density (LPD), daylighting control strategy, and glazing system luminous efficacy. We used an LPD of 1.5 W/ft^2 (16.1 W/m^2), no daylighting controls, and a glazing efficacy of 1.0 to establish current targets levels. By 1995, we assume the use of daylighting controls, 1.25 W/ft^2 (13.5 W/m^2) LPD, and glazing efficacy of 1.50; by 2005, we postulate a 0.5 W/ft^2 (5.4 W/m^2) LPD and glazing efficacy of 3.0. The 2005 criteria are speculative but physically achieveable values which assume a significant advancement in current technologies and better design leading to the use of integrated envelope and lighting systems.

Using these criteria, individual commercial building EUIs and peak demand can be reduced as follows:

- Lighting electricity consumption 38% by 1995 and 74% by 2005 for all geographic locations.
- Cooling electricity consumption due to lighting 40% in Los Angeles and Sacramento and 47% in San Francisco by 1995 and 75% in all locations by 2005.
- Cooling electricity consumption due to solar gain 33% by 1995 and 65% by 2005 for all locations.
- Summed electricity consumption due to lighting and cooling 38% by 1995 and 74% by 2005 for all locations.
- Peak demand 22% by 1995 and 40% by 2005.

The individual building peak demand figures translate into a state-wide total demand reduction of 1.2 GW by 2005 using a scenario where 6.0 GW represents the total demand in which no new office buildings meet the targets and 4.8 GW is the demand in which all new and 10% of the building retrofits in 1995 and 30% of retrofits in 2005 meet the targets.

Future work may include further revisions to these performance targets to encompass more complex building envelope and lighting technologies. Most notably, we would expect even lower performance targets by including dynamic-property glazings such as electrochromics and through greater use of lighting controls (core daylighting) in our simulations. Other future research may address the impact for commercial buildings other than offices, for retrofit buildings, and for variations in HVAC systems.

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Table 2.1

Glazing Parameters Used in the DOE-2 Simulation Study

Glazing Description		U-value (Btu/ft^2-hr°F)	Shading Coefficient SC	Visible Transmittance Tvis	Glazing Efficacy $K_e=T_{vis}/SC$
Clear	G	1.07	0.95	0.88	0.93
Clear IG	G-G	0.56	0.82	0.78	0.95
Heat Mirror 66	HM66	0.22	0.41	0.53	1.29
Clear Low-E IG (green)	Gg-EsG	0.33	0.41	0.61	1.48
Reflective IG (bronze)	Gb-G	0.40	0.20	0.10	0.50

Table 2.2

Example Regression Coefficients for Los Angeles

	Cooling	Peak Cooling	Heating
U-Value			
β1N	-30.5718	-2.1586	17.7130
β1E	-36.3049	-2.7618	9.4162
β1S	-44.6849	-5.6923	7.9470
β1W	-35.9698	5.7115	11.3792
Shading Coefficient			
β2N	55.0808	39.0346	-6.9067
β2E	101.9818	84.6606	-5.2206
β2S	136.5786	92.9789	-5.1380
β2W	116.2407	82.3652	-6.1217
Lighting			
β3N	5.6460	3.2937	-0.6688
β3E	5.9571	3.2102	-0.3419
β3S	6.1244	3.4049	-0.2917
β3W	6.0964	3.3052	-0.4683
Equipment			
β4N	4.9326	3.0518	-0.4865
β4E	5.3221	3.1795	-0.2576
β4S	5.4651	3.1825	-0.2240
β4W	5.3939	3.1827	-0.3531
Other			
β5N	3.5799	12.3397	2.4218
β5E	5.0089	14.7572	1.5077
β5S	5.5245	13.6490	1.3231
β5W	4.7276	14.7015	2.0212

Table 2.3

Incremental Annual Electricity Use (kWh/ft^2-yr) as a Function of Solar andEffective Apertures for a Prototypical Commercial Office Building Module in Los Angeles with 1.5 W/ft^2 Lighting Power Density, 50 fc Continuous Daylighting (No Daylighting at Tvis*WWR=0.0)

Tvis*WWR

NORTH ZONE		0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7
	0.7	10.7	8.5	7.6	7.3	7.1	7.1	7.1	7.1
	0.6	10.3	8.1	7.2	6.9	6.8	6.7	6.7	6.7
	0.5	9.9	7.7	6.8	6.5	6.4	6.3	6.3	6.3
SC*WWR	0.4	9.5	7.3	6.4	6.1	6.0	5.9	5.9	5.9
	0.3	9.1	6.9	6.0	5.7	5.6	5.5	5.5	5.5
	0.2	8.7	6.5	5.6	5.3	5.2	5.1	5.1	5.1
	0.1	8.3	6.1	5.2	4.9	4.8	4.7	4.7	4.7
	0.0	8.0	5.7	4.8	4.5	4.4	4.3	4.3	4.3

EAST ZONE		0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7
	0.7	16.3	13.8	13.0	12.7	12.7	12.6	12.6	12.6
	0.6	15.1	12.6	11.8	11.5	11.4	11.4	11.4	11.4
	0.5	13.8	11.3	10.5	10.3	10.2	10.2	10.2	10.2
SC*WWR	0.4	12.6	10.1	9.3	9.1	9.0	9.0	9.0	8.9
	0.3	11.4	8.9	8.1	7.8	7.8	7.7	7.7	7.7
	0.2	10.2	7.6	6.8	6.6	6.5	6.5	6.5	6.5
	0.1	8.9	6.4	5.6	5.4	5.3	5.3	5.3	5.3
	0.0	7.7	5.2	4.4	4.1	4.1	4.0	4.0	4.0

SOUTH ZONE		0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7
	0.7	19.1	16.1	15.5	15.4	15.4	15.4	15.4	15.4
	0.6	17.4	14.4	13.9	13.7	13.7	13.7	13.7	13.7
	0.5	15.8	12.8	12.2	12.1	12.1	12.1	12.1	12.1
SC*WWR	0.4	14.1	11.1	10.6	10.4	10.4	10.4	10.4	10.4
	0.3	12.5	9.5	8.9	8.8	8.8	8.8	8.8	8.8
	0.2	10.8	7.8	7.3	7.1	7.1	7.1	7.1	7.1
	0.1	9.2	6.2	5.6	5.5	5.5	5.5	5.5	5.5
	0.0	7.5	4.5	4.0	3.8	3.8	3.8	3.8	3.8

WEST ZONE		0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7
	0.7	17.1	14.4	13.6	13.4	13.3	13.3	13.3	13.3
	0.6	15.8	13.1	12.3	12.1	12.0	12.0	12.0	12.0
	0.5	14.5	11.7	11.0	10.7	10.7	10.7	10.7	10.7
SC*WWR	0.4	13.1	10.4	9.6	9.4	9.3	9.3	9.3	9.3
	0.3	11.8	9.1	8.3	8.1	8.0	8.0	8.0	8.0
	0.2	10.5	7.7	7.0	6.7	6.7	6.7	6.7	6.7
	0.1	9.1	6.4	5.6	5.4	5.4	5.3	5.3	5.3
	0.0	7.8	5.1	4.3	4.1	4.0	4.0	4.0	4.0

Table 3.1
Office Building Energy Use Intensity and Load Shape Studies

Study	Location	Objective	Data Collection & Analysis	Study Period	Sample Size	Building Characteristics
Akbari, 1989.	Data from California utilities used for calibration.	Forecasting tool.	Computer simulation of prototypical buildings with reconciliatn against on-site surveys, 15 min. load research billing accounts, mail surveys, other EUI/LS studies, weather data & sub-metered energy use data.	Surveys from 1983 to 1987.	Load research data from SCE include 375 offices.	On-site surveys for prototype development include 15 large offices & 70 small offices.
ELCAP, 1989.	Seattle, WA.	End use energy consumptn survey.	Hourly submetering of end use equipment with mixed use circuits disaggregated.	1984-1988.	16 buildings.	7 post 1980 Seattle energy code, 9 constructed before adoption of energy code.
BECA-CN CAL-BECA 1986.	National and California.	Document performance of 'energy-efficient' buildings.	Billing data, submetered data & predictions during design stage.	1986.	103 National, 22 California.	76 large (334 ksf), 27 small (20ksf). Energy management buildings with significant energy saving or load shaping features.
PG&E, McCollister, 1985.	Pacific Gas & Electric territory, CA.	Forecasting survey.	1982 mail survey. Conditional demand analysis with engineer-ing formulations for end-use specifications.	July 1981 to December 1982.	1289 buildings.	Not available.
PG&E, CEC, Schultz, 1984.	Pacific Gas & Electric territory, CA.	Forecasting survey.	Energy audits. Percentage of utility bills attributable to each end use.	1980 to 1983.	909 small buildings, 93.7 Msf, 488 large @ 8.4 Msf.	Not available.
SCE, SRC, 1987.	Southern California Edison, CA.	Forecasting survey.	Computer simulation with TMY weather data and mail survey data.	1983 and 1985 SCE mail surveys.	Not available.	Not available.
SCE, Ignelzi, 1984.	Southern California Edison, CA.	Forecasting survey.	Conditional demand analysis with mail survey data.	1982.	Not available.	Not available.
SDG&E, McCollister, 1987.	San Diego Gas & Electric, CA.	Forecasting survey.	Mail and phone surveys. Conditional demand analysis with weather data.	1984 and 1986 surveys.	163 small, 20 large.	Not available.
NBECS, EIA, 1986.	National.	Energy consumptn survey.	Energy auditor estimates & bill disaggregation from on-site visits. Conditional demand analysis to obtain avg. climate EUIs.	1986.	614,000 buildings, 9,546 Msf	See Table 3.3 and Table 3.[illegible] for detailed statistics of office building characteristics for the U.S.

Table 3.2
Office Building Prototype Characteristics

Study		Floor Area (ft^2)	R_{wall}	R_{roof}	WWR	SC	Tvis	LPD (W/ft^2)	Equip. (W/ft^2)
ELS	Base Case	[a] 16,000	11.00	[b] 35.00	0.30	0.41	0.53	1.50	0.50
	Maximum	16,000	11.00	35.00	0.70	0.95	0.88	2.70	0.50
	Minimum	16,000	11.00	35.00	0.00	NA	NA	0.30	0.50
AKB	Small	3,800	6.83	15.62	0.14	0.71	NA	1.27	0.88
	Large	66,147	5.24	15.77	0.31	0.63	NA	1.59	0.48
SCE '87	Small	11,934	3.44	7.94	0.19	0.64	NA	2.00	NA
	Large	149,000	2.37	8.13	0.26	0.64	NA	2.00	NA
NBECS		15,600	NA	NA	NA	NA	NA	NA	NA

Study		Occupancy (ft^2 per person)	Standard Day Operating Hrs	Min. Outside Air (%)	HVAC System	Heating (°F)	Cooling (°F)
ELS	Base Case	100	NA	[c] 5	SZRH	[d] 72.0	[d] 78.0
	Variables	100	NA	[c] 5	SZRH	72.0	78.0
AKB	Small	234	10	21	PSZ	68.9	74.7
	Large	256	14	14	SZRH, PSZ	72.4	73.2
SCE '87	Small	166	10	20	PSZ	70.0	74.0
	Large	204	15	20	VAV, PSZ	71.0	73.0
NBECS		382	8.0 - 9.6	NA	CC	NA	NA

NA	Not applicable or available	WWR	Window-to-Wall Ratio
SZRH	Single Zone Reheat	Rwall	R-Value of Wall
PSZ	Package Single Zone	Rroof	R-Value of Roof
VAV	Variable Air Volume	SC	Shading Coefficient of Glass
MZS	Multiple Zone System	Tvis	Visible Transmittance of Glass
DDS	Dual Duct System	LPD	Lighting Power Density
CC	Central Cooling	Equip	Miscellaneous Equipment Load (Computers, etc.)

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[a] Square footage per floor.

[b] Roof acts adiabatically. No heat transfer between ceiling and floor surfaces.

[c] CFM per person.

[d] Setpoints for the hours of 7:00 to 18:00 weekdays.

Table 3.3
NBECS Building Characteristics 1986
Energy Conservation Features Installed
Percentage of Total Office Buildings Surveyed (9,546 Mft^2)

Building Size	
Mean (ksf)	15.50
Median (ksf)	4.70
1K-5K	11%
5K-10K	10%
10K-25K	13%
25K-50K	13%
50K-100K	11%
100K-200K	11%
200K-500K	16%
>500K	14%

Climate Zone	
<2K CDD &	
>7K HDD	7%
5.5K-7K HDD	30%
4K-5.5K HDD	21%
<4K HDD	26%
>2K CDD & <4K HDD	16%

Year Constructed	
<1900	4%
1901-20	7%
1921-45	13%
1946-60	11%
1961-70	18%
1971-73	7%
1974-79	14%
1980-83	15%
1984-86	11%

Weekly Operating Hours	
39 or less	3%
40-48	50%
49-60	26%
61-84	15%
85-167	3%
Open continuously	3%

Total Workers	
Aggregate sf/worker	381.70
Median sf/worker	437.90
<5	4%
5 to 9	8%
10 to19	10%
20 to 49	14%
50 to 99	10%
100 to 249	15%
250 or more	39%

Weekly Operating Schedule	
Monday - Friday	62%
Monday - Saturday	28%
Monday - Sunday	5%
24 hours/day, all week	3%

Percentage of Buildings Vacant At Least 3 Months	
None	59%
1-25%	26%
26-50%	8%
57-99%	5%
100%	2%

Wall & Frame Materials	
Masonry over	
Wood frame	9%
Masonry frame	31%
Steel frame	24%
Siding over	
Wood frame	6%
Masonry frame	
Metal Panels	5%
Concrete panels	10%
Other	14%

Roof Materials	
Built-up	63%
Shingles (not wood)	12%
Metal shingles	4%
Synthetic or rubber	16%
Slate or tile	
Wood shingles, shakes or other	2%

Cooling Production	
Central cooling system	59%
Individual AC in walls/windows	17%
Packaged AC units	36%
Air-source heat pumps	15%
Rec. distributed chilled water	4%

Heating & Cooling Distribution	
Ducted forced air	
Heating only	3%
Cooling only	8%
Heating and cooling	76%
VAV used	38%
Radiators & baseboards	
Steam	14%
Hot water	16%
Fan coil units	
Heating only	4%
Cooling only	4%
Heating and cooling	22%
Heating panels	5%

Table 3.4

NBECS Building Characteristics 1986
Energy Conservation Features Installed
Percentage of Total Office Buildings Surveyed (9,546 Mft^2)

Building Shell Conservation Features as of 12/31/86	%
Roof or ceiling insulation	84
Wall insulation	61
Storm or multiple glazing	52
Tinted, reflective, shading glass or film	58
Exterior or interior shadings or awnings	55
Weatherstripping or caulking	82
Other	3

Lighting Conservation Features	%
High efficiency ballasts	46
Delamping program	32
Natural lighting control sensors	7
Other lighting controls	30
Other lighting conservation features	8

Notice that of the total number of office buildings surveyed nationally in 1986:
Only 58% have installed tinted, reflective, shading glass or film, and
only 7% have natural lighting control sensors.

Table 4.1

Total Demand Reduction for Commercial Offices in the State of California

Year	Base case All new offices do not meet targets (GW)	All new offices meet targets (GW)	All new + 10% retrofits meet targets (GW)	All new + 10% retrofits in 1995 + 30% retrofits in 2005 meet targets (GW)
1991	4.438	4.438	4.438	4.438
1995	4.906	4.803	4.705	4.705
2005	6.036	5.458	5.272	4.802
Total power saved in 1995		0.103	0.201	0.201
Total power saved in 2005		0.578	0.764	1.234

Note: The total demand reduction figures above are a product of the peak demand performance targets presented in Section 4 of this report and the projected office space areas given by the CEC California Energy Demand Forecast Model presented in Table 4.2.

Table 4.2

Market Sector Sizes for Commercial Offices

CEC California Energy Demand Forecast Model (CEC 91)

Location	Office Floor Area (Mft^2) 1991	1995	2005	LBL Weather File	CEC 1991 Planning area, Climate zone
Sacramento	71.2	81.2	108.8	CTZ12	PG&E CZ2, SMUD CZ6
San Francisco	167.0	184.3	221.0	CTZ03	PG&E CZ5
Los Angeles	619.7	679.3	826.4	CTZ09	SCE CZ8/9, BGP CZ16, LADWP CZ11/12
Other Areas	380.5	424.4	528.0		
Total Area	1,238.4	1,369.2	1,684.1		

GRI Cogeneration Market Assessment Model (Huang et al 1990)

Large Office Market	Office Floor Area (Mft^2) Stock Pre-1981	Current '81-88	Total '88	Growth Rate	Demolition Rate	Office Floor Area (Mft^2) 1991	1995	2005
Los Angeles 1	175.4	96.2	271.6	0.086	0.009	291.7	318.4	385.4
Los Angeles 2	30.9	31.7	62.6	0.114	0.007	72.8	86.4	120.5
San Francisco	87.5	52.1	139.6	0.043	0.008	144.2	150.3	165.7
San Diego	21.5	22.7	44.2	NA	0.008	NA	NA	NA

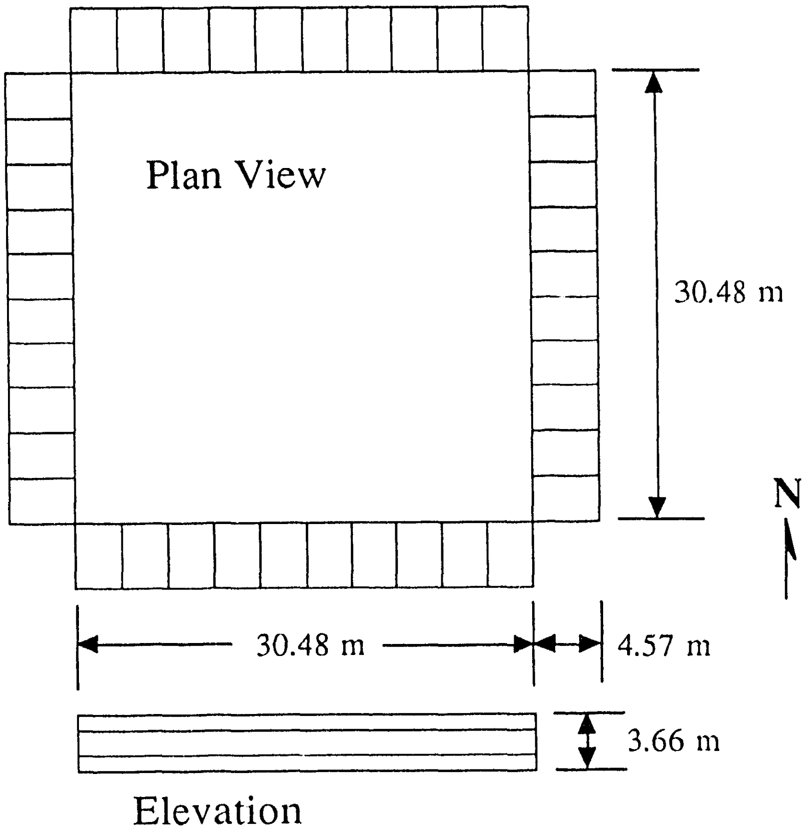
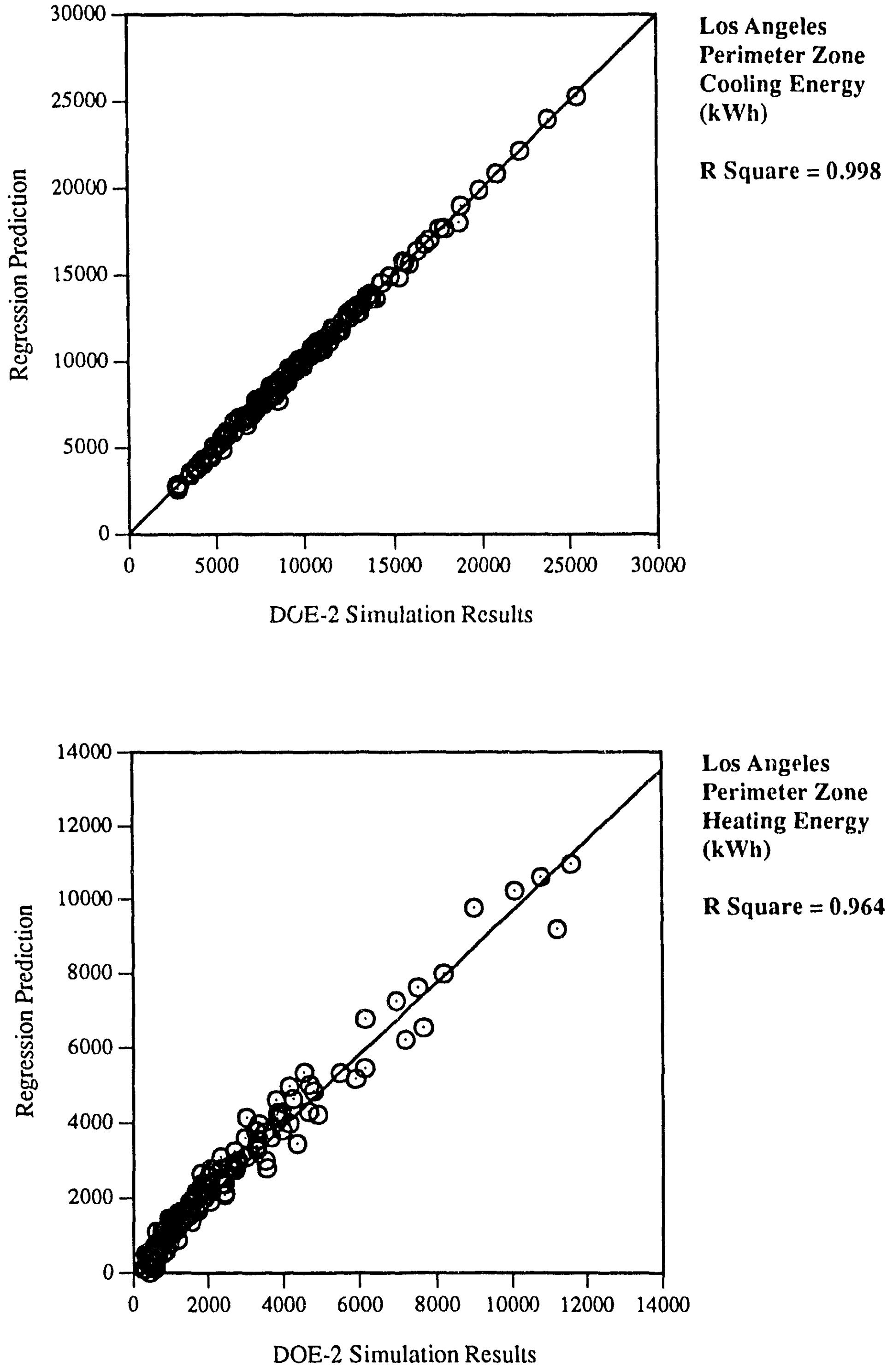


Figure 2.1: Prototypical commercial office building module used in the DOE-2 simulations.



Los Angeles
Perimeter Zone
Cooling Energy
(kWh)

R Square = 0.998

Los Angeles
Perimeter Zone
Heating Energy
(kWh)

R Square = 0.964

Figure 2.2: Heating and cooling energy comparison between DOE-2 simulation results and regression prediction.

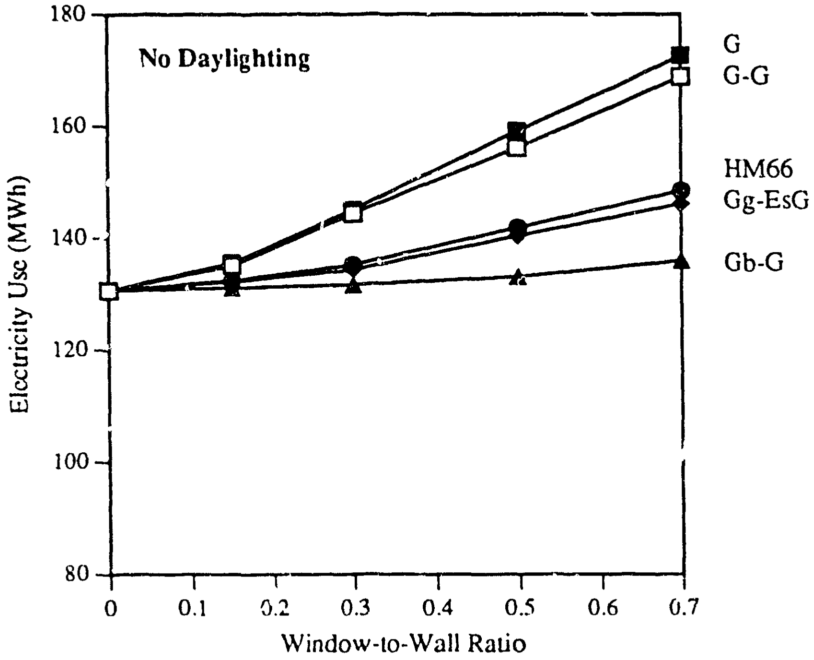


Figure 2.3: Total electricity consumption for a prototypical commercial office building module in Los Angeles as a function of window-to-wall ratio. The data shows the performance of several glazing types without the use of daylighting.

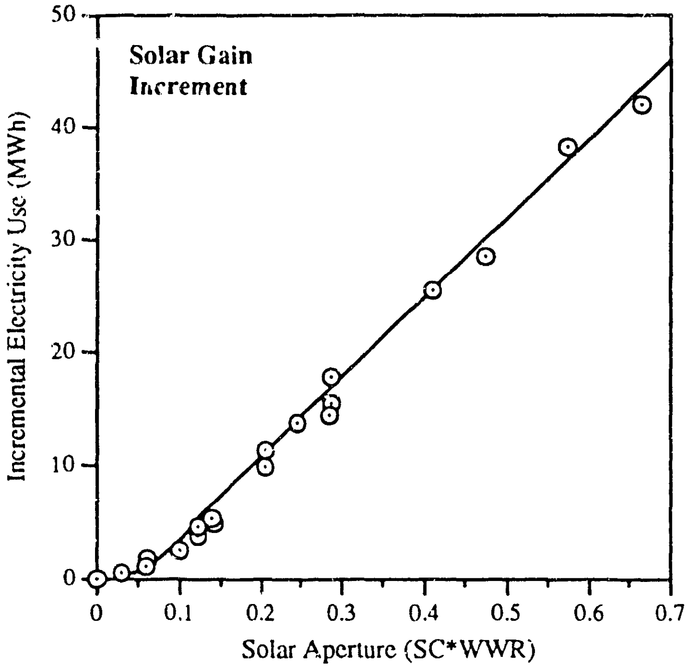


Figure 2.4: Incremental electricity consumption for a prototypical commercial office building module in Los Angeles as a function of *solar aperture*, which is the product of shading coefficient and window-to-wall ratio.

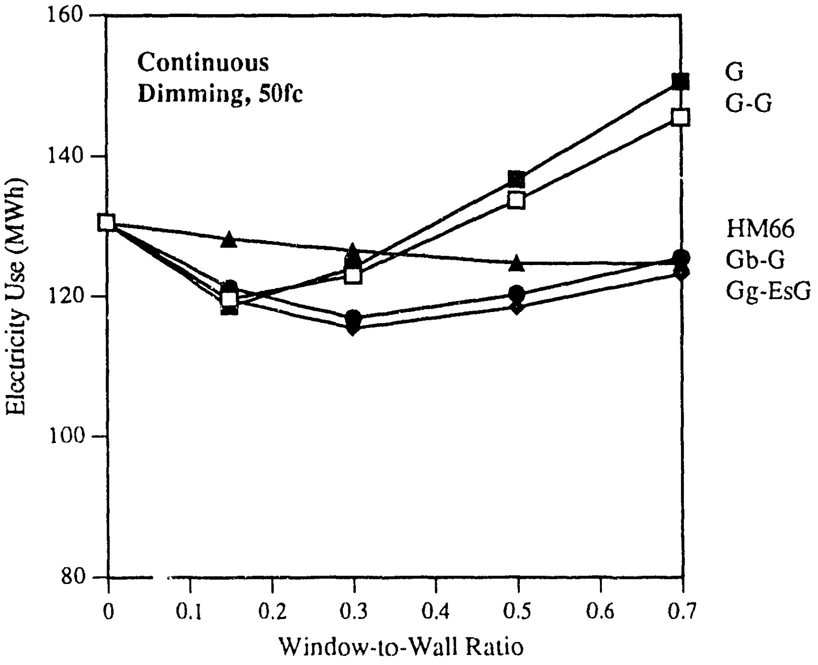


Figure 2.5: Total electricity consumption for a prototypical commercial office building module in Los Angeles as a function of window-to-wall ratio. The data shows the performance of several different glazing types with the use of a continuous daylighting strategy.

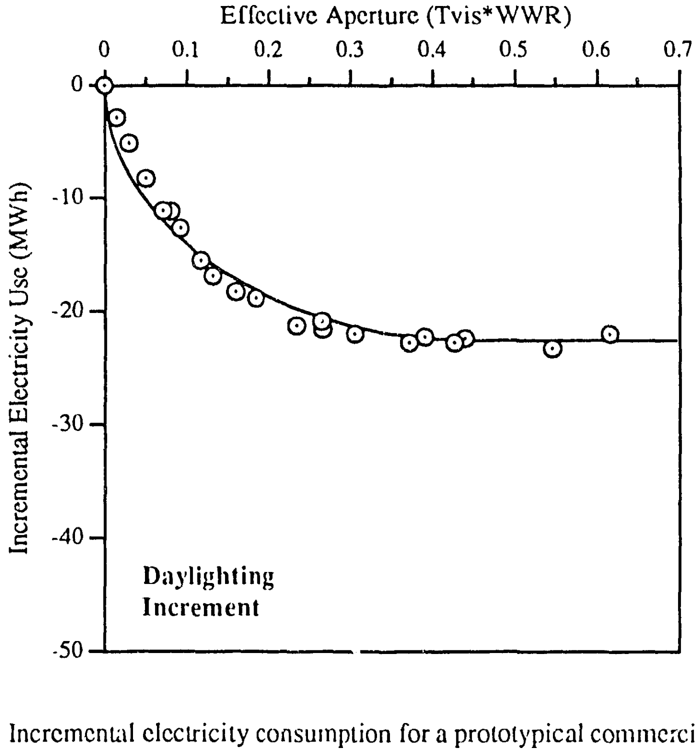


Figure 2.6: Incremental electricity consumption for a prototypical commercial office building module in Los Angeles as a function of *effective aperture*, which is the product of visible transmittance and window-to-wall ratio.

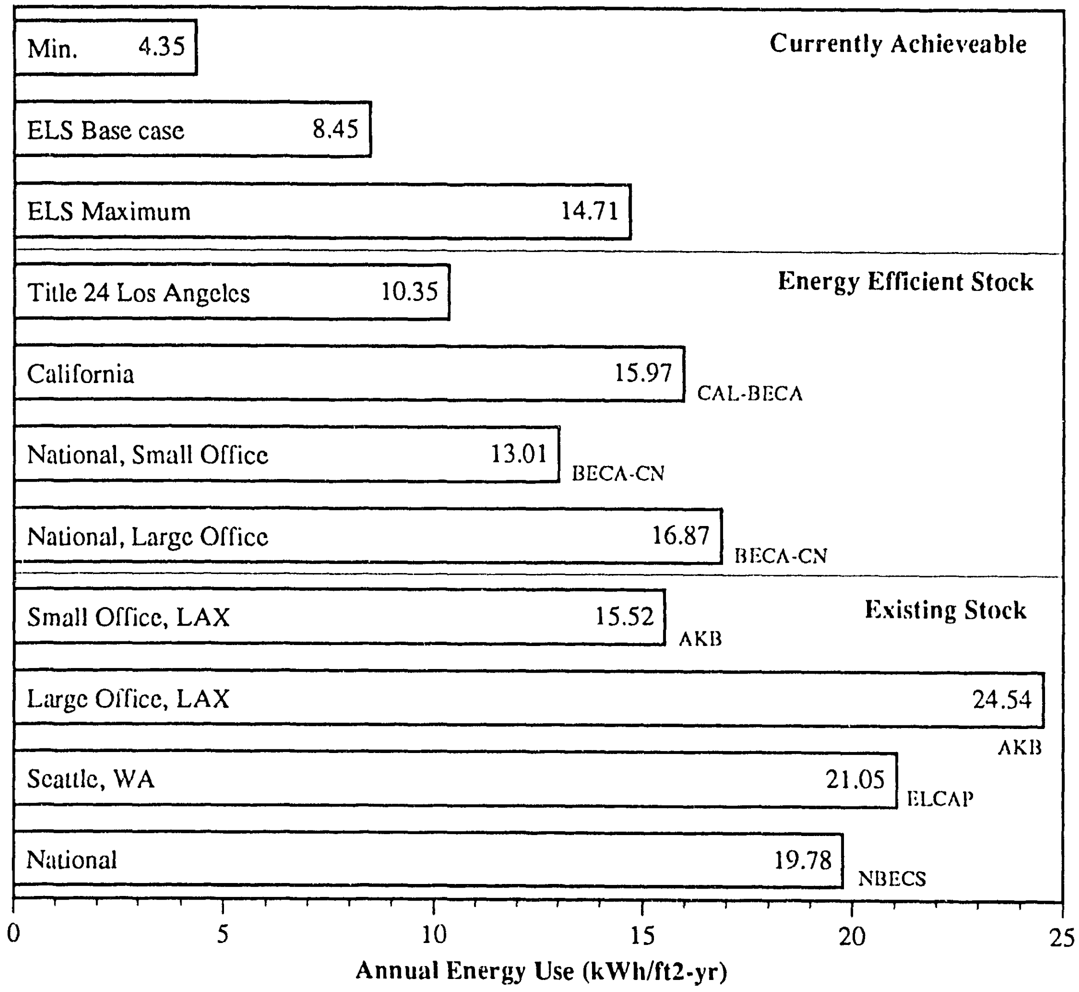


Figure 3.1: Annual total electricity use for a prototypical commercial office building module in Los Angeles (ELS) compared with other energy use surveys.

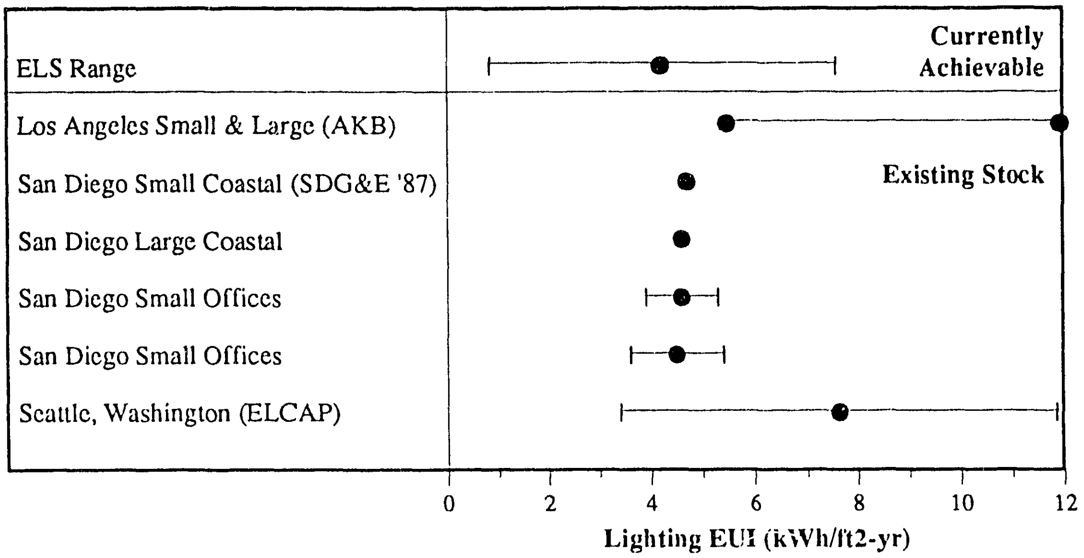


Figure 3.2a: Annual interior lighting energy use intensity for a prototypical commercial office building module in Los Angeles (ELS) versus existing stock energy use surveys.

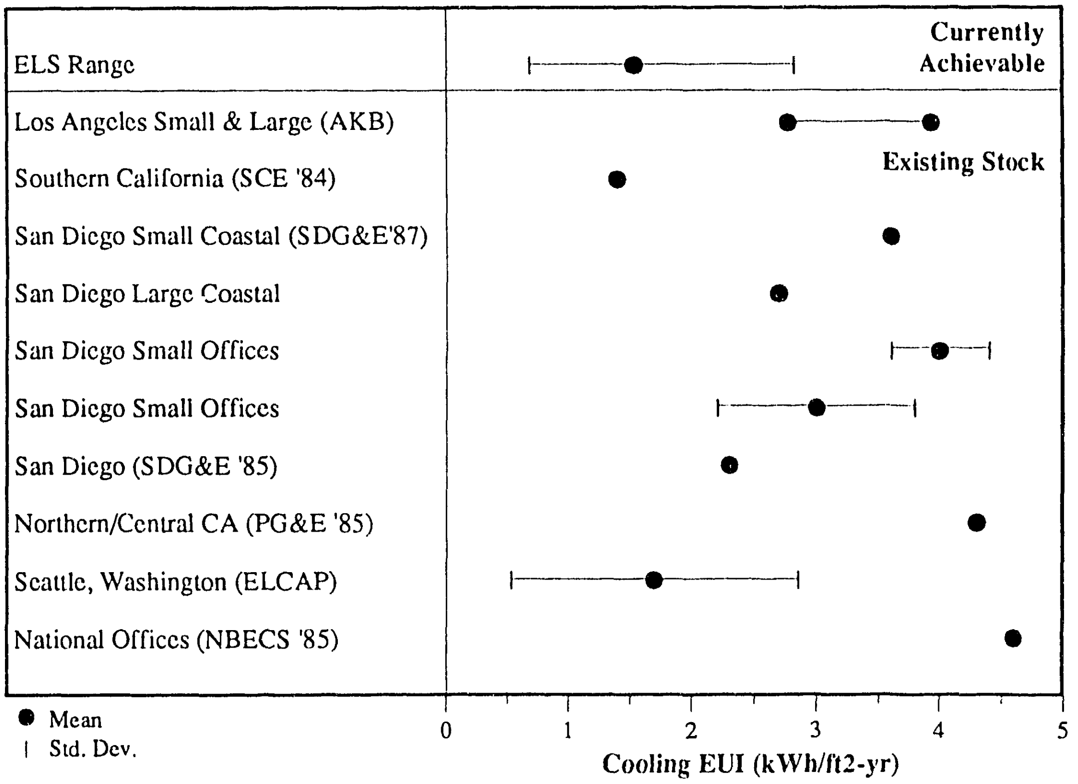


Figure 3.2b: Annual cooling energy use intensity for a prototypical commercial office building module in Los Angeles (ELS) versus existing stock energy use surveys.

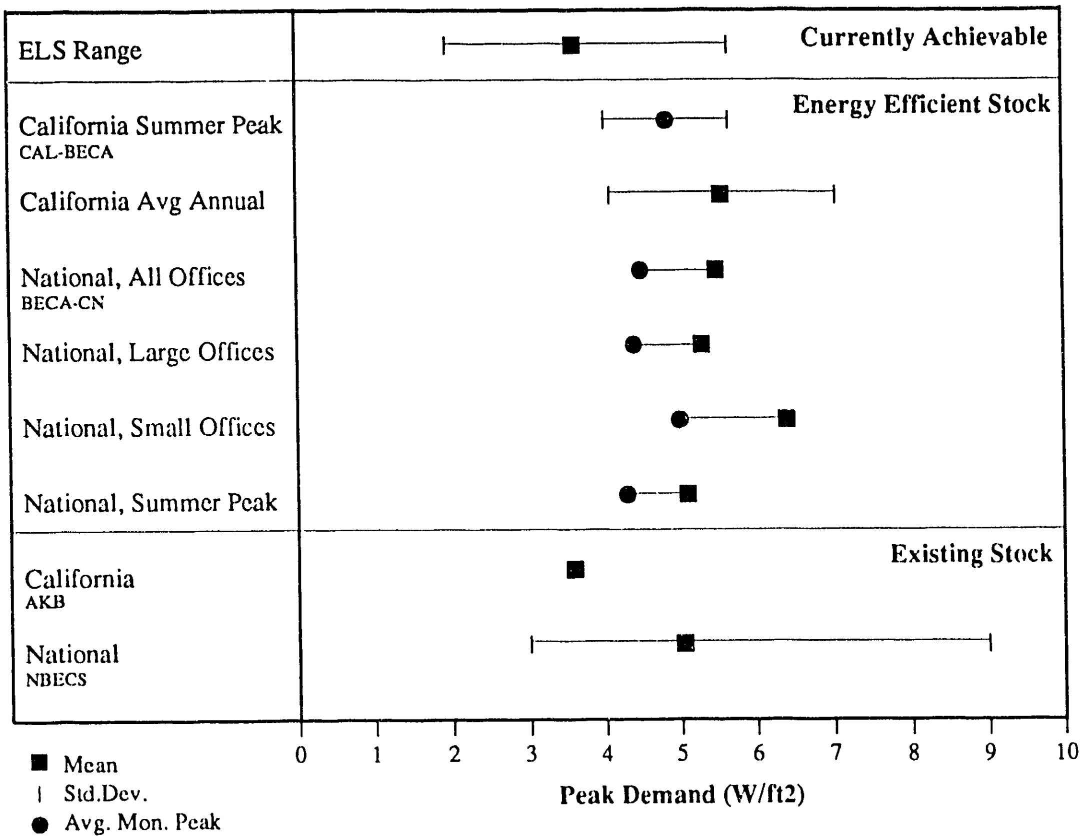


Figure 3.3: Peak demand for a prototypical commercial office building module in Los Angeles (ELS) compared with other energy use surveys.

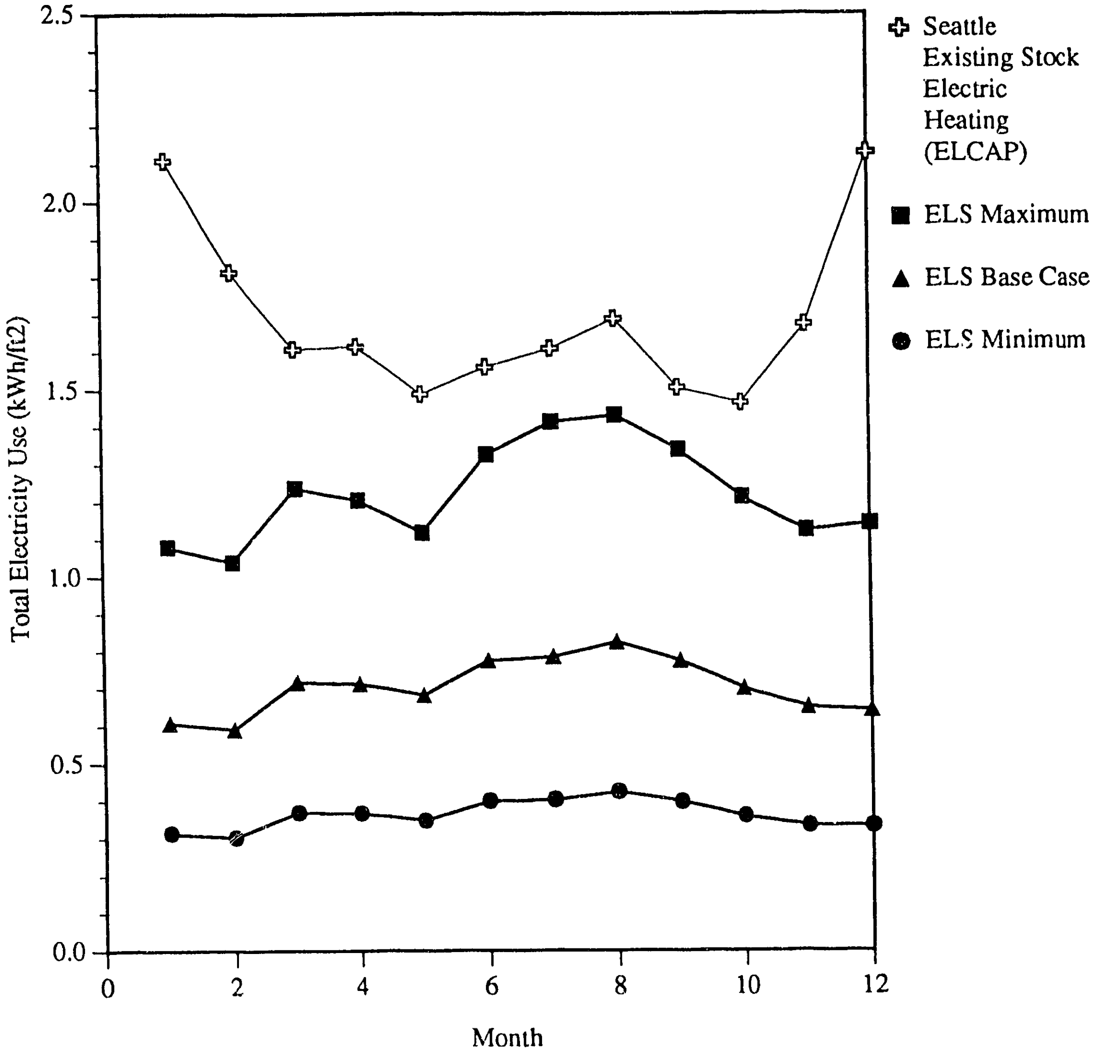


Figure 3.4: Monthly total electricity use for a prototypical commercial office building module in Los Angeles (ELS) compared with the ELCAP 1989 study for 14 submetered office buildings in Seattle, WA.

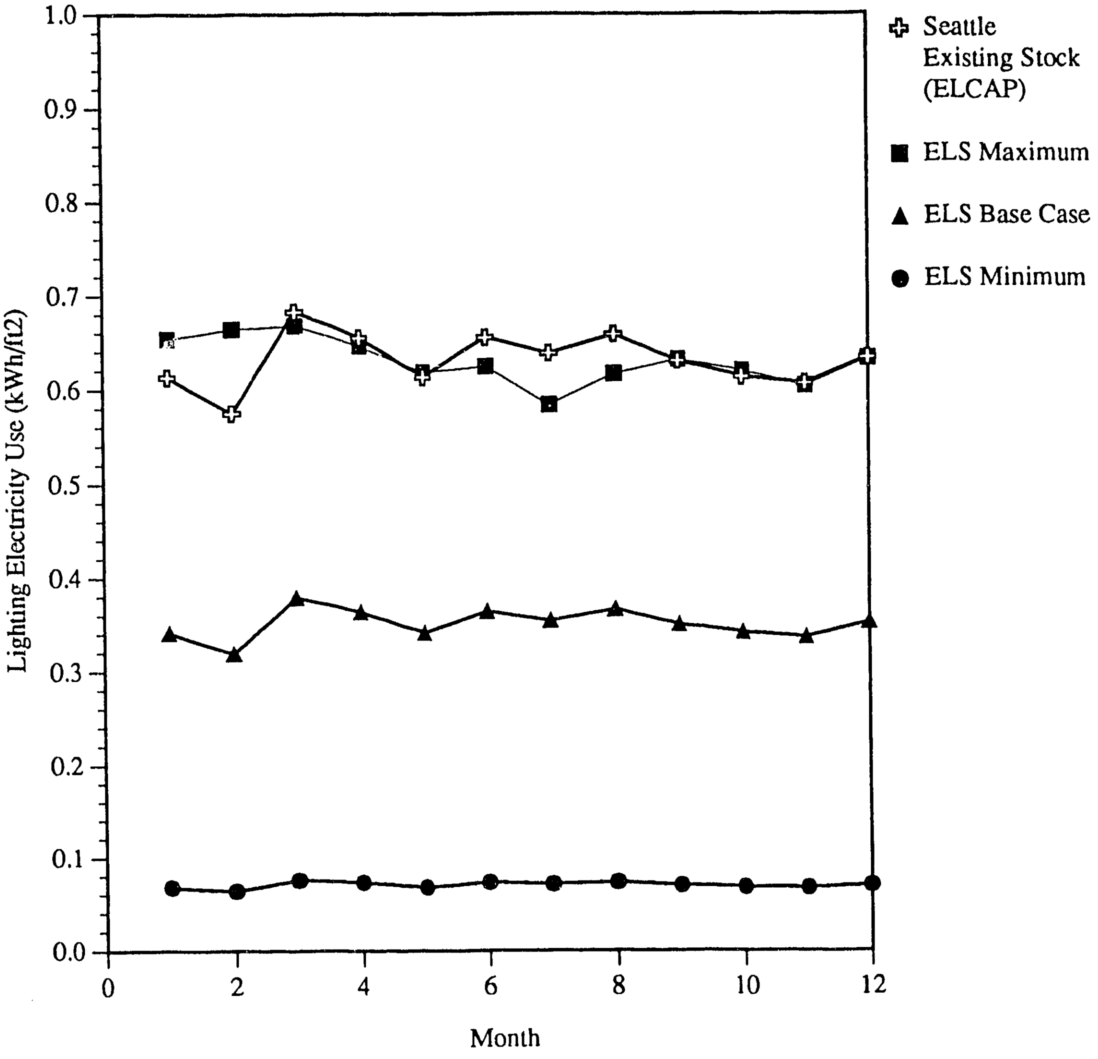


Figure 3.5: Monthly interior lighting electricity use for a prototypical commercial office building module in Los Angeles (ELS) compared with the ELCAP 1989 study for 14 submetered office buildings in Seattle, WA.

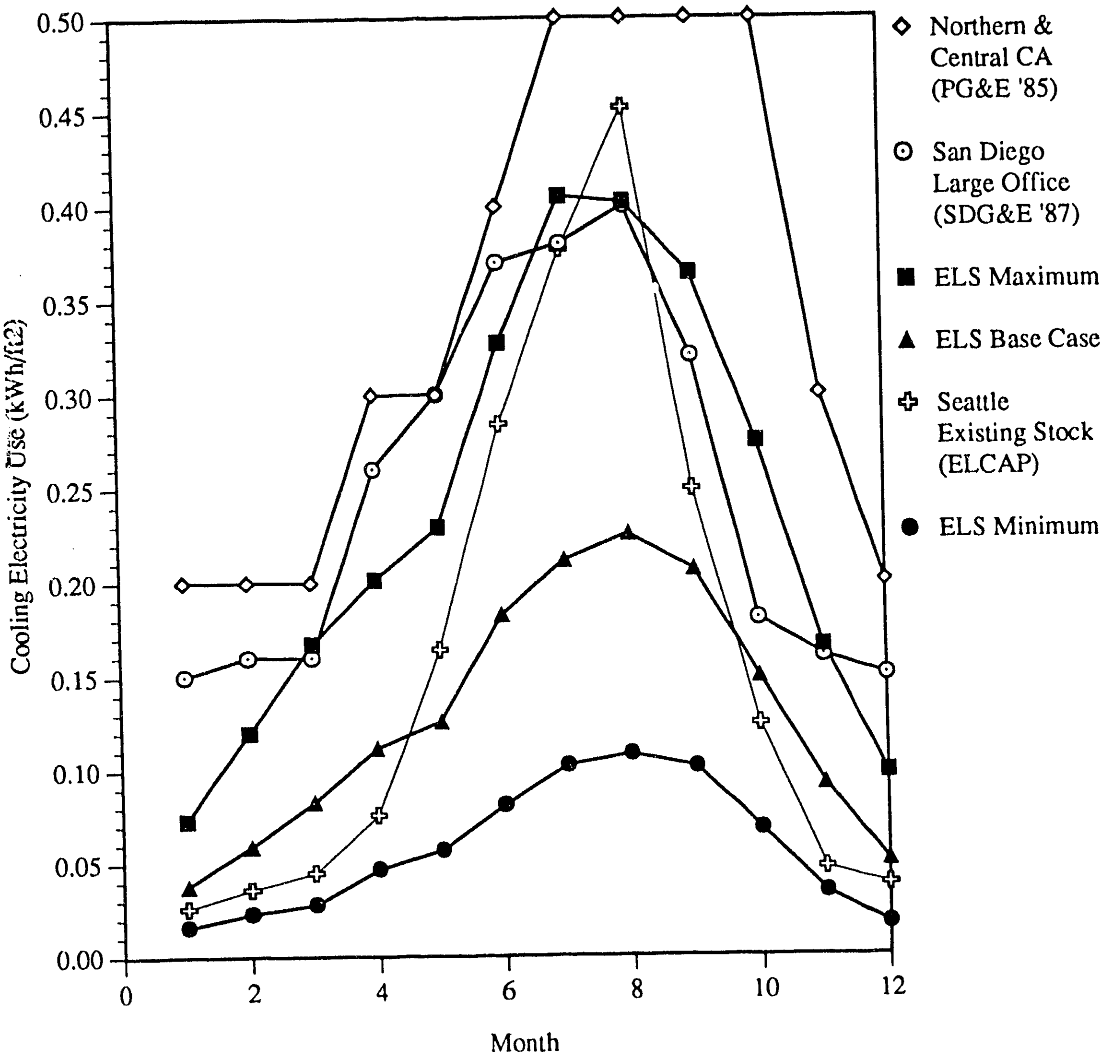


Figure 3.6: Monthly cooling electricity use for a prototypical commercial office building module in Los Angeles (ELS) compared with results from other existing stock energy use surveys.

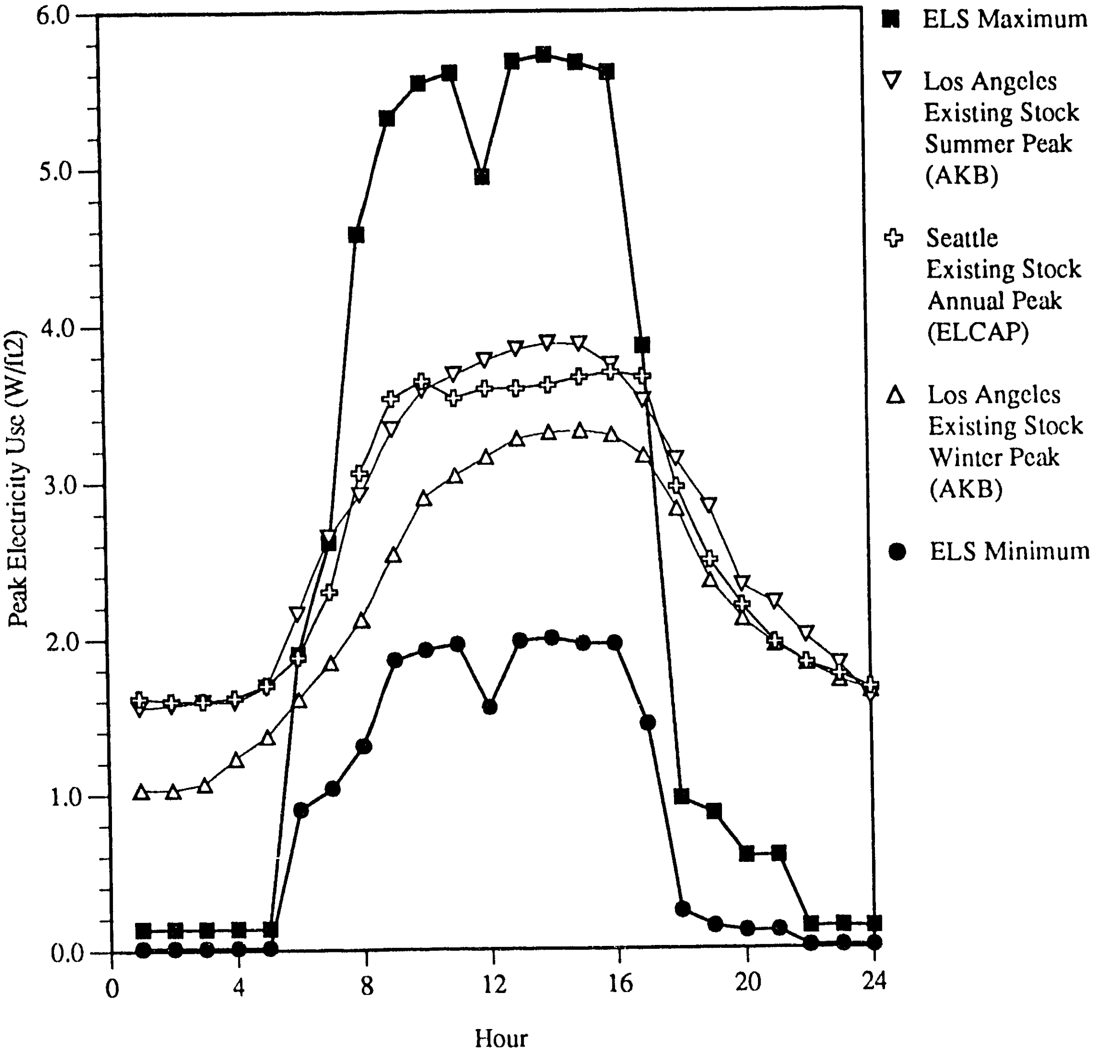


Figure 3.7: Hourly total electricity use for a prototypical commercial office building module in Los Angeles (ELS) compared with existing stock energy use surveys.

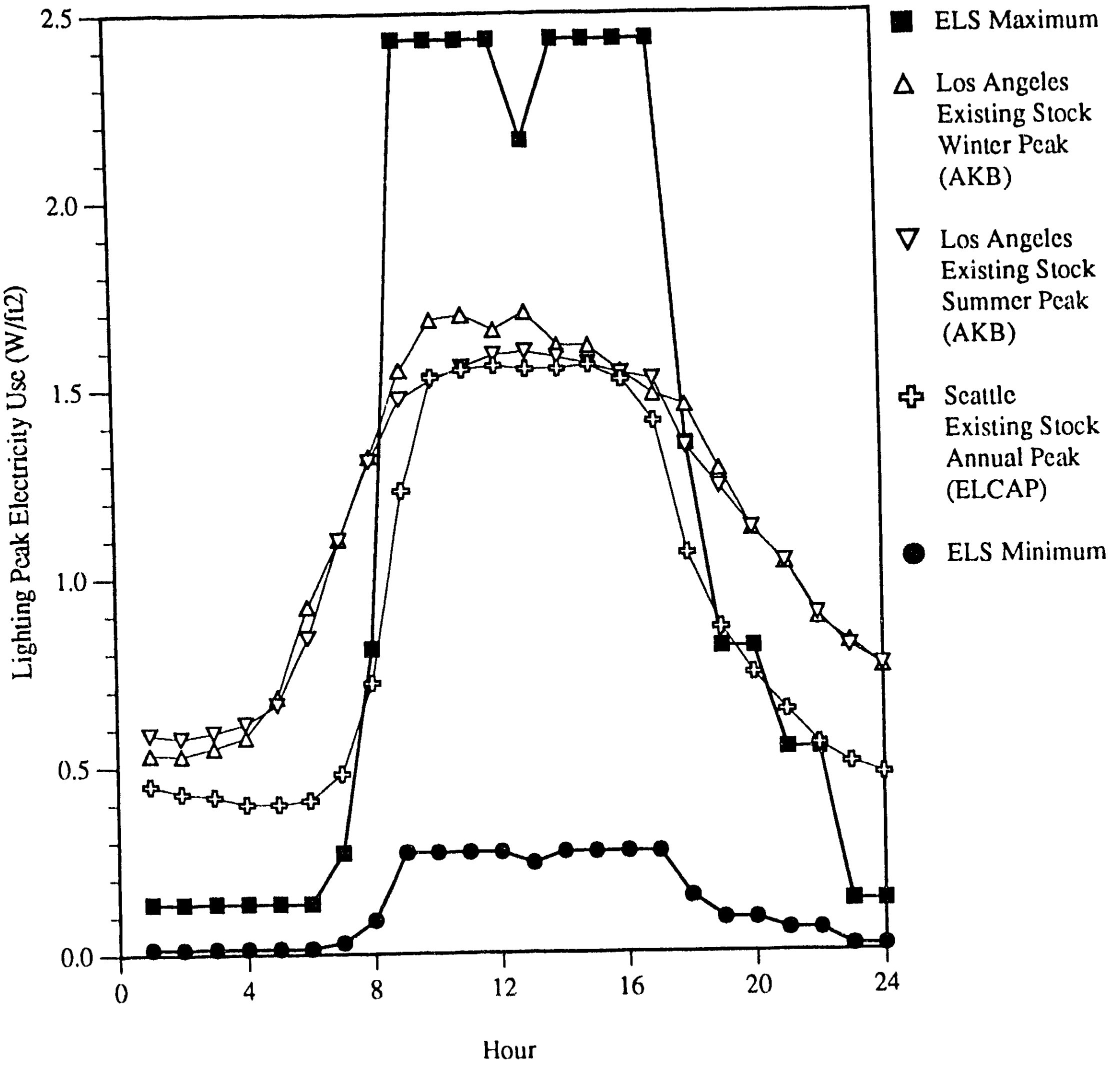


Figure 3.8: Hourly interior lighting peak electricity use for a prototypical commercial office building module in Los Angeles (ELS) compared with existing stock energy use surveys.

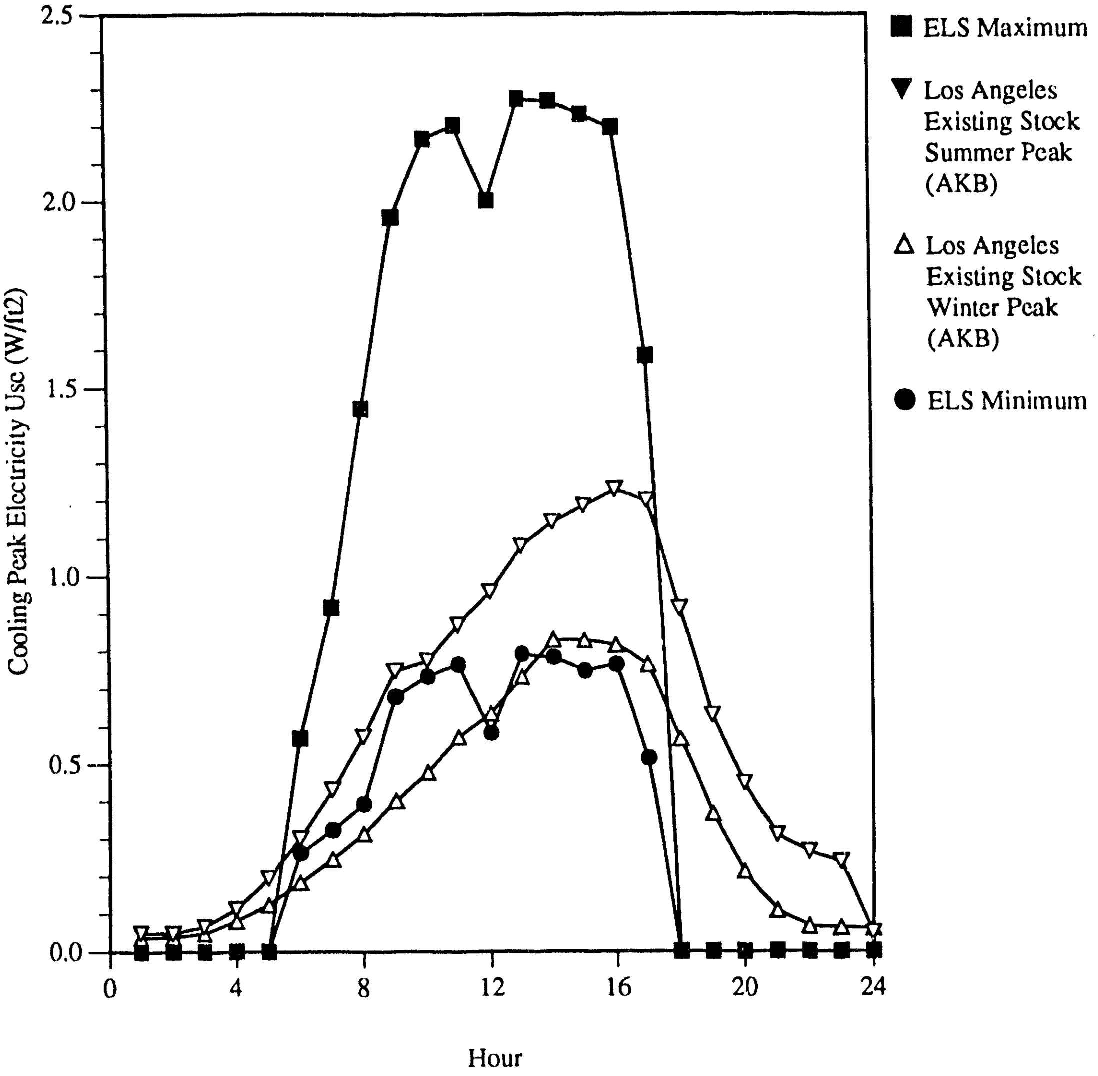


Figure 3.9: Hourly cooling peak electricity use for a prototypical commercial office building module in Los Angeles (ELS) compared with existing stock energy use in Los Angeles (AKB).

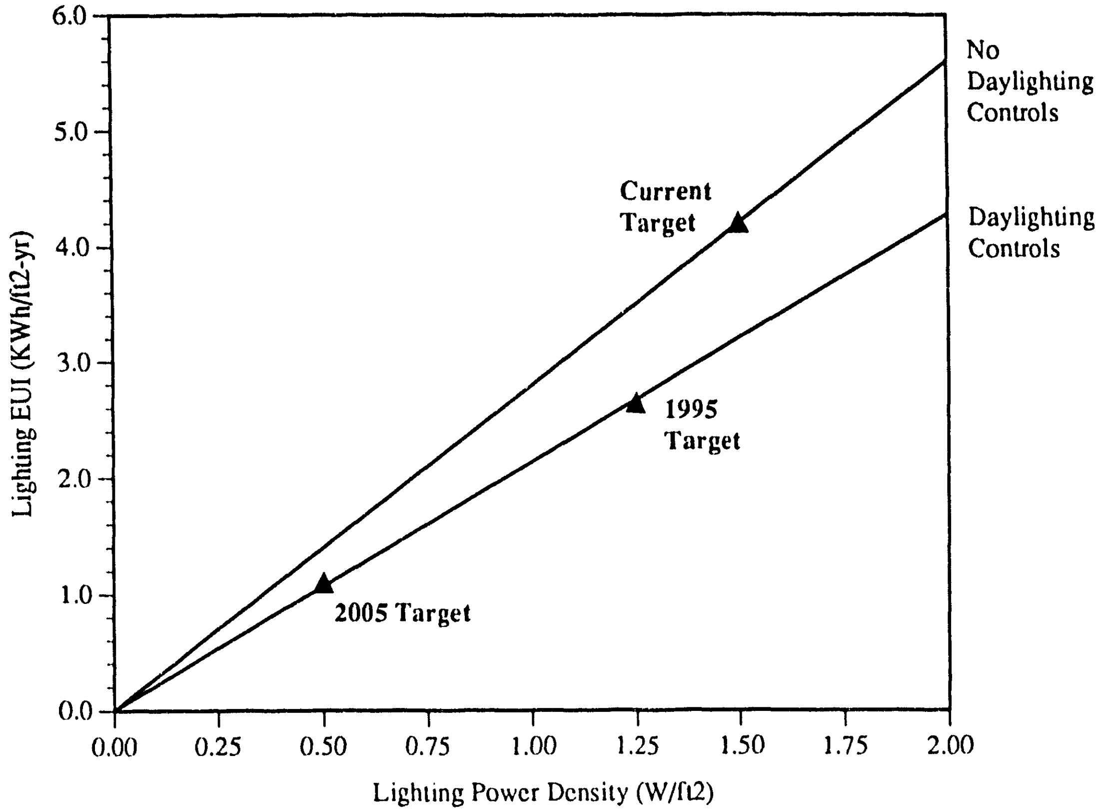


Figure 4.1: Lighting performance targets for all locations for commercial office buildings given variations in the lighting power density.

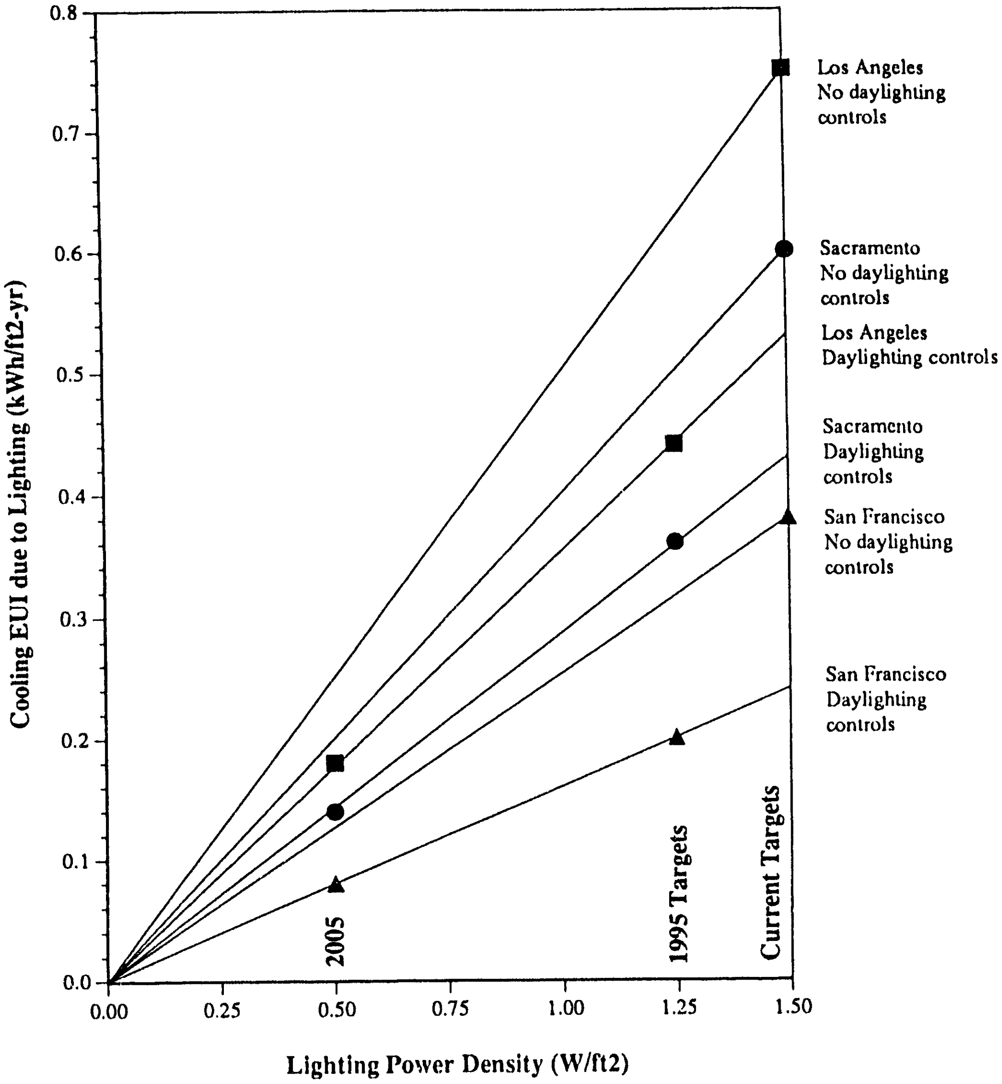


Figure 4.2: Cooling energy use targets for commercial office buildings due to variations in the lighting power density and the use of daylighting controls.

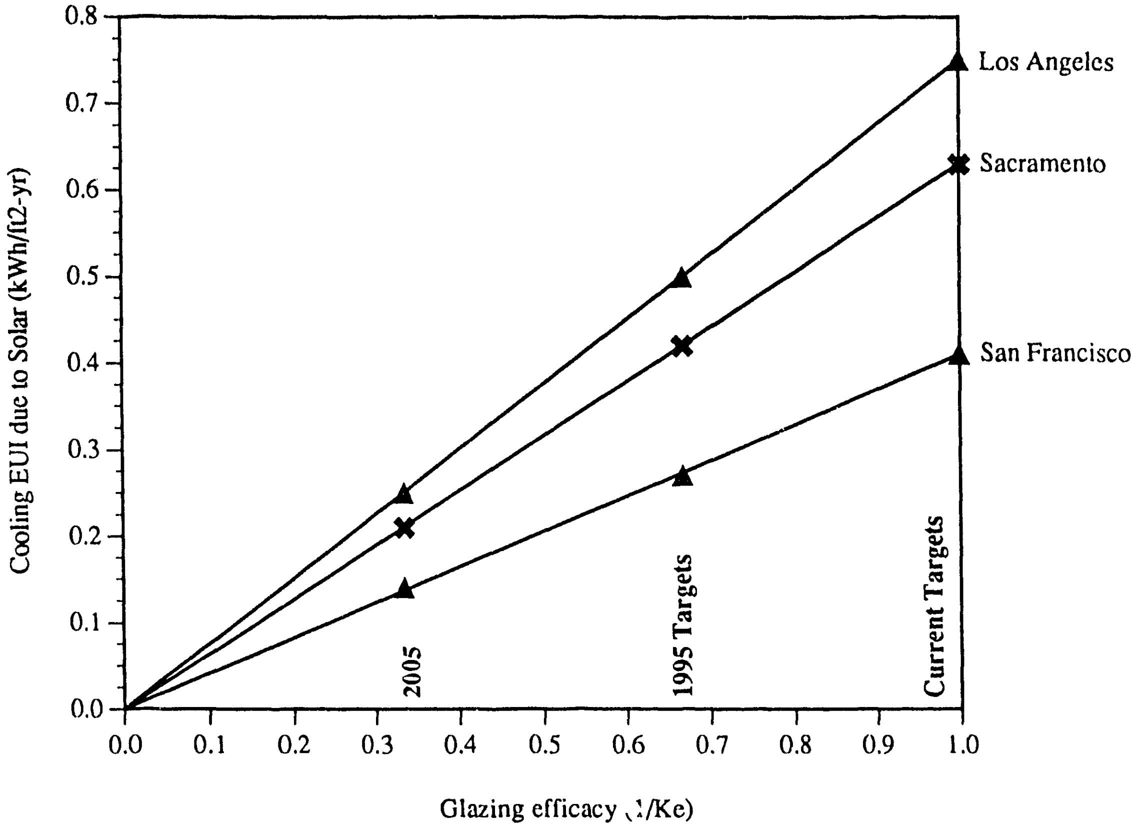


Figure 4.3: Cooling energy use targets due to solar radiation performance targets for commercial office buildings given variations in the glazing efficacy (1/Ke or SC/Tvis).

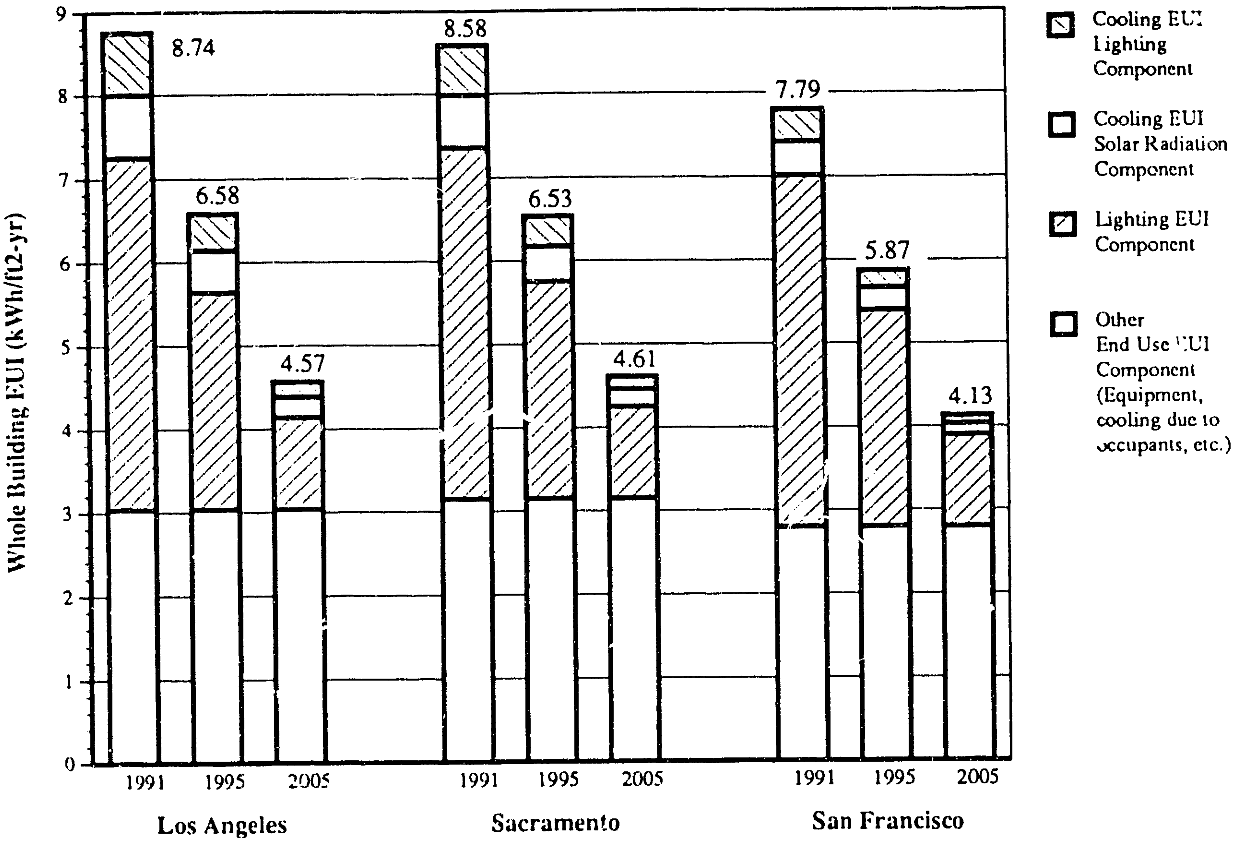


Figure 4.4: Annual total electriciy use intensity for a prototypical commercial office building module at three locations given performance targets of lighting power density, glazing efficacy, and use of daylighting controls.

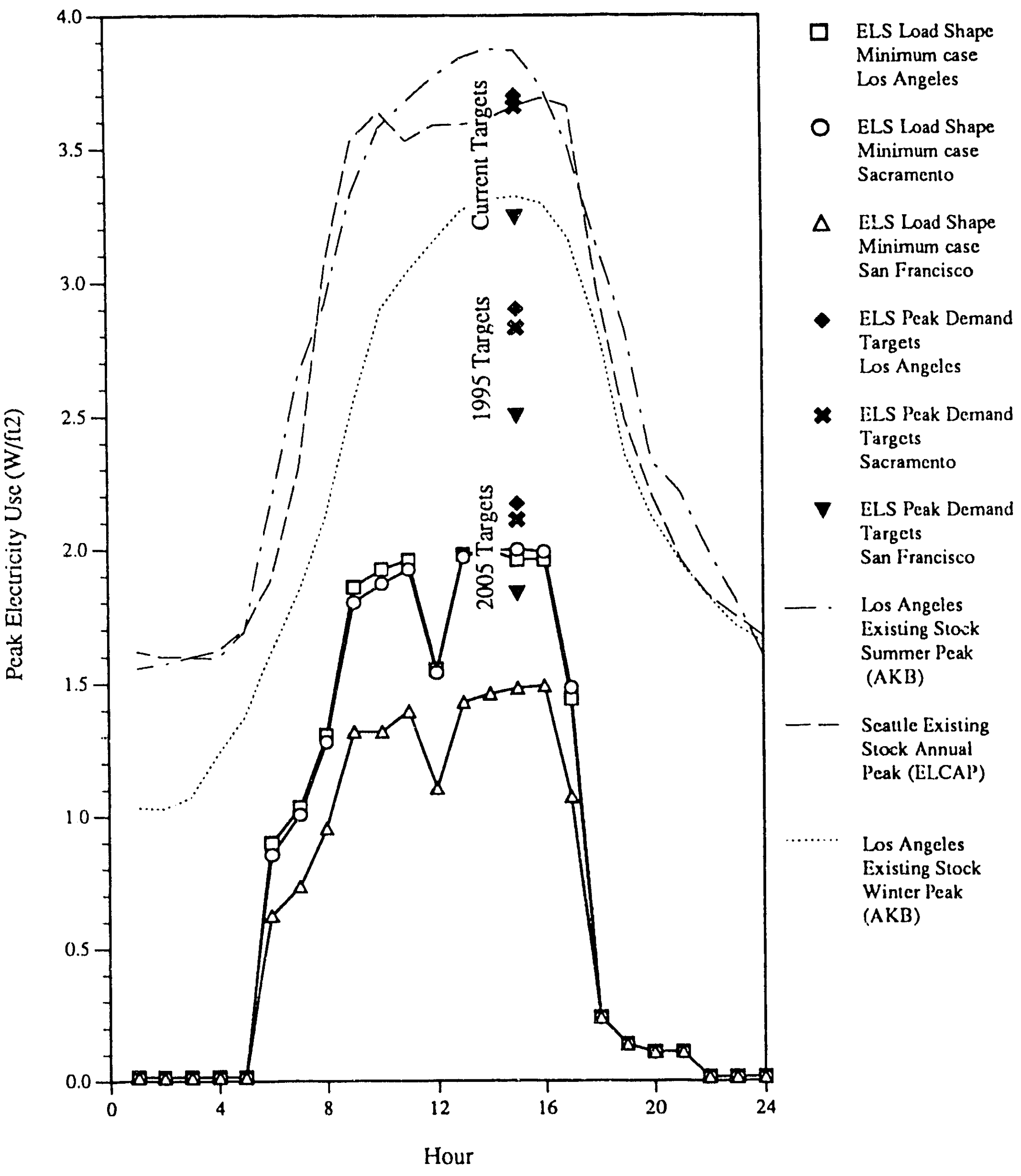


Figure 4.5: Peak electricity performance targets for a prototypical commercial office building module in Los Angeles, Sacramento, and San Francisco compared with hourly ELS minimum total electricity use and existing stock energy use surveys.

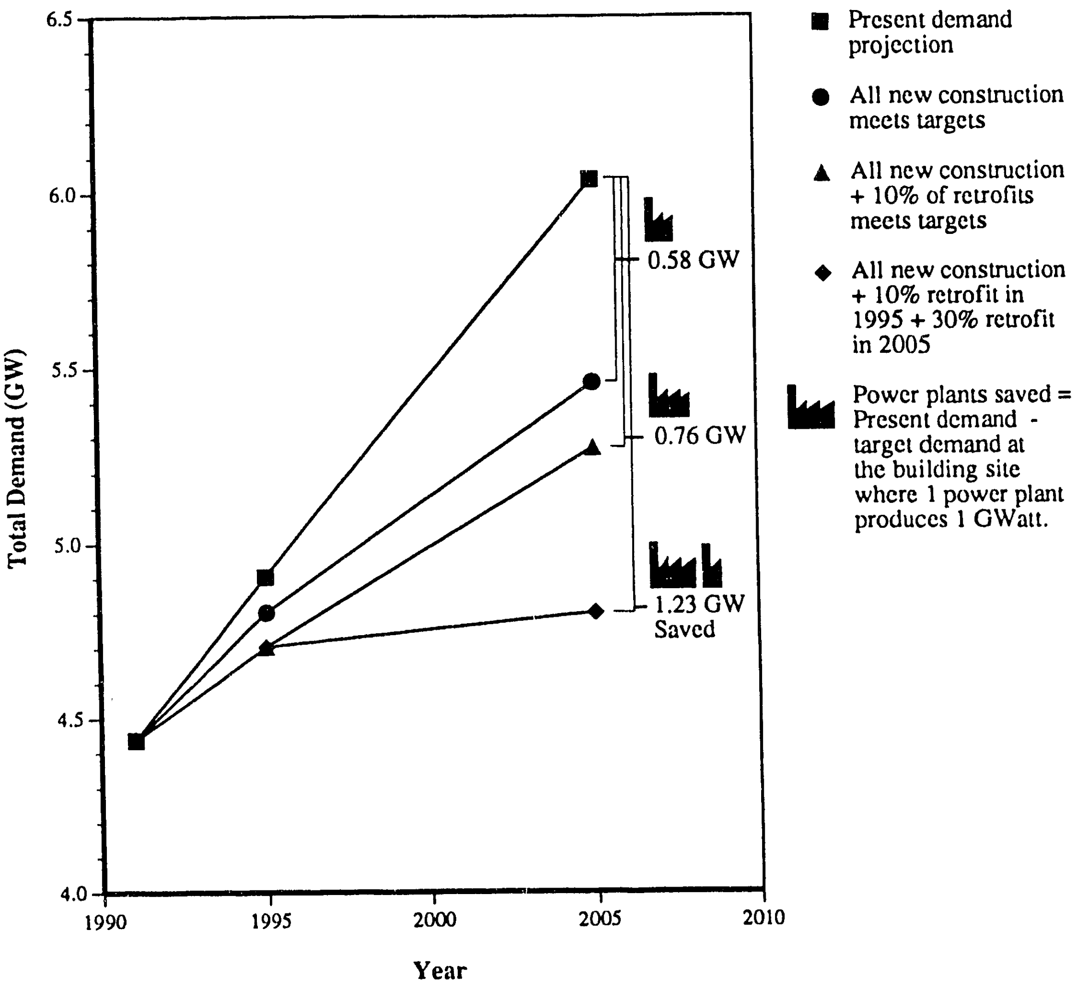


Figure 4.6: Total demand reduction for commercial office buildings in the state of California due to lighting and building envelope performance targets for 1995 and 2005.

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