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End-Use Load and Consumer Assessment Program:

Comparison of ELCAP Data with Lighting and Equipment Load Levels and Profiles Assumed in Regional Models

Z. T. Taylor
R. G. Pratt

September 1990

Prepared for
the Bonneville Power Administration
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Pacific Northwest Laboratory
Richland, Washington 99352

SUMMARY

Pacific Northwest Laboratory performed an analysis that compared the lighting and equipment load profiles observed in office and retail buildings monitored by the End-Use Load and Consumer Assessment Program (ELCAP) with the assumed load profiles used as input to regional planning models. The study was done in cooperation with the Bonneville Power Administration for the Northwest Power Planning Council.

Many regional power planning activities are based on energy consumption estimates obtained by computer simulation of several representative prototype buildings. Estimates of lighting and equipment capacities and use schedules are inputs to the engineering model; space heating and cooling consumption are the outputs. It has been postulated that a discrepancy between the planning models' output and observed commercial sector loads in the region is attributable to faulty inputs to the model.

The work reported here tested that hypothesis by examining the lighting and equipment loads in the ELCAP offices and retails and comparing the typical observed capacities and load shapes with those assumed in the models. The inputs to several modeled prototypes, including large, small, new (built post-1980), and existing offices and retails, are presented for comparison. However, the most meaningful comparisons are between the ELCAP buildings and the small prototypes because no large offices or retails were monitored by ELCAP.

The ELCAP lighting and equipment loads were decomposed such that several features could be characterized and averaged across buildings: 1) the apparent installed capacity of lighting and equipment, 2) the general shape of the hourly lighting and equipment load profiles, 3) the distribution of various load shapes by day of week, and 4) the lighting and equipment energy consumption that would be calculated by the engineering models if given the

ELCAP capacities and load shapes as input. The last of these is the most important in comparing the ELCAP loads with modeling assumptions.

Ascertaining the actual installed capacities in the ELCAP buildings was problematic, and the resulting tallies are somewhat difficult to interpret for several reasons. First, the site inspections in which connected capacities were collected occurred several years prior to the analysis and the resulting data have not been updated since. Second, the inspections collected only nominal lamp wattages, excluding capacities of fluorescent ballasts. Finally, lighting loads measured by ELCAP are occasionally contaminated with miscellaneous equipment loads that are connected to a building's lighting circuits.

Nonetheless, several generalizations are possible. ELCAP lighting capacities appear to be slightly higher than those assumed in the engineering models, while retail capacities appear to be slightly lower. The impacts of these discrepancies are minimal, as indicated by very similar average daytime load levels for the modelled prototypes and the ELCAP buildings. Equipment capacities, however, differ by a greater amount. For both office and retail buildings, the ELCAP equipment capacities appear to be several times higher than assumed in the models.

To extract average lighting and equipment load profiles from the ELCAP buildings, we developed an averaging methodology that preserves a number of profile characteristics considered important for comparison with the engineering model inputs. This includes 1) the typical hour of morning start-up, 2) the typical length of a workday, 3) the fraction of lights or equipment left on during unoccupied hours, 4) the number of days each building operated in full-workday mode, partial-workday mode, and minimal-workday mode, and 5) the character of load transitions between unoccupied and occupied periods.

By integrating the average ELCAP lighting and equipment load profiles over a typical operating year, we calculated the annual energy consumption that would be estimated by the engineering models. We found that ELCAP office lighting energy consumption generally exceeds that of the modeled prototypes primarily because of higher nighttime load fractions, a larger number of full workdays each year, and slightly longer operating hours. ELCAP office equipment energies are also higher, due largely to higher installed capacities. ELCAP retail lighting energy consumption is lower than that of the modeled prototypes because of lower nighttime load fractions and slightly shorter typical workdays. ELCAP retail equipment energies are higher than the modeled estimates, again because of higher installed equipment capacities.

Another objective of the analysis was to observe the real effect of the 1980 Seattle Energy Code on the energy consumption of the ELCAP buildings. This assessment was based on the estimated annual energy consumption calculated for the previous comparisons. We found that New (post-1980) offices use about 27% less energy for lighting than do Existing offices. This seems to indicate that the newer buildings do implement higher levels of conservation, especially since it was observed that the New offices operate in full workday mode for a larger fraction of the year than do the Existing offices. A similar drop in lighting and equipment consumption was observed in the ELCAP New retails.

ACKNOWLEDGMENTS

The analysis documented herein was conducted for the Bonneville Power Administration, Office of Energy Resources and the Northwest Power Planning Council by the Pacific Northwest Laboratory (PNL). This report reflects a team effort involving close collaboration between Bonneville, the Council, and PNL.

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Section 1

INTRODUCTION

For some time, forecasting staff from both the Bonneville Power Administration (Bonneville) and the Northwest Power Planning Council (the Council) have observed that the commercial sector loads are increasing faster than predicted. Two fundamental components of the commercial forecast are involved in this discrepancy: 1) the rate of growth in floor space in each building type of the commercial sector and 2) the magnitude of the end-use load intensities (EUIs, expressed in terms of kilowatt-hours per year per square foot [kWh/yr-ft^2]). Because estimates of floor area are available for the period from 1980 through 1986 and because more energy-efficient building components and equipment are known to be in use since the Model Conservation Standards (MCS) were imposed (Northwest Power Planning Council 1986), the discrepancy has been postulated to result from a change in the level of "service" being provided in commercial buildings.

A change in service level can result from any one of several factors. First, the total installed capacity of various types of equipment may exceed previous estimates. For example, because space in new buildings tends to be expensive to rent, tenants may increase the density of workers, resulting in a corresponding increase in small equipment such as task lights, typewriters, and personal computers. Second, the hours of operation may exceed those assumed in building prototype simulations of energy performance. Third, the intensity of use may exceed that assumed in a forecasting model. For example, the actual levels of lighting in unoccupied buildings might be substantially higher than those assumed.

To identify the potential source of the discrepancy between observed loads and the forecast, Pacific Northwest Laboratory (PNL)[a] researchers analyzed the EUIs for lighting and equipment in commercial buildings. They compared the EUIs derived from actual measurements of end-use consumption with those assumed in the computer-simulated prototypes used in the forecasting process, to test the following hypothesis: that an *amenity factor*, reflecting increased consumption for lighting, equipment, and ventilation, above the levels in the prototypes, is responsible for the divergence, in new and/or existing buildings.

The lighting and equipment end uses can be considered (along with ventilation) as amenities in commercial buildings, because increased consumption generally results in increased comfort, habitability, hours of operation, or utility of the building for the conduct of business by the occupants. Although maximum installed lighting capacity is prescribed for new construction by building energy standards, the occupants may choose to add task lighting or to retrofit alternative lighting systems in their space, making lighting levels (and hence energy consumption) a behavioral *choice*. For convenience, the term *amenity* as used here encompasses the lighting end use as well as other equipment that is subject to occupant control.

OBJECTIVES

This analysis was driven by two primary objectives:

- to determine whether and to what extent the lighting and miscellaneous equipment electricity consumption measured by metering in real buildings differs from the levels assumed in the various prototypes used in power forecasting

- to determine the reasons for those differences if, in fact, differences were found.

(a) The Pacific Northwest Laboratory is operated for the U.S. Department of Energy (DOE) by Battelle Memorial Institute (BMI) under Contract DE-AC06-76RLO 1830

BACKGROUND

As a baseline, forecasters use estimates of the existing regional floor space from 1980 through 1986 obtained from the Pacific Northwest Nonresidential Energy Survey (PNNonRES; Bonneville Power Administration and ADM Associates, Inc. 1989). Growth rates for regional floor space are based on regional indicators such as building permits, new service hookups, and Dodge construction data, and on forecasts of economic activity by business type.

The initial EUI estimates in the forecast for existing buildings (in 1979) are based on existing assessments of end-use load shares, resolved with historical billing records and floor space estimates. Growth in these loads with time is based on estimates of economic activity and extant knowledge about the efficiency of new buildings and equipment, although this is often a subjective criterion.

Much of the understanding of the performance of new buildings comes from computer simulations of prototypical buildings built to comply with various standards. In particular, ten prototypes representing existing commercial buildings are used to represent the region when developing conservation resource estimates (see, for example, United Industries Corporation 1987a). Some of these prototypes have been modified to reflect actual metered loads from a few commercial buildings in the End-Use Load and Consumer Assessment Program (ELCAP) sample.

New commercial buildings are mandated to have low lighting power levels resulting from the use of high-efficiency fixtures. However, task lighting can be installed by the occupants and is essentially unregulated. It also has been postulated that the penetration of personal computers is driving up equipment loads, especially in offices (Norford et al. 1988). These effects may cause equipment loads in older buildings and lighting loads in newer buildings to be higher than expected.

The process of *tuning* the building simulations to the metered data involves developing equipment and lighting load profiles as input data for the simulations. These are thus presumed to reasonably approximate the non-heating/ventilating/air conditioning (HVAC) loads in the existing buildings of the commercial sector.

For new construction, changes in efficiency due to the implementation of standards and improved technology must be assumed. Four relevant energy standards are applicable to commercial buildings in the Bonneville region:

- the Oregon and Washington commercial energy codes, which have been deemed equivalent to the Council's Model Conservation Standards (MCS) for the commercial sector (Northwest Power Planning Council 1986)

- the ANSI/ASHRAE/IES Standard 90A-1980, which, with the addition of lower limits on lighting levels, forms the basis of the MCS (American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. 1980)

- the Major Projects Requirements adopted by the City of Seattle for large buildings, which require consumption levels 10% below the MCS (City of Seattle 1984)

- ASHRAE/IES Standard 90.1-1989 (ASHRAE 1989) being adopted by the U.S. Department of Energy (DOE) as its Commercial Building Interim Standards which, when formally adopted, will become a revision to the existing ASHRAE standard.

The Council has recently revised the Model Conservation Standards (Northwest Power Planning Council 1989). Evaluation of all of these standards is based on DOE-2 simulations describing the theoretical performance of various sizes and types of prototypical commercial buildings.

The floor space data obtained through PNNonRES are considered generally more reliable than the EUI estimates, and are therefore less suspect as a source of the divergence between the forecast and actual commercial sector consumption. A key assumption in the forecast is that new buildings in the region are designed, constructed, and operated to have EUI levels that correspond to the MCS. Because this has been observed to not be the case, it has been postulated that an *amenity factor* reflecting increased consumption above the prototype assumptions for lighting, equipment (plug loads), and ventilation may be responsible, in new and/or existing buildings. Thus, this analysis was undertaken to test the degree to which the ELCAP data support or refute this hypothesis, and to quantify the effect (if it is found) in a means that can be incorporated in the commercial forecast.

Commercial building energy standards are the fundamental delivery mechanism for conservation in the commercial sector. In the current climate of power surplus, they are also the primary near-term resource acquisition program for the commercial sector, due to the penalty of lost opportunities. Thus, an important secondary purpose of this analysis was to shed light on the expected impact of commercial building standards on non-HVAC loads by separately estimating amenity factors for new and existing buildings.

REPORT ORGANIZATION

Our key findings based on the results we obtained are presented and discussed in Section 2. Section 3 provides an overview of the analysis; there we describe the scope and the research questions we addressed. In Section 4, we document the methodology we used. The analysis results are presented in Section 5 in both narrative and graphical form.

Section 2

KEY FINDINGS

This section delineates the major findings of this analysis, although it is by no means a comprehensive list of pertinent observations. The section is divided into three parts: 1) observations related to installed capacities of lighting and equipment, 2) observations related to annual energy consumption inferred from capacities, usage profiles, and day type distributions, and 3) observations comparing new and existing ELCAP buildings.

This study has examined the lighting and equipment loads of office and retail buildings as observed in the ELCAP commercial buildings and assumed in several prototype simulations. Because the primary impetus for this work was the observation of discrepancies between actual loads and those predicted by the Northwest regional forecast, the findings listed here relate only to the prototypes that pertain to that forecast--those developed by United Industries Corporation (UIC 1987a,b; 1988a,b). In addition, because the ELCAP offices and retails include no very large buildings, the primary comparisons are made between the ELCAP buildings and the corresponding small UIC prototypes.

INSTALLED CAPACITIES

Lighting

The average installed capacities for the various building types and prototypes are summarized in Table 2-1. Office lighting capacities on dedicated circuits are at or below the levels assumed in the various prototype simulations. When task lighting and lighting on mixed circuits are considered, the capacities exceed the simulation assumptions for both Existing and New buildings. However, the average daytime lighting loads in the ELCAP buildings are very close to those assumed in the UIC Small prototypes. In retails, the

TABLE 2-1

Summary of Installed Lighting Capacities, W/ft²

	Installed[(a)] (Dedicated)	Installed[(b)] (Anywhere)	Observed Peak	Average Daytime Load
Office				
ELCAP Existing	1.93	2.78	2.29	1.93
ELCAP New	2.02	2.47	1.69	1.35
ELCAP New Alternate[(c)]	2.42	2.50	2.02	1.62
UIC Small Existing	2.20	NA	NA	1.87
UIC Small New	2.20	NA	NA	1.87
UIC Large Existing	2.38	NA	NA	2.02
UIC Large New	2.19	NA	NA	1.86
ASHRAE Small New	2.72	NA	NA	2.42
Retail				
ELCAP Existing	1.42	1.50	1.90	1.50
ELCAP New [(d)]	1.96	1.70	1.52	1.16
UIC Small Existing	1.93	NA	NA	1.35
UIC Small New	2.10	NA	NA	1.47
UIC Large Existing	2.78	NA	NA	2.36
UIC Large New	2.52	NA	NA	2.14
ASHRAE Small New	1.95	NA	NA	1.75

(a) Small amounts of miscellaneous equipment may be included on these circuits.

(b) Because fluorescent lighting ballast capacities were not collected in the ELCAP equipment surveys, the reported averages are likely about 7% low for offices and 4% low for retails. See Section 5 for details.

(c) These averages are for the sample of New ELCAP offices exclusive of two buildings that have 24-hour operating schedules.

(d) The lighting on dedicated circuits exceeds the total lighting anywhere because dedicated lighting circuits power some miscellaneous equipment circuits (wall plugs) in some buildings. The capacity of connected miscellaneous equipment is known (see Figure 5-1), but was not subtracted here because the observed peak and average daytime loads will reflect the presence of that equipment.

total installed lighting capacities are considerably below the model assumptions. Again, however, average daytime load levels are very close to those assumed in the Small prototypes.

Contrary to expectations, the installed lighting capacities of ELCAP New retail buildings are higher than those of the Existing buildings. However, both the peak observed loads and average daytime loads indicate that New retails use less lighting than Existing.

Equipment

For both office and retail buildings, installed capacities of miscellaneous equipment greatly exceed the assumptions in the UIC prototypes. The differences are apparent in Table 2-2. Although the effect of this discrepancy is partially mitigated by the higher assumed operating load

TABLE 2-2

Summary of Installed Equipment Capacities, W/ft^2

	Installed (Surveyed)	Observed Peak	Average Daytime Load
Office			
ELCAP Existing	6.65	1.84	0.81
ELCAP New	5.38	1.25	0.65
UIC Small Existing	2.00	NA	0.40
UIC Small New	2.00	NA	0.40
UIC Large Existing	1.94	NA	0.39
UIC Large New	1.94	NA	0.39
ASHRAE Small New	0.75	NA	0.67
Retail			
ELCAP Existing	4.50	1.36	0.50
ELCAP New	5.57	1.13	0.30
UIC Small Existing	1.50	NA	0.18
UIC Small New	1.50	NA	0.18
UIC Large Existing	1.10	NA	0.19
UIC Large New	1.10	NA	0.19
ASHRAE Small New	0.25	NA	0.23

fraction of the UIC prototypes, the surveyed capacity in ELCAP buildings is generally about three times the UIC assumption. In fact, the observed hourly peak equipment load in ELCAP buildings is roughly equivalent to the assumed total capacity in the UIC prototypes.

ESTIMATED ANNUAL ENERGY CONSUMPTION

This analysis derived average lighting and equipment load profiles for the various types and classes of building. By integrating those load profiles over a typical operating year, estimates of annual lighting and equipment consumption were obtained for comparison with similar estimates for the modeled prototypes. The primary discrepancies between estimated energy consumption in the UIC prototypes and in the ELCAP buildings are summarized in Table 2-3.

TABLE 2-3

Summary of Primary Observations

	Office	Retail
Lighting	• ELCAP Existing consumption exceeds UIC Small by 50%. • ELCAP New consumption exceeds UIC Small by 6% to 10%.	• ELCAP Existing consumption is 12% less than UIC Small. • ELCAP New consumption is 52% less than UIC Small. • ELCAP New consumption is 41% less than ELCAP Existing.
Equipment	• ELCAP Existing consumption exceeds UIC Small by 100%. • ELCAP New consumption exceeds UIC Small by 55%. • ELCAP New buildings consume 22% less energy than Existing.	• ELCAP Existing consumption exceeds UIC Small by 147%. • ELCAP New consumption exceeds UIC Small by 45%.

Table 2-3 shows that the UIC Small prototypes generally underpredict both lighting and equipment energy consumption relative to the loads implied by the ELCAP profiles. The only exception is lighting in retail buildings, where the UIC prototype estimates exceed those observed in the ELCAP buildings.

OFFICE

Lighting

ELCAP lighting energies are higher than those of the UIC Small prototypes primarily because of higher nighttime load fractions, a larger number of full workdays each year, and slightly longer operating hours. The UIC prototypes assume a night usage of about 10% of daytime usage, while the ELCAP buildings show levels of 25% to 40%. In contrast, the UIC large prototypes, which have nighttime load fractions exceeding those of ELCAP, have correspondingly higher energy consumption.

Equipment

ELCAP equipment energies are higher than those of the UIC Small prototypes primarily because of greater installed capacities. ELCAP capacities appear to be about three times those assumed in the UIC prototypes. This difference is partially countered by higher UIC daytime load fractions (20% for UIC compared to 12% for ELCAP). The ELCAP Existing buildings' workdays appear to be about one hour longer than those of the ELCAP New or the UIC prototypes.

RETAIL

Lighting

ELCAP consumption is lower than that of the UIC prototypes for two primary reasons. First, the unoccupied (nighttime) load fractions are 20% to 30% lower than those of the UIC prototypes. Second, the length of the typical workday appears to be shorter in the ELCAP buildings, particularly in the New (although the New sample is very small--three buildings).

Equipment

ELCAP retail buildings have higher equipment loads, primarily because installed capacities are higher than those assumed in the UIC prototypes. Based on building surveys, rated equipment capacities are at least three times the levels assumed by UIC. Daytime usage fractions evident in the ELCAP data are lower than those assumed by UIC, but not low enough to counter the difference in installed capacity. Peak hourly equipment loads observed in the ELCAP data are almost equivalent to the assumed capacities in the UIC prototypes--actually greater than in the large prototypes.

DIFFERENCES BETWEEN NEW AND EXISTING STRUCTURES

A primary objective of this analysis was to reveal the effect of the 1980 Seattle Energy Code on the buildings in the ELCAP sample. The following were observed:

- ELCAP New offices exhibit full workdays for a larger fraction of the year than do Existing offices.
- ELCAP New offices exhibit much higher nighttime lighting load fractions than do Existing offices. However, this discrepancy disappears when two buildings with 24-hour operation are removed from the analysis.
- ELCAP New offices use about 27% less energy for lighting than do Existing offices. If the two 24-hour buildings are removed from the analysis, the difference is about 30%.
- There is a decrease in energy consumption of about 40% between Existing and New retail buildings for both lighting and miscellaneous equipment.

Section 3

ANALYSIS OVERVIEW

The scope of this analysis is limited to non-HVAC loads, for two fundamental reasons. First, it is proposed that lighting and equipment loads are amenities subject to occupant need and preference. Actual loads can differ from predictions not only because of inaccurate engineering estimates of conservation measure performance, but also because of actions on the part of building occupants. Second, the analysis of HVAC loads is far more complicated, since all internal heat generated by the non-HVAC loads is supplemented and/or removed by the operation of HVAC system, and because the HVAC systems are complicated and reflect a wide range of design, installation, and operating characteristics. Consequently, this initial investigation is focused on the non-HVAC loads, because they must be analyzed prior to any detailed analysis of HVAC loads anyway.

Ventilation air also has an amenity value in commercial buildings. Increasing ventilation flow rates can produce a more pleasant environment in which to work or shop. While ventilation rates are not measured in ELCAP, the electricity consumption for ventilation is metered and could be compared with assumptions in the existing building and energy standards prototypes as indicators of increased ventilation rates. This was considered for inclusion in the scope of this effort, but was rejected. We judged that energy consumption for ventilation is an unreliable proxy for ventilation flow rates, given the diversity in fan sizes and duct friction losses resulting from the variation in HVAC system types, duct sizes, and duct run lengths. This issue is better retained for later analysis as part of an HVAC analysis task that would include the lighting and equipment load internal gain impacts on HVAC loads.

The analysis was applied to only the office and retail building types (8 New and 8 Existing office sites, and 3 New and 13 Existing retail sites from the Commercial Base sample), instead of all the building types available in ELCAP. This reduction in scope is principally a cost-saving measure. The combination of small sample sizes in the other types and lack of comparability with the building prototypes used to develop the Standard 90A-1980 (ASHRAE 1980) makes analyzing other building types of only marginal value.

The analysis scope includes applying a methodology to provide class average load profiles for *hat-like* load profiles for lighting and equipment end uses, but not other generally random end-use loads such as hot water. The new and existing buildings are analyzed separately.

The resulting class average load profiles are compared with those assumed for the class of buildings in three different building prototype simulations:

- the regional prototypes for existing buildings
- the current MCS assumptions for new buildings
- the ASHRAE 90A-1980 current practice assumptions for existing buildings.

In addition, the New and Existing class average load profiles from the metered data will also be compared as an indicator of the likely impact of the MCS standards.

Five aspects of the class load profiles will be compared with the prototype assumptions, where possible:

- the integral of the load profile (the energy consumption)
- the average occupied (i.e., daytime) power level
- the average unoccupied (i.e., nighttime) power level
- the number of equivalent *fully occupied* hours
- the installed capacity.

Section 4

METHODOLOGY

Lighting and equipment loads are input to regional planning models as a combination of installed capacities and use schedules. For example, the installed lighting capacity of a building might be 3 watts per square foot of floor space, meaning that 3 W/ft^2 would be consumed when all the lights in that building were turned on. A corresponding schedule of lighting usage fractions is simultaneously entered into the planning model so that the model can calculate the lighting load for any given day and hour.

To achieve the objectives of this analysis, we needed to compare the lighting and equipment loads from the sample of ELCAP buildings with the assumptions and inputs used in the regional planning models. Thus, the methodology we chose had to enable us to express or represent the loads from the metered buildings in a format directly comparable to that used by the planning models.

In this section, we document the methodology we used. First, we describe the hat-shaped profile and its characteristics specific to this analysis. Next, we discuss how we imposed day type definitions onto the metered data to achieve even closer comparability. Finally, we explain the steps we used to average the hat-shaped load profiles of lighting and equipment end uses so that we could directly compare the metered data with planning model inputs and test our hypotheses.

THE HAT-SHAPED PROFILE

Because actual regional lighting and equipment loads differ from those predicted by the planning models, it is desired to identify the reasons for the discrepancy. There are several possibilities:

- The installed lighting and/or equipment capacities in actual buildings might differ from the capacities assumed in the models. For example, although maximum permissible lighting capacities are stipulated in the current Seattle Energy Code (City of Seattle 1984), the building occupants might actually be supplementing the originally installed lighting base.

- The actual levels of use during occupied and/or unoccupied periods might differ from the usage levels assumed in the models. For example, building occupants might not turn off lights at night with the same regularity assumed in the models.

- The hours of building operation might differ from those assumed in the models.

- The number of days during which actual buildings are occupied and used might differ from those assumed in the models. For example, are office buildings typically occupied on weekends? What fraction of retail stores are open for business on Sundays?

Figure 4-1 shows a workday use schedule typical of commercial buildings. The plotted asterisks correspond to the fractions of the installed capacity operating during the various hours shown on the X axis. In this case, about 30% of the lights are assumed to be on at night, while virtually all are on during the day. In the mornings and evenings are transition periods between the two levels. This hat-shaped load profile is typical of most lighting and equipment end uses, for which building operating schedules are the primary determinant of energy consumption.

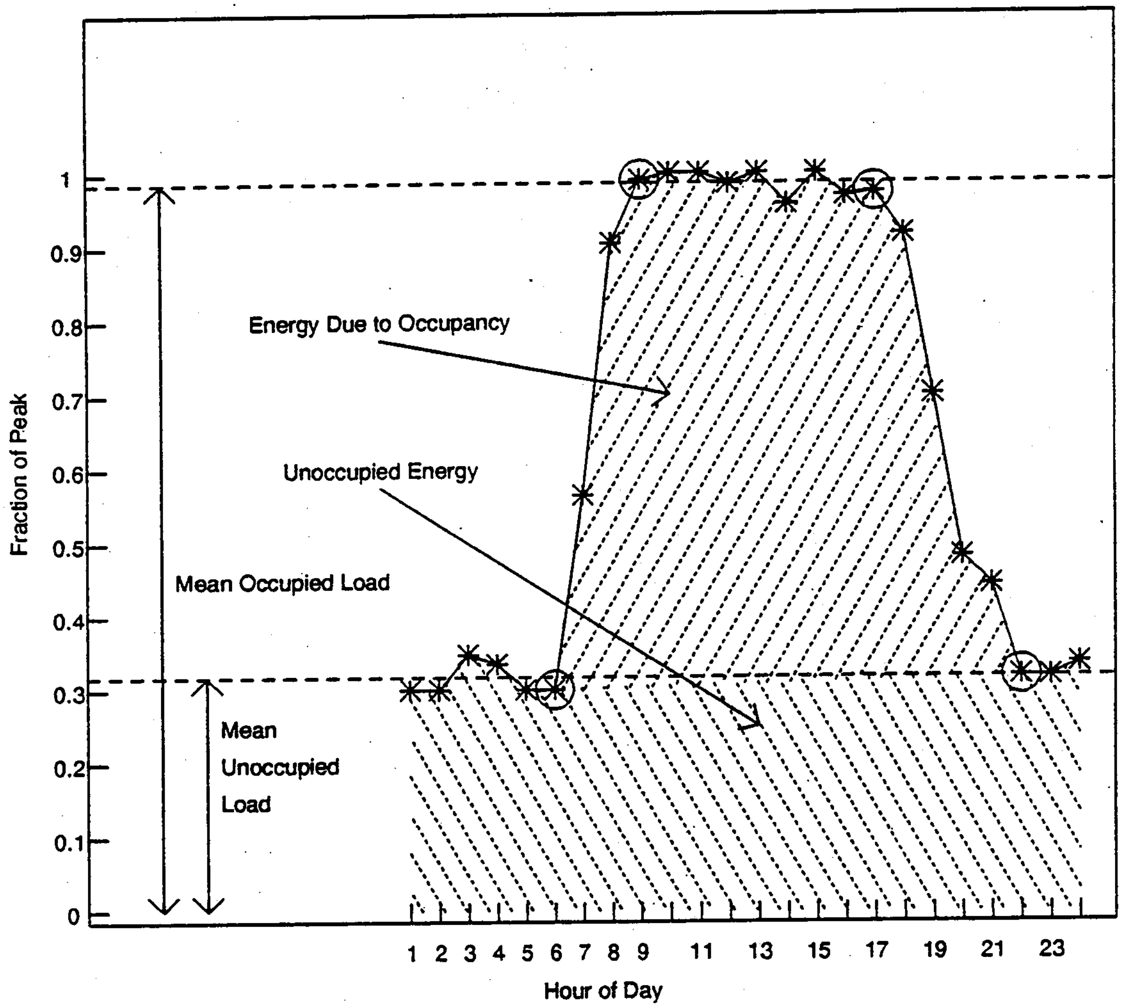
To facilitate comparisons between the profiles observed in the metered data and those assumed in regional planning models, several characteristics of a hat-shaped profile are defined. These characteristics are as follows:

- Transition hours are the hours at which the building begins to transition from one operating regime (portion of the hat) to another. For example, the transition hours circled in Figure 4-1 show that the last unoccupied hour is 6:00 a.m. This hour marks the beginning of the morning warm-up transition period, which lasts until 9:00 a.m. The fully-occupied condition persists until 5:00 p.m., after which a ramp-down transition begins.

- The mean occupied load is the average power consumed during hours of occupancy. In Figure 4-1, the average occupied load is almost 100% of the installed capacity.

FIGURE 4-1

Characteristics of a Hat-Shaped Profile



- The mean unoccupied load is the average power consumed during unoccupied periods. In Figure 4-1, the nighttime load is shown to be slightly over 30% of the installed capacity.

- The energy due to occupancy is the daily energy consumption that is directly attributable to building occupancy and use. It is proportional to the area under the top part of the "hat" in the profile (see the top shaded region in Figure 4-1).

- The unoccupied energy is the energy that would be consumed in a day if there were no occupancy or use of the building. For example, the bottom shaded region in Figure 4-1 shows that about 30% of the lights are on when the building is not being used. Summing 30% usage over 24 hours gives the unoccupied energy.

DAY-TYPE DEFINITIONS

By segregating lighting and equipment loads into installed capacities and usage schedules as described above, comparisons can easily be drawn between the metered loads and the assumed loads of the planning models. However, a second dimension not shown in Figure 4-1 is the day-of-week use schedule. Typically, an hourly usage profile such as that in Figure 4-1 will apply only to workdays. A different profile will apply to weekends and/or holidays when the building is not used.

The regional planning models assume that there are three distinct day types for offices and retails: 1) weekdays, 2) Saturdays, and 3) Sundays and holidays. Further, the models assume that the operating hours and usage levels for each of the three day types differ from each other, a reasonable presumption for the population of buildings as a whole. However, this assumption is clearly not accurate for all individual buildings. Some retail stores, for example, have identical operating hours seven days a week. The variety of operating schedules complicates a direct comparison of model assumptions with metered data from the ELCAP sample.

To allow such a direct comparison, we coerced the observed profiles in the ELCAP data to fit the assumed three day types. That is, we categorized each day during which data were collected for a building as either a full workday (corresponding to the modeled weekdays), a partial workday (corresponding to the modeled Saturdays), or a minimal workday (corresponding to the modeled Sundays and holidays).

To promote a meaningful and fair comparison, we tailored the day-type definitions to best match the model assumptions. The definitions we used are presented in Table 4-1.

TABLE 4-1

Day-Type Definitions

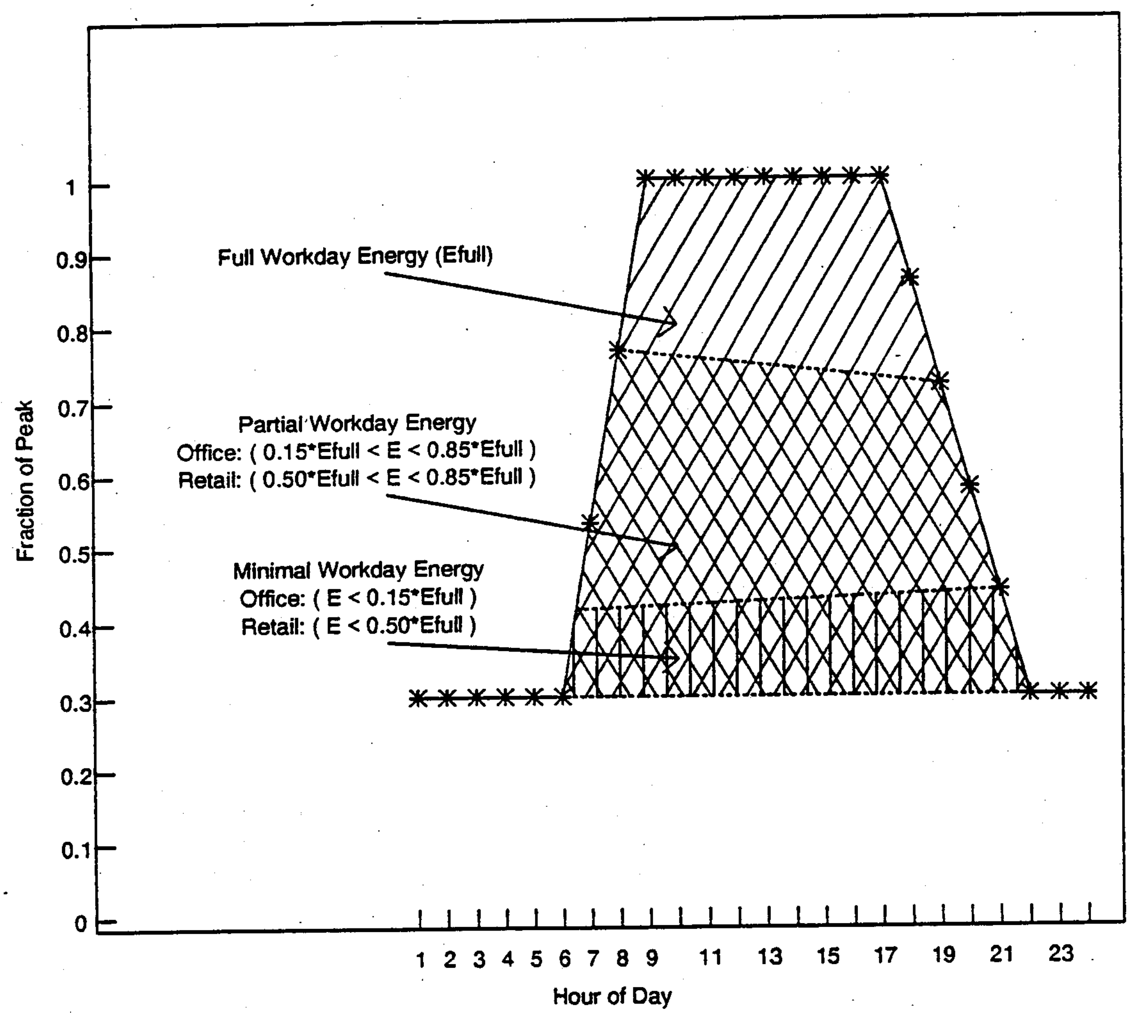
Day Type	Office Definition	Retail Definition
1 Full Workdays	The day type with the highest energy consumption	The day type with the highest energy consumption
2 Partial Workdays	Days with occupied energy consumption less than 85% of full workdays, but more than 15% of full workdays (generally week-ends or holidays when a fraction of the work force is present)	Days with occupied energy consumption less than 85% of full workdays, but more than 50% of full workdays (generally week-ends or other days when the store is open for business, but with reduced operating hours)
3 Minimal Workdays	Days with occupied energy consumption less than 15% of full workdays (generally Sundays or holidays when virtually nobody works)	Days with occupied energy consumption less than 50% of full workdays (generally days with very few or no hours open for business)

The somewhat fuzzy difference between a full workday and a partial or minimal workday can result from two factors. First, the level of use may differ. In an office building, for example, only a few employees might work on Saturdays; thus, the amount of energy consumed for *occupied* lighting will be considerably lower than it is on weekdays, even if those employees work a full 8-hour Saturday. Second, the hours of operation may differ. An obvious example is a retail store that opens on Saturdays with shorter hours than on weekdays. The lights will be on at the same power level, but for fewer hours. In both cases, the result is lower energy consumption due to occupancy.

The differences between day types are illustrated in Figures 4-2 and 4-3. Both figures show a typical full workday profile with partial and minimal workday profiles superimposed. In Figure 4-2, the partial and minimal workdays are results of lower usage levels, while in Figure 4-3 they also include the

FIGURE 4-2

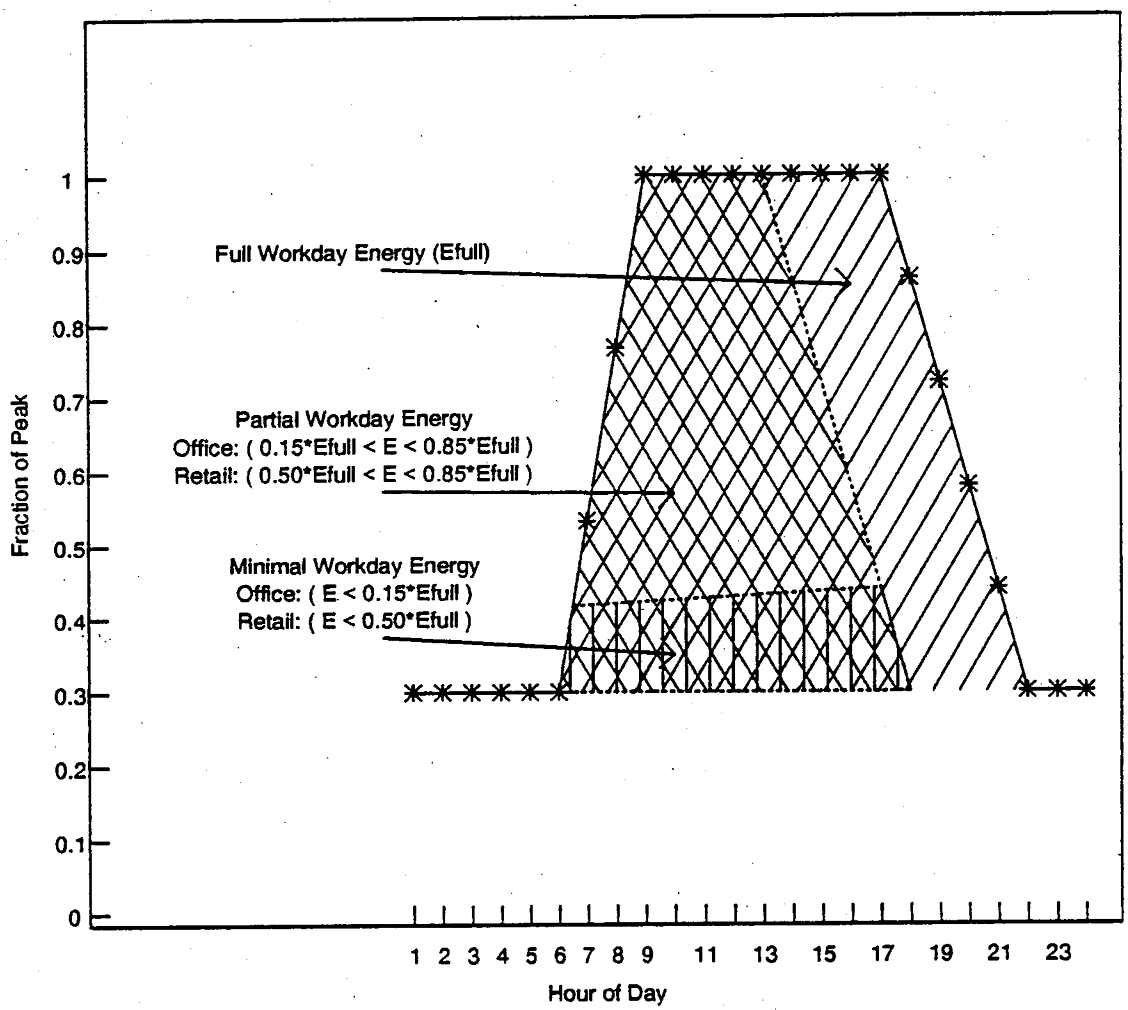
Day-Type Definitions Reflecting Lower Building Usage Levels



effects of shorter working hours. The labels on the figures imply that the day-type definitions are based on the energy consumption due to occupancy, which is proportional to the area under the top part of the hat.

FIGURE 4-3

Day-Type Definitions Reflecting Lower Building Usage Levels and Shorter Working Hours



AVERAGING PROFILES ACROSS SITES

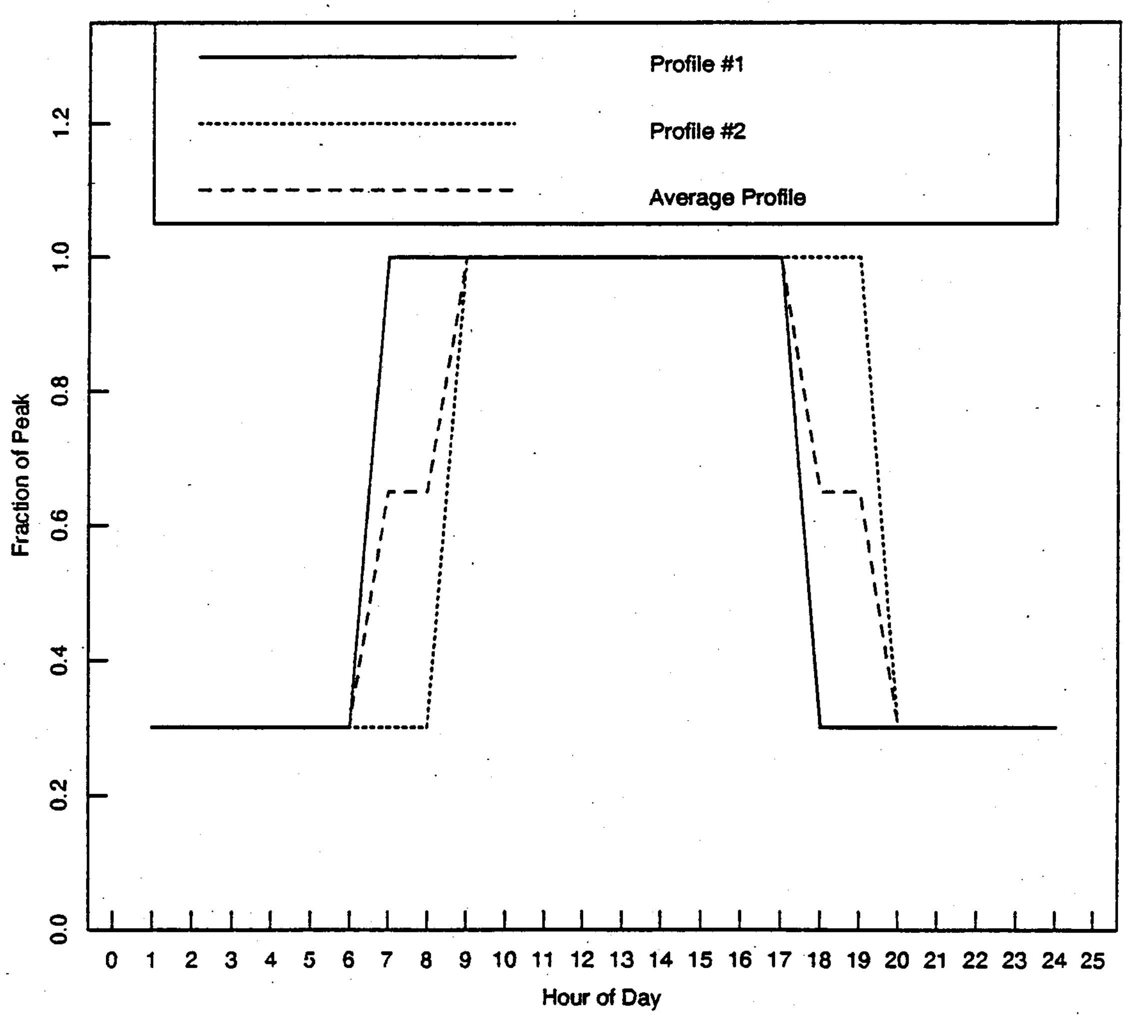
Comparison of planning model assumptions with ELCAP data requires that the profiles for individual sites be consolidated to provide a single profile that is typical or representative of the entire sample. Such a profile allows direct comparison of the various load shape characteristics described in Figure 4-1.

The simplest approach to obtaining a single representative profile is to average the loads for all metered sites at each hour of the day. This process results in a profile that accurately captures the class average energy consumption (area under the profile). However, because of the multiplicity of operating hours in commercial buildings, simple averaging does not accurately capture the typical load shape.

Figure 4-4 illustrates the problem. Two profiles are shown representing two hypothetical sites. Both sites have identical operating schedules except that

FIGURE 4-4

Distinction Resulting from Simple Profile Averaging



one starts and ends its workday 2 hours later than the other. As shown, the simple average differs substantially from either of the two individual profiles; the morning and evening transition periods are longer than they should be.

To avoid the distortion associated with simple averaging of profiles, we used a technique that preserves the important characteristics of each site's profile in the averaging process. The characteristics that are preserved are those described in Figure 4-1: 1) the time between the four transition hours (see circled points on Figure 4-1); 2) the mean occupied load level; 3) the mean unoccupied load level; and 4) the shape of the profile between each pair of transition hours. If these four characteristics are preserved, the energies consumed during occupied and unoccupied periods will also be preserved because they are defined as simple areas under portions of the profile.

The averaging procedure is illustrated in Figures 4-5 and 4-6. Figure 4-5 shows the processes applied to each individual site's end-use data in preparation for the cross-site averaging. Three steps are shown:

1. Segregate each site's data into three day types - Each day for which data are available is classified as either a full workday, a partial workday, or a minimal workday according to the definitions in Table 4-1. Each day type is then processed separately. Prior to categorizing days, each site's data are examined to identify and eliminate any vacant periods or other periods of unusual operation.

2. Average each day type's data across days - The product of this step is a single 24-hour profile for each day type, which represents the average end-use load shape.

3. Normalize each 24-hour profile by its peak and calculate profile characteristics - Dividing each hourly load by the peak hourly load in the profile scales the loads to a maximum value of 1.0, allowing direct comparison of profiles from buildings of differing size. Then, the transition hours and associated load levels are identified and average occupied and unoccupied load levels are calculated.

FIGURE 4-5

Data Flow Diagram for Processing Individual Sites and End Uses

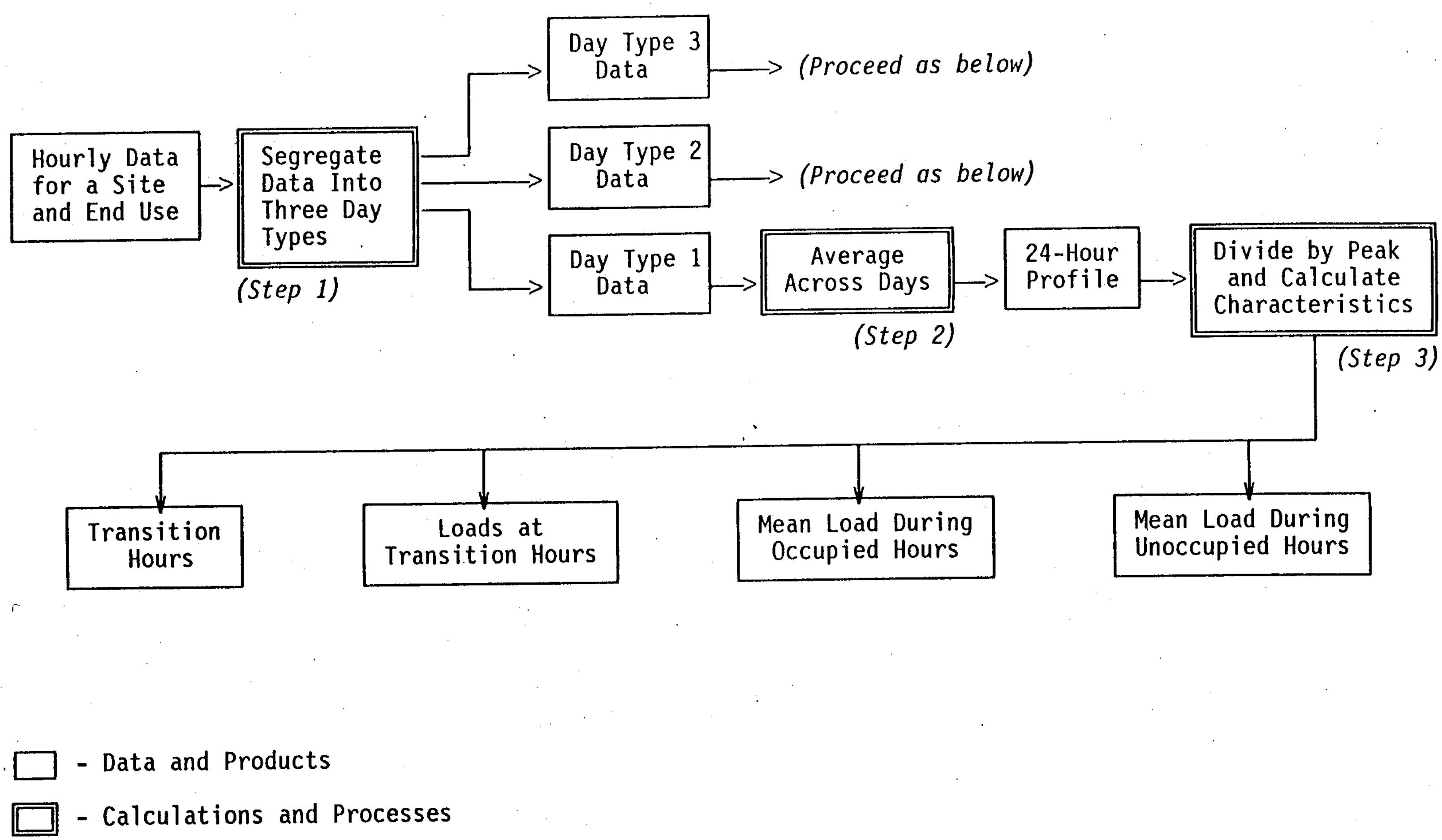


Figure 4-6 shows the process applied after all individual sites, end uses, and day types have been processed. Two major steps are shown, which are described below:

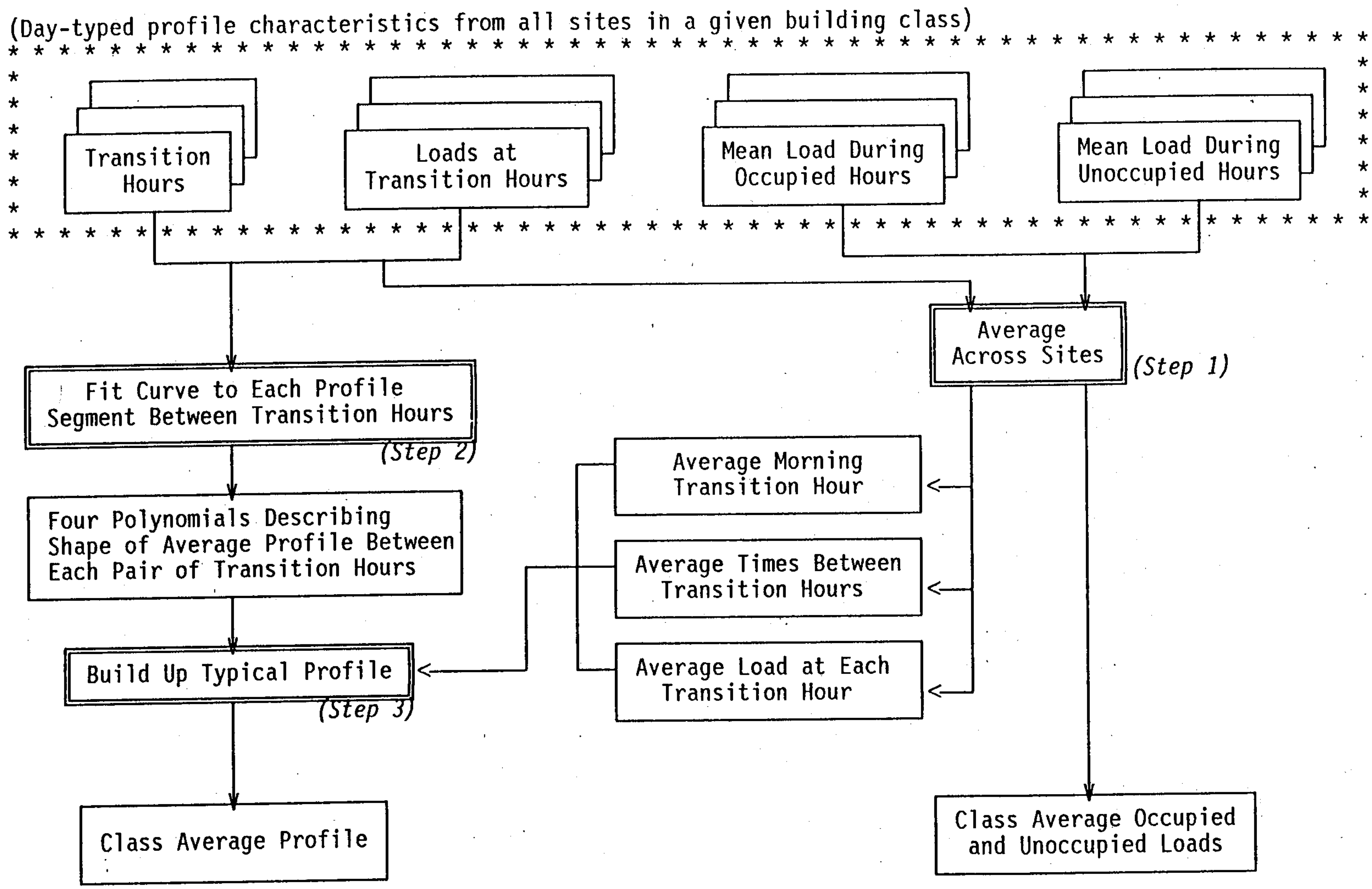
1. Average profile characteristics across sites - The results of this step are 1) the average hour of morning startup, 2) the average number of hours between each pair of adjacent transition hours, 3) the average load at each transition hour (NOT at the average transition hour), and 4) the average loads during occupied and unoccupied hours. The last of these are end results used in direct comparisons with modeling assumptions. The first three are intermediate results that are used later in Step 3.

2. Fit curves to the profile segments between transition hours - These curves, which are third-order polynomials, will be used to characterize the typical *shape* of a load profile between each pair of transition hours.

3. Build up a typical profile from the results of Steps 2 and 3 - The average startup hour is used to anchor the typical profile. Then, the average times between pairs of adjacent transition hours are used to establish the remaining transition hours. The average loads at each transition hour are used to establish the height of the profile at that hour. Finally, the polynomials are used to draw in the lines between transition hours, ensuring that the resulting profile has the appropriate shape.

FIGURE 4-6

Data Flow Diagram for Averaging End-Use Profiles Across Multiple Sites



Section 5

RESULTS

The results of our comparisons between regional modeling assumptions and the office and retail lighting and equipment metered data are presented in this section. The comparisons involve several aspects of the lighting and equipment loads, including the installed capacities, time of use, levels of use during occupied and unoccupied hours, day-of-week schedules, and the general shapes of the daily load usage curves. When combined, these characteristics form an estimate of annual energy consumption that would be obtained if the profiles and capacities were used as input to an hourly building load model such as that used in regional planning.

For each building type category (office and retail), we examined load information from five different sources: 1) ELCAP sites built prior to the implementation of the 1980 Seattle Energy Code, termed *Existing*; 2) ELCAP sites built subsequent to the 1980 Seattle Energy Code, or *New* sites; 3) the small building prototype used by United Industries Corporation (UIC) in regional modeling activities; 4) the UIC large building prototype; and 5) the small building prototype used in the development and testing of the ASHRAE commercial energy standards.

This section is organized into three main subparts. In the first, we describe the characteristics that we calculated and plotted in graphic form to illustrate our results. We explain what will be shown in each series of graphs contained in the last two parts of the section, which correspond to office and retail buildings. Within each of those two subparts, lighting and equipment loads are discussed separately and illustrated with their appropriate graphics. Additional graphics not specifically commented on in these sections are presented in the appendix of this report.

DESCRIPTION OF THE GRAPHICS

The graphics interspersed with our discussions of office and retail lighting and equipment loads summarize the metered loads and the loads assumed in the regional forecasting models. The characteristics that we plotted are described here, to provide a basis for the illustrated discussions of results to come.

Load Profiles

For each generic building type in the ELCAP sample, and for each prototype building in the regional models, a set of profiles is presented that describes the basic scheduled behavior in the buildings. Each profile is a set of 24 numbers (load ratios) that describe the fraction of lighting or miscellaneous equipment used during each hour of a typical day. All profiles we present in this report are scaled such that the maximum value in the full workday profile is equal to 1.0. They cannot, therefore, be multiplied by the actual installed capacity to obtain building loads. Instead, they must be multiplied by the average daytime peak load, or profile peak capacity, which is easier to identify in real buildings.

Each load profile figure shows the normalized load profiles for a single combination of building type, end use, and day type. One profile is shown for each of the five prototypes. Office lighting plots also have an additional profile for the ELCAP New building type. The "Alternate" curve represents the average of the same buildings as the ELCAP New curve except that two buildings that operate 24 hours per day have been eliminated. Whether 24-hour office schedules are as common as the ELCAP New sample would suggest is unknown, so the second profile is shown for reference.

Estimated Annual Energy Consumption

For each end use and building type, three day-typed profiles are available. The energy consumption can be calculated by multiplying the profile load ratios by the profile peak capacities, and summing according to the number of each day type that occurs in a typical year. This is summarized in Equation (5-1):

$$E_{annual} = \sum_{d=1}^{3} F_{d} * \sum_{h=1}^{24} P_{d,h} * CAP * 365 \qquad (5\text{-}1)$$

where E_{annual} = Estimated annual energy consumption (watt-hours)

d, h = subscripts referencing day type and hour of day respectively

$P_{d,h}$ = the dimensionless profile value (load ratio) for day type d at hour h

CAP = the profile peak capacity of lighting or equipment (W)

F_d = the fraction of days in a typical year that are day-type d

365 = the number of days in a year.

The annual energy consumption estimates (E_{annual}) are computed separately for each ELCAP building, converted to units of kilowatt-hours, and divided by building floor area to allow easy cross-building comparisons, then averaged across buildings to obtain the numbers presented in this report. The estimated annual energy consumption is the foremost characteristic used for comparison in this analysis. If there are substantial differences between ELCAP energies and those resulting from prototype modeling assumptions, then the other load profile characteristics must be examined to explain those differences.

It is important to understand that these annual energy estimates do not correspond directly to the measured energy consumption of the ELCAP buildings. The lighting and equipment profiles for each building were developed from carefully selected subsets of the total database of measured consumption. Periods of vacancy and other periods of anomalous usage were eliminated prior to computing the average profiles. Likewise, for buildings that show radical changes in operating schedule at any point in time, only the dominant (longest) operating regime was included in the profile development process. The energy estimates are meant for comparison with prototype assumptions and should not be interpreted as actual energy measurements during the monitoring period.

One annual energy consumption figure is shown for each combination of building type and end use. Each figure contains two graphs. The top graph is a bar chart showing the annual estimates broken down by day-type shares. Above each bar is the total annual consumption estimate in parentheses and the percentages of that load contributed by each day type. Percentages are stacked in the same order as the stacked bars. The bottom graph in each figure is a box plot of the individual ELCAP building energy estimates that comprise the averages shown above. The data represented by each box have been normalized by their mean value to keep the scales consistent and readable.

Mean Occupied and Unoccupied Power Levels

The load profiles of lighting and miscellaneous equipment tend to be hat-shaped, meaning that there are relatively constant load levels during occupied and unoccupied periods with relatively sharp transitions between. The mean occupied load is simply the average power consumption during the occupied period, which usually represents typical daytime working hours. Likewise, the mean unoccupied load levels describe the amount of power typically drawn during unoccupied (e.g., nighttime) hours.

Each figure showing the occupied and unoccupied power levels for all combinations of building type, end use, and day type has two graphs. On top is a bar chart showing the occupied and unoccupied power levels for all prototypes. Beneath this chart is a box plot of the individual site loads that comprise the ELCAP averages above.

Equivalent Full-Workday Hours of Occupancy

This metric is akin to the estimated annual energy consumption, but relates to a single, day-typed profile rather than the integral of all applicable profiles over a full year. It is thus useful for examining the characterizations of individual day types in the regional load models, to obtain a sense of whether occupancy representations are too high or low.

The equivalent hours of occupancy are defined in terms of the area underneath the "top" portion of a hat-shaped profile. By dividing this area by the difference between occupied and unoccupied load levels, an estimate of the effective length of the work day is obtained. The occupied/unoccupied load difference for the full workday is used as the divisor for all day types, so that the equivalent hours for all day types can be related to the full work day. Therefore, although the units of this metric are hours, they represent full workday hours and can be interpreted as the length of the workday only for the full-occupancy day type.

The equivalent full-workday occupied hours are shown for each combination of building type and end use. The top graph in each figure is a bar chart with a set of three bars, representing the three day types, for each prototype. Beneath the bar chart is a box plot of the individual site data that comprise the ELCAP averages.

Annual Day-Type Fractions

To allow comparisons of day-of-week schedule assumptions, the fractions of a typical year attributable to full work days, partial work days, and minimal work days are shown for each building type and prototype. Each bar in the top graph shows the distribution of the three day types throughout a typical year. Beneath the bar chart is a box plot of the individual site data that comprise the ELCAP averages.

Installed Capacities

By the most literal definition, the installed capacity is the amount of actual lighting or miscellaneous equipment installed in a building, expressed in watts (or kilowatts). The regional planning model assumptions specify these as capacity densities, or the amount of equipment capacity per square foot of floor space (watts/square foot), and this convention is adopted for the presentations of ELCAP capacities.

For ease of cross-building comparisons, this study also employs a less literal definition of capacity, referred to as the profile peak capacity or profile peak load. This is simply the "active" capacity (watts/square foot) corresponding to the peak value in the full-workday profile. Because all profiles shown in this report are scaled to a maximum value of 1.0, the profile peak load represents the maximum power a building uses on a typical day. The profile peak capacity is generally expected to be smaller than the actual capacity and can never be larger.

Unfortunately, the exact installed capacities in the ELCAP buildings are difficult to determine for several reasons. First, the site surveys were conducted several years ago and are possibly out of date if building owners have since made modifications. Second, the lighting loads measured in ELCAP include only those lighting fixtures that are powered by dedicated circuits in the building's electrical system. Thus, the actual installed lighting capacity may differ from the capacity that is monitored. This discrepancy is usually small, but is significant in some buildings with extensive "task" lighting that is powered by wall outlets. Finally, the capacity data obtained from the ELCAP surveys include no accounting for fluorescent lighting ballasts.

The absence of ballast capacities in the ELCAP survey data is particularly problematic. Most standard ballasts will consume close to 20% of the energy consumed by the attached fluorescent tubes. However, some newer ballasts may use as little as one-half this much energy. State-of-the-art solid-state ballasts are even more efficient, using as little as 5% to 7% of the tube consumption. Although capacity data were collected separately for each type of lighting, the data are not complete enough to allow an exact breakdown for each building, complicating any attempt to apply a ballast *multiplier*.

Based on the available data, fluorescent lighting appears to comprise about 38% of the total installed capacity in ELCAP offices and 22% in retails, although these percentages differ widely from building to building. Assuming that the ballasts in the ELCAP sample consume an average of 20% of the installed tube capacity, the average installed capacities reported here could be low by roughly 7% for offices and 4% for retails.

Because of the uncertainties in the ELCAP lighting capacities, several different measures of the installed lighting are given in this report. These are defined as follows:

Total Capacity on ILT. Based on the site survey, this is the total electrical capacity of all circuits that are metered as interior lighting. *ILT* is the ELCAP end-use designation for interior lighting. This value may contain small amounts of miscellaneous equipment loads, such as ceiling-mounted ventilators or plug circuits, that are powered by the building's lighting circuit. The value does not include the capacity of task lights powered by plug circuits or other mixed channels. Capacities of fluorescent lighting include only the nominal wattage of the lamps. (No ballast factor has been applied.) The total capacity on ILT corresponds directly to the loads that produced the profiles in this analysis.

Lighting on ILT. Based on the site survey, this is the amount of lighting capacity on the circuit(s) measured as pure lighting (ILT). It is obtained by subtracting any miscellaneous capacity from the total capacity on ILT. Because it excludes any miscellaneous equipment that might be on the lighting circuit, it does not correspond exactly to the loads used to produce the profiles in this report.

Lighting Anywhere. This is the total lighting capacity recorded in the building survey, regardless of whether or not it is powered by a dedicated circuit (and, hence, included in the metered lighting loads). Because it includes the additional capacity of task lighting and other lighting fixtures powered by plug or miscellaneous circuits, it does not correspond exactly to the loads used to produce the profiles in this report.

Hourly Peak. This is the peak load observed in the metered lighting data. If at any time during the metering period all the lights were on for a full hour, this should correspond to the installed ILT capacity (subject to the caveats regarding other equipment on lighting circuits and ballast factors).

Profile Peak. This is the load corresponding to the peak value of the full-workday load profile. The profile peak, which represents the highest load experiences by a building on a typical day, will often be considerably lower than the hourly peak, which represents the highest load ever experienced. Contrary to a common expectation that commercial buildings' lights are always on at full power every-day, the ELCAP data show considerable variability in the daily peaks. Figure 5-1 shows the distribution of hourly loads from an example building. The building clearly operates in two distinct modes for occupied and unoccupied periods. However, there are several days with hourly loads as much as 16% above the typical daily peak, clearly illustrating a phenomenon observed in most of the ELCAP buildings.

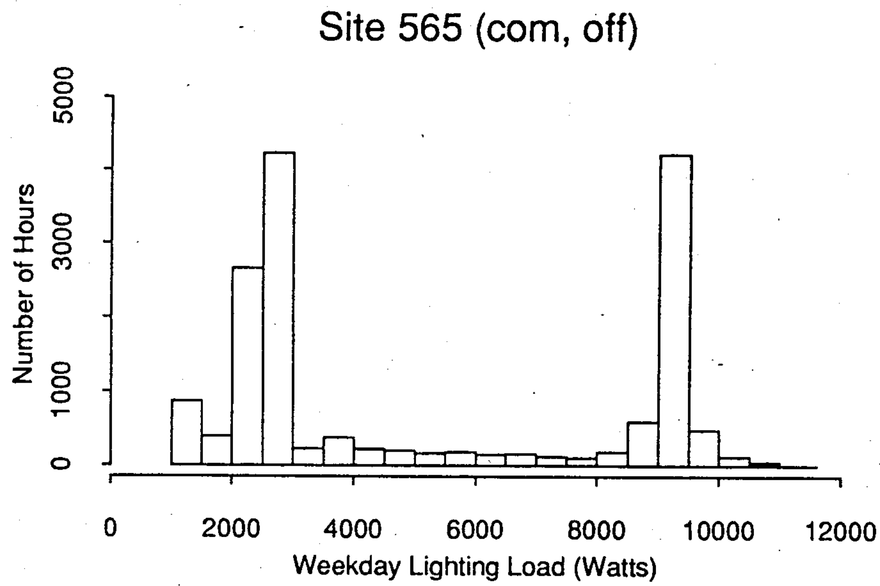
Figures presented in the next two sections show the five measures of lighting capacity for the ELCAP Existing and New building types. The top graph in each figure is a bar chart of the averages. The bottom graph is a box plot of the individual site data.

The uncertainty in lighting capacity also has implications related to the miscellaneous equipment capacity. Because some lighting loads are metered as part of a general mixed end use, the reported equipment capacities may be inflated for some buildings. In addition, some equipment profiles may be based on loads that resulted partially from lighting use.

A similar phenomenon occurs when HVAC loads are indistinguishable from other miscellaneous loads in a building's electrical system. Common examples are window-mounted air conditioning systems that are powered by wall outlets and ceiling-mounted ventilation fans that are powered by wall plug circuits. Therefore, when reviewing the results of this analysis, it is important to remember that reported lighting capacities and loads may be lower and equipment capacities and loads higher than in actuality. Previous analyses have shown that, on an annual energy basis, the average office building has about

FIGURE 5-1

Example Site Showing Occurrences of Hourly Loads
Above the Profile Peak Load



1.24 kWh/ft²-yr of lighting and HVAC (largely ventilation) metered through the miscellaneous circuits. This mixing of loads is more common in Existing offices (1.89 kWh/ft²-yr) than in New offices (0.59 kWh/ft²-yr). Retails show less mixing in both Existing and New buildings, with 0.16 and 0.13 kWh/ft²-yr, respectively.

Figures will compare the ELCAP lighting and equipment capacities with those of the modeled prototypes. The *Observed Peak Load* corresponds to the hourly peak in the surveyed lighting capacity figures, and the *Surveyed Capacity* corresponds to the total on ILT.

The office figures contain an alternative presentation of the ELCAP New buildings that excludes two buildings that operate 24 hours per day. Because the number of new offices in the region that will have 24-hour operations is unknown, the alternative statistics are presented for reference.

A Procedure for Comparing Prototypes

Because of the multidimensional nature of the lighting and equipment load profiles, the relationships that can be examined in comparing ELCAP data with regional model assumptions are numerous. To facilitate comparisons and to enhance the readability of these results, we followed a consistent procedure in making the comparisons. The steps in this procedure are described in the following paragraphs.

Before we examine individual end uses, we look at plots of the day-type fractions to identify differences between ELCAP buildings and the prototypes that would be expected to affect energy consumption of both end uses. For example, the ELCAP office buildings operate in full-workday mode more often than do the UIC prototypes, which would suggest that the ELCAP buildings' energy consumption would be higher, other factors being equal.

For each end use, the profile plots are examined to convey a general understanding of the character of the loads in the building type being examined. Any obvious discrepancies between the ELCAP profiles and the prototype profiles, such as differences in nighttime load levels or workday lengths, are noted.

The plots of estimated annual energy consumption are examined to determine whether there are significant differences between the ELCAP data and the prototype assumptions. The results of this examination direct all steps that follow. If there are substantial differences, the remaining steps serve to identify the reasons for the discrepancies. If not, the remaining steps serve either to confirm that the prototypes are in reasonable agreement with the ELCAP sample or to identify offsetting differences.

The plots of occupied and unoccupied power levels are examined to determine if these explain any differences in energy consumption. Although the power levels are plotted separately for each day type, the full workdays are generally of primary interest because they contribute the most to annual energy consumption.

The plots of equivalent full-workday occupied hours are examined to identify any day-type characterizations that explain differences in energy consumption. The equivalent hours for the full workdays represent literally the average hours of occupancy. For other day types, they represent hours of occupancy if the power levels were the same as for full workdays.

Finally, the installed capacities are examined to identify potential causes of energy consumption discrepancies. Although the installed capacity is one of the most important contributors in the equation that estimates annual energy consumption, it is examined last because of the uncertainties associated with the capacities in ELCAP buildings.

In all cases, the most important comparisons are between ELCAP buildings and the UIC Small prototypes. There are no ELCAP buildings corresponding to the UIC Large prototypes.

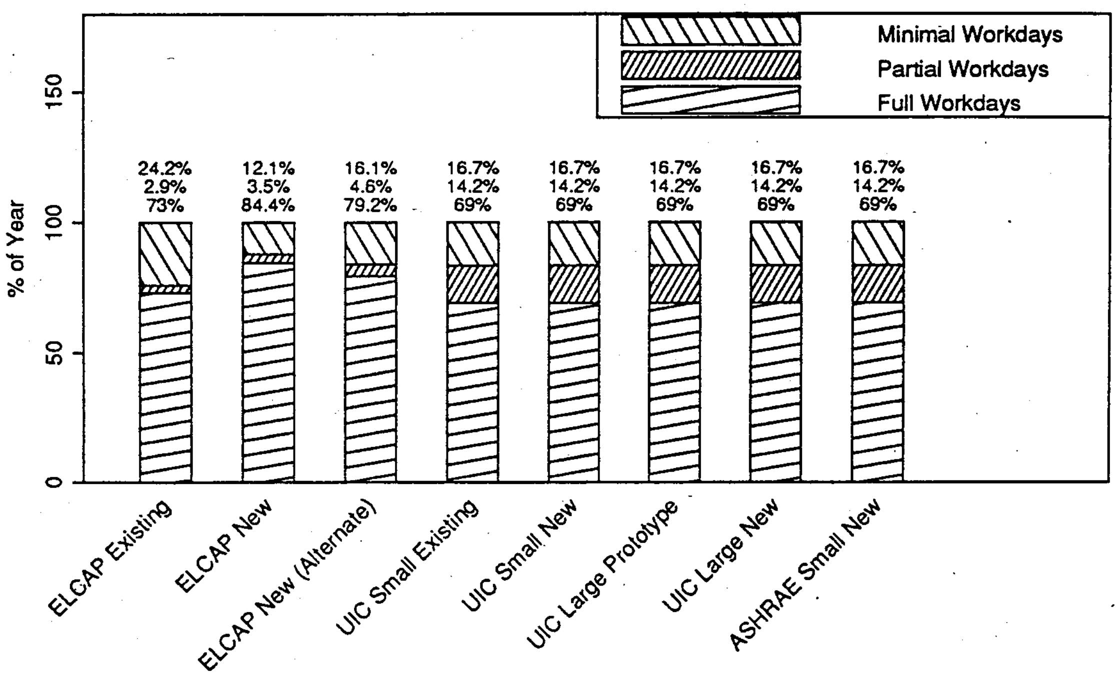
OFFICES

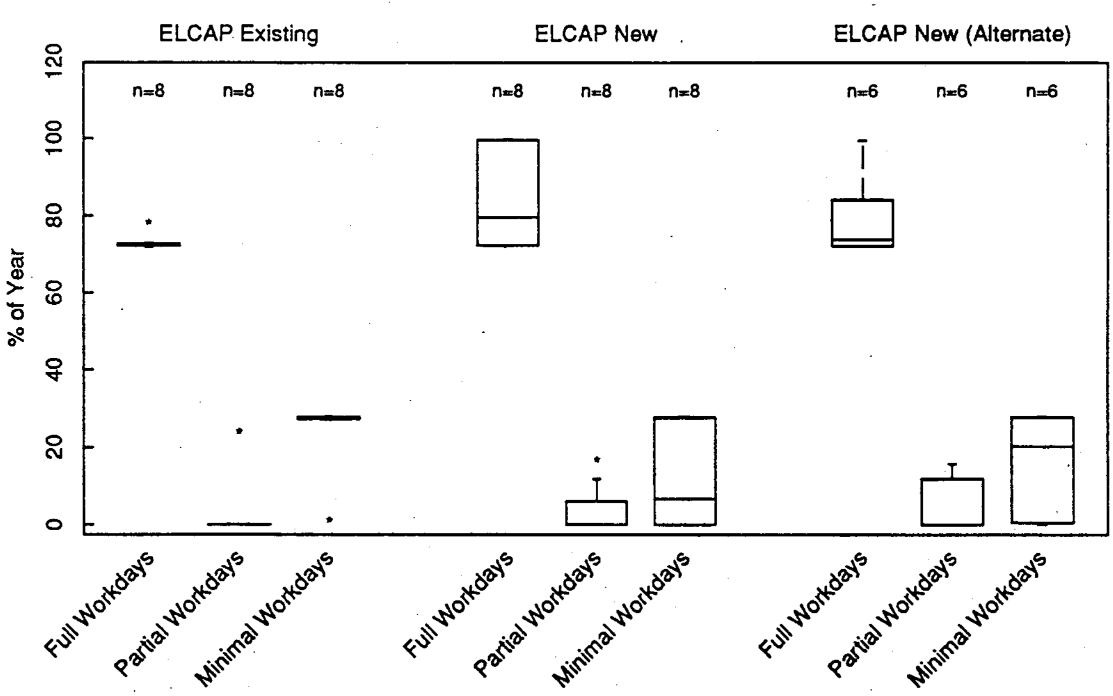
Day-Type Distributions

Figure 5-2 shows the annual distribution of day types for each of the prototypes. The UIC and ASHRAE prototypes base day-type distributions on the occurrences of weekdays for full workdays, Saturdays for partial workdays, and Sundays and holidays for minimal workdays. ELCAP day-type distributions are based on the actual occurrence of the full-, partial-, or minimal-occupancy operating days.

FIGURE 5-2

Day-Type Percentages in Offices





Both ELCAP Existing and ELCAP New buildings show a very small number of partial workdays compared to the prototypes. ELCAP New buildings also show a considerably smaller number of minimal workdays than do the prototypes,although the distinction is considerably less pronounced when the two 24-hour offices are excluded. This would tend to suggest that, all else being equal, the ELCAP New buildings would use more annual energy for both lighting and equipment than would the prototypes.

Lighting Observations

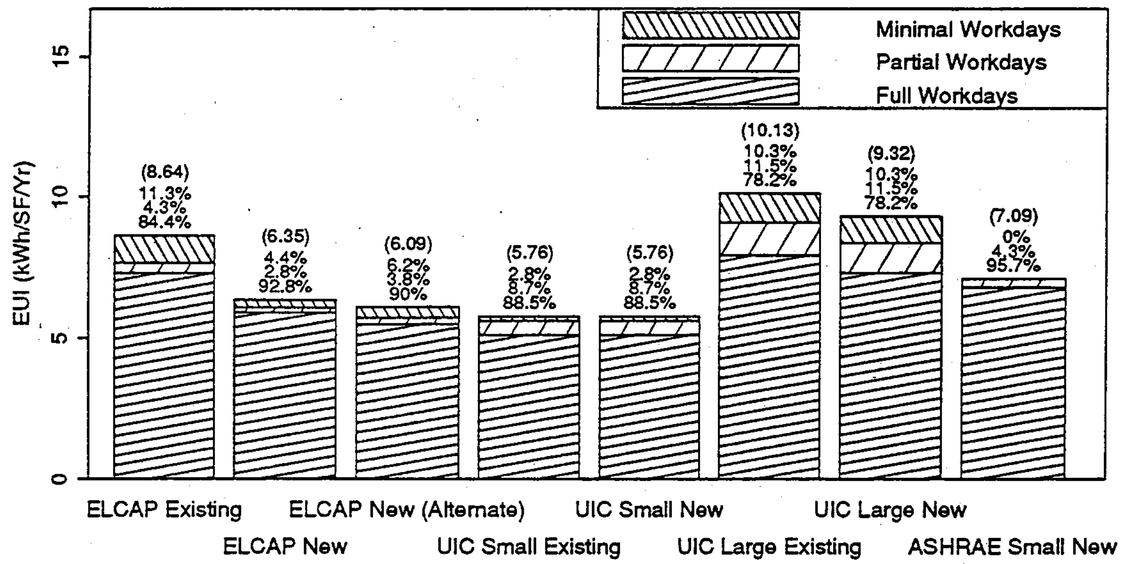
Annual Energy Consumption Differences. Figure 5-3 shows the estimated annual energy consumption for lighting in all office prototypes. The ELCAP Existing buildings show about 50% more consumption than the corresponding UIC prototype, while the ELCAP New buildings average only 6% to 10% higher than the UIC New prototype. In contrast, the UIC Large prototypes exceed the ELCAP buildings in consumption, raising the question of whether size is a significant factor in determining the energy use intensities.

Explanations of Energy Differences. The average load profiles (Figures 5-4 through 5-6) are reasonably similar between ELCAP and UIC prototypes except that the ELCAP transition periods are longer. One potential reason for the observed higher ELCAP loads is that the ELCAP New profile has a much higher unoccupied load fraction during full workdays, a level about equal to that of the UIC Large prototype. However, exclusion of the 24-hour office operations lowers the unoccupied load fraction by about 50%. The nighttime loads are still higher than those of the UIC Small prototype, but not as dramatically.

Overall lighting power levels are lower for ELCAP New buildings than for the corresponding UIC prototype as shown in Figure 5-7. ELCAP New occupied power is about 0.5 W/ft^2 less than that of the UIC New prototype (0.25 W/ft^2 less when 24-hour operations are excluded). The ELCAP Existing occupied level

FIGURE 5-3

Estimated Annual Energy Consumption for Lighting in Offices



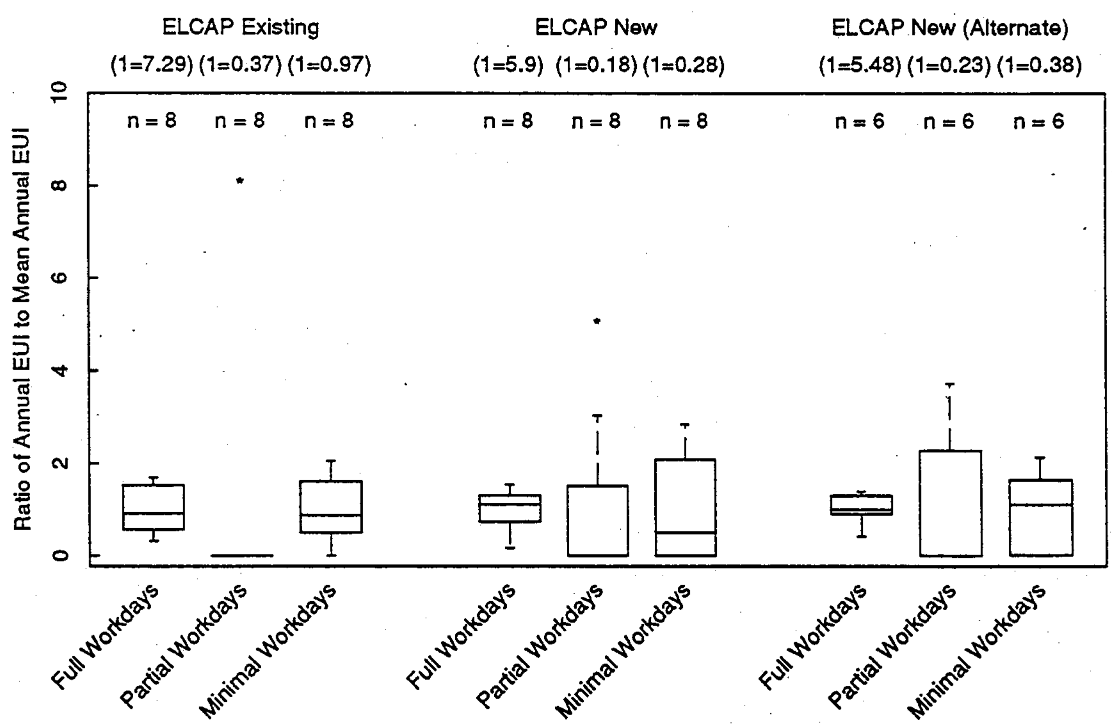


FIGURE 5-4

Full Workday Lighting Profiles for Offices

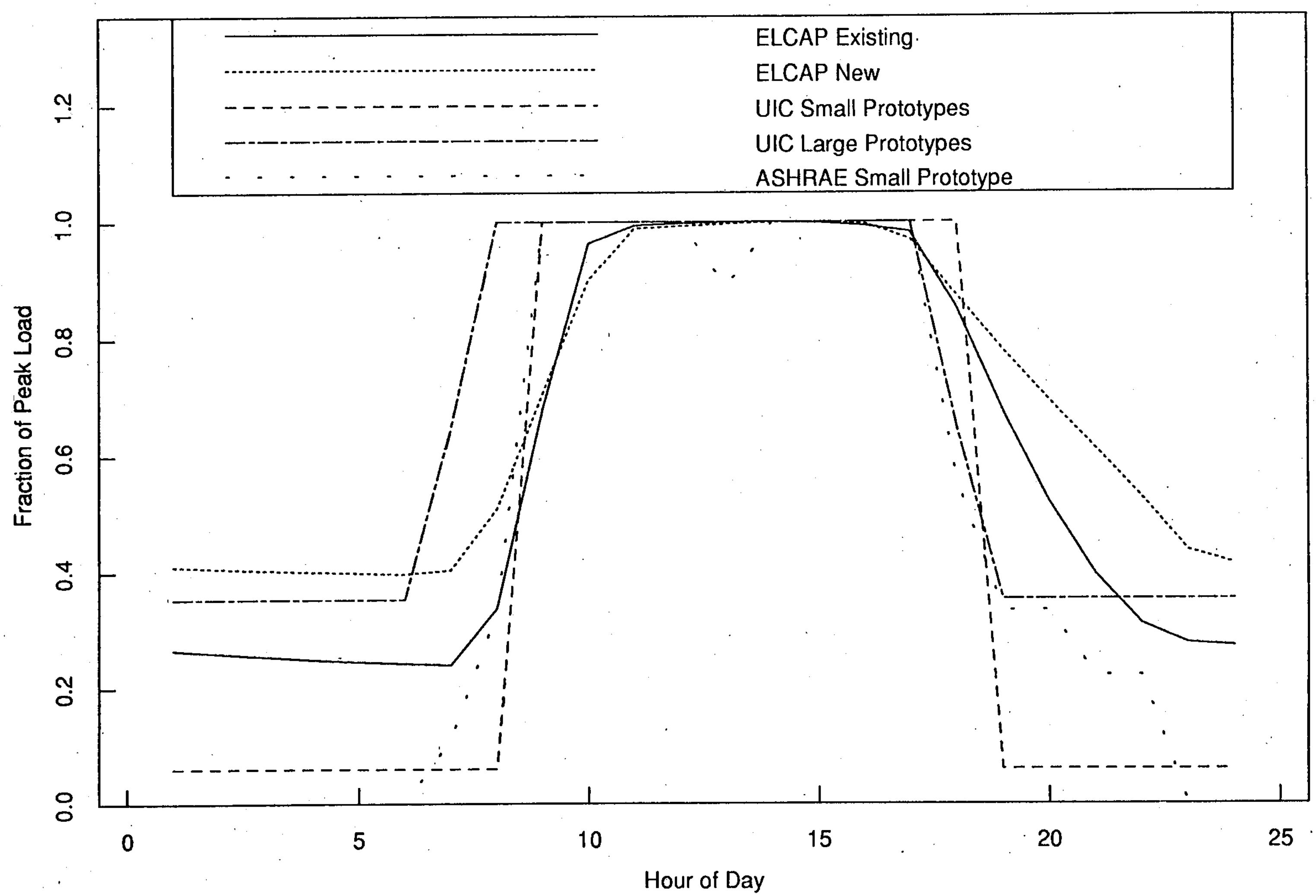


FIGURE 5-5

Partial Workday Lighting Profiles for Offices

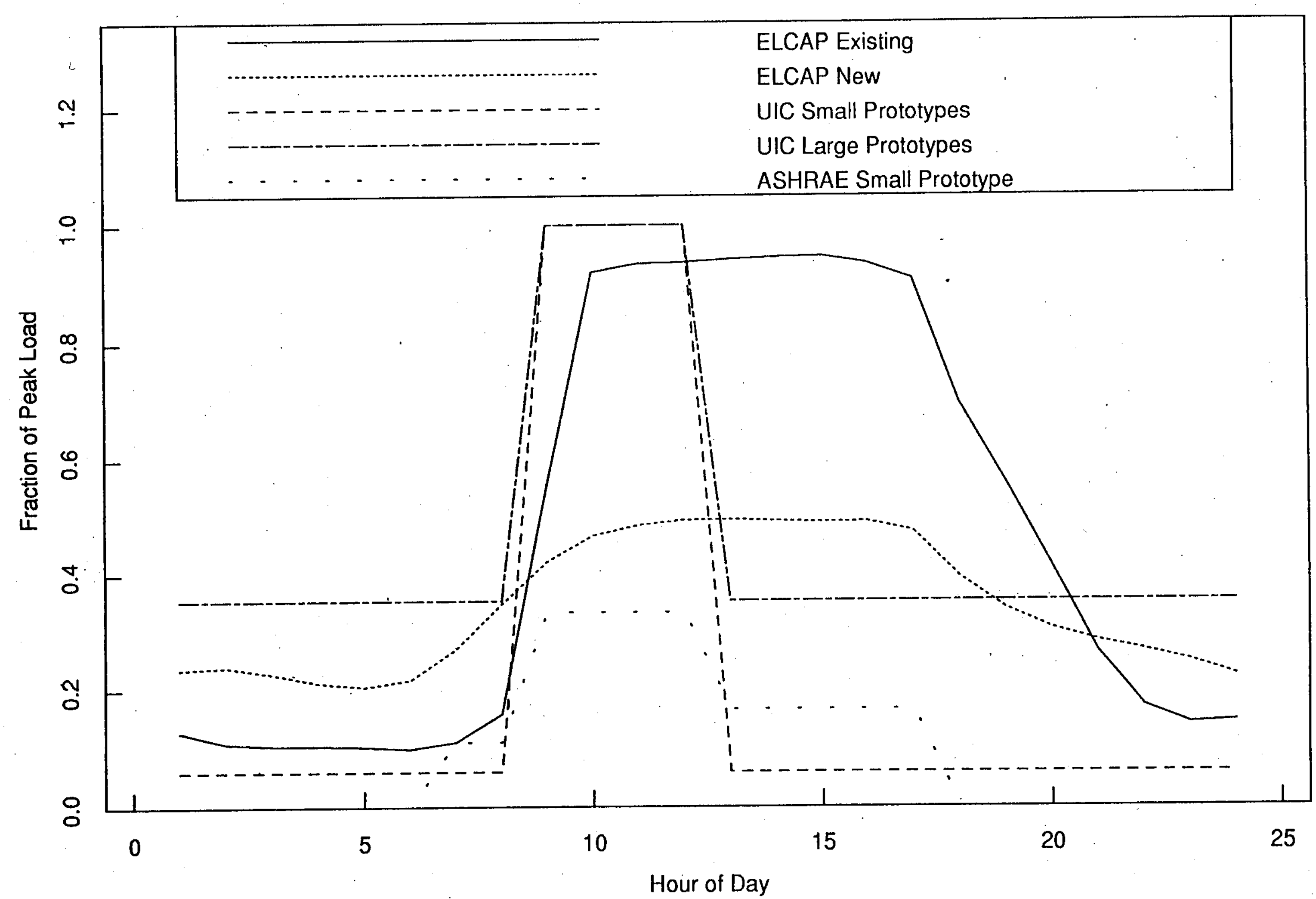


FIGURE 5-6

Minimal Workday Lighting Profiles for Offices

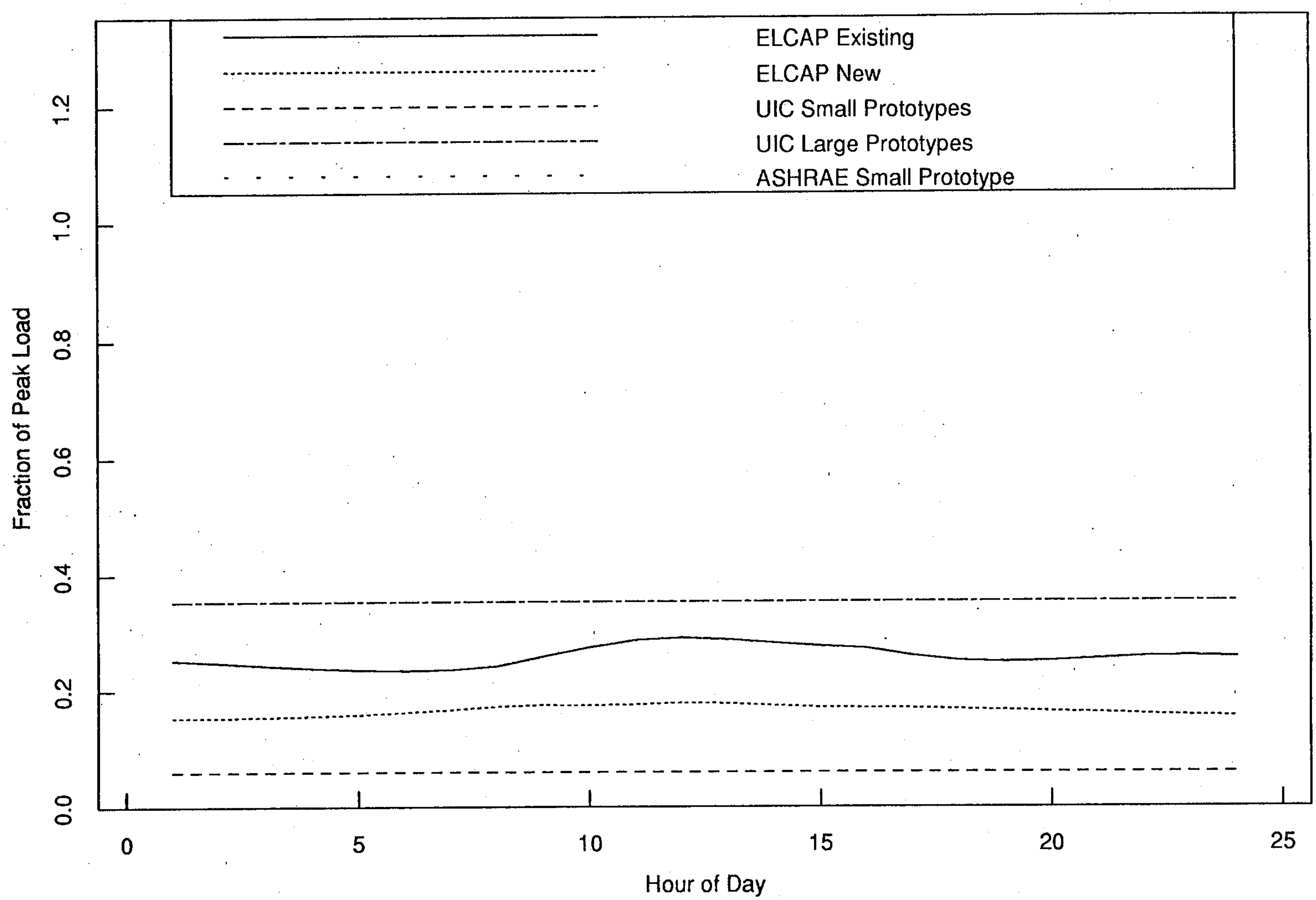
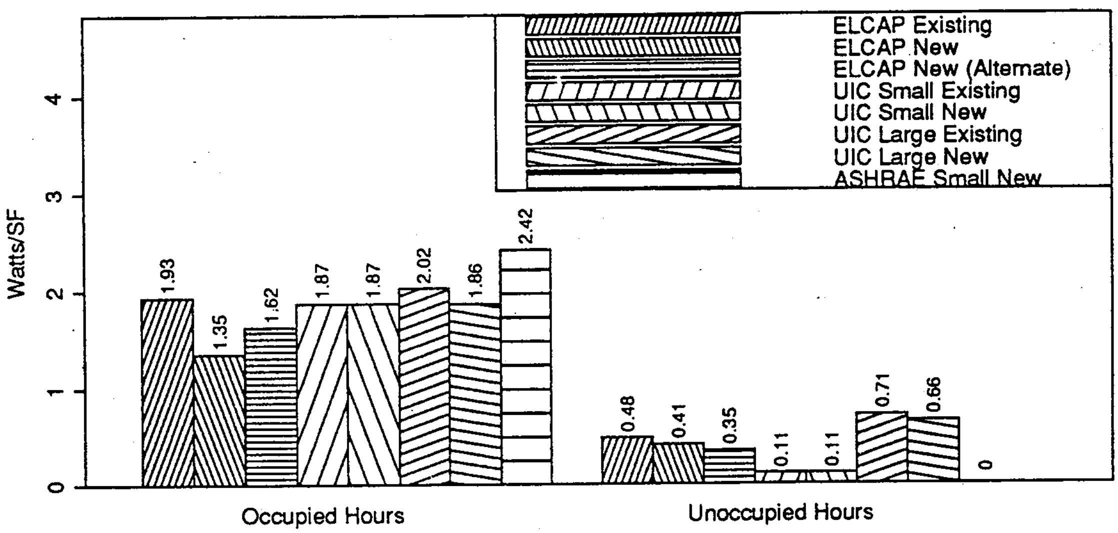
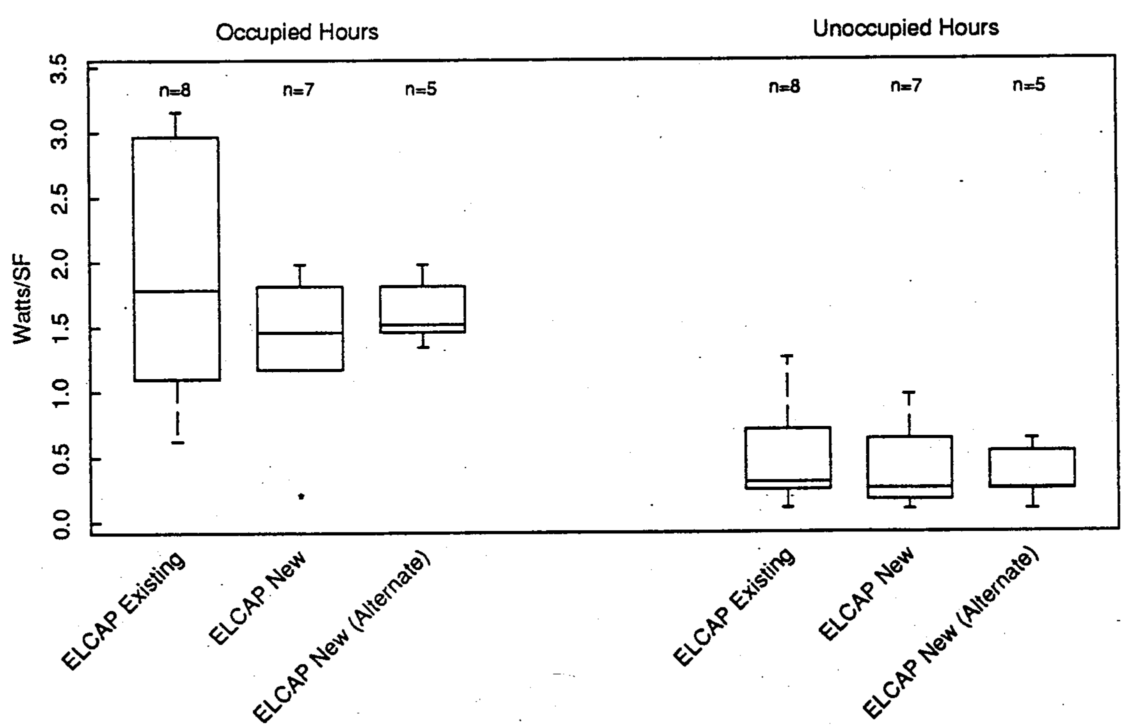


FIGURE 5-7

Mean Occupied and Unoccupied Lighting Power Levels
in Offices - Full Workdays





is almost identical to that of the UIC, which might partially explain why the ELCAP New energy consumption exceeds that of the UIC prototypes by a smaller amount than does the ELCAP Existing.

The equivalent full-workday occupied hours (Figure 5-8) show that the ELCAP New buildings are operated an average of 1.1 hours longer than assumed in the corresponding UIC prototype. ELCAP Existing hours are also longer, but by a smaller amount. The UIC Large prototypes, in contrast, have hours very similar to those of ELCAP.

Equipment Observations

Annual Energy Consumption Differences. As shown in Figure 5-9, ELCAP Existing building equipment consumption exceeds that of the corresponding UIC prototype by 100%. ELCAP New exceeds UIC by about 55%. UIC Large energies are identical to those of the UIC Small. Unexpectedly, ELCAP New buildings use less equipment energy than ELCAP Existing buildings.

Explanations of Energy Differences. It is important to remember that the loads metered as *miscellaneous equipment* in the ELCAP buildings often include some lighting and HVAC loads that were not separable to the metering hardware. This suggests that the estimated loads of Figure 5-9 might be too high. Previous analyses of the actual loads connected to each metered circuit indicated that the miscellaneous end use in ELCAP Existing offices contains an average of 1.89 kWh/ft^2-yr of lighting and HVAC (largely ventilation) loads. For ELCAP New offices, the value is 0.59 kWh/ft^2-yr. If these amounts are subtracted from the loads in Figure 5-9, the ELCAP Existing and New office consumptions exceed those of the UIC prototypes by only 19% and 29%, respectively. While these differences are not as dramatic as those in Figure 5-9, it is apparent that the miscellaneous equipment loads in the ELCAP buildings do exceed the prototype model assumptions.

FIGURE 5-8

Equivalent Full-Workday Occupied Hours for Lighting in Offices

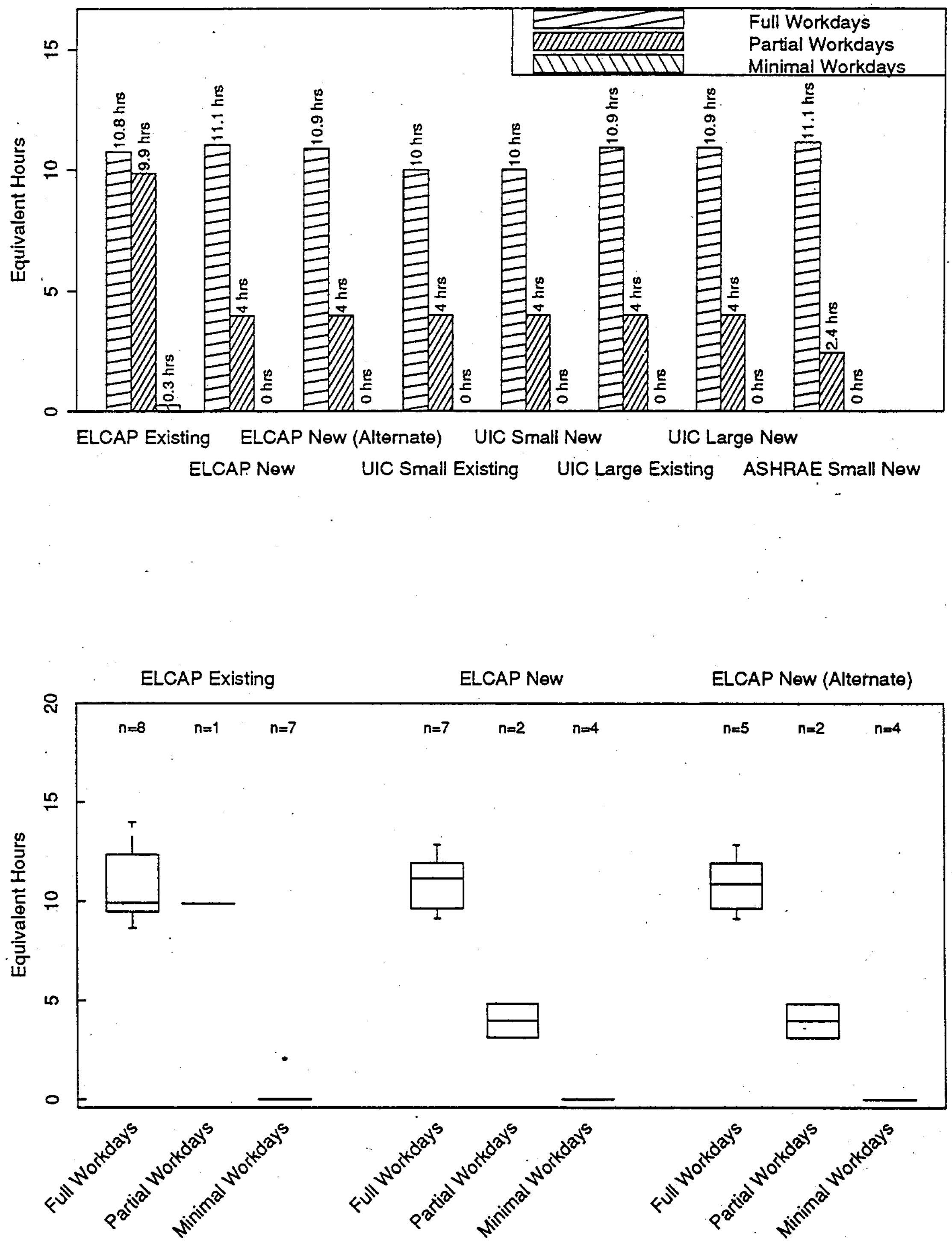
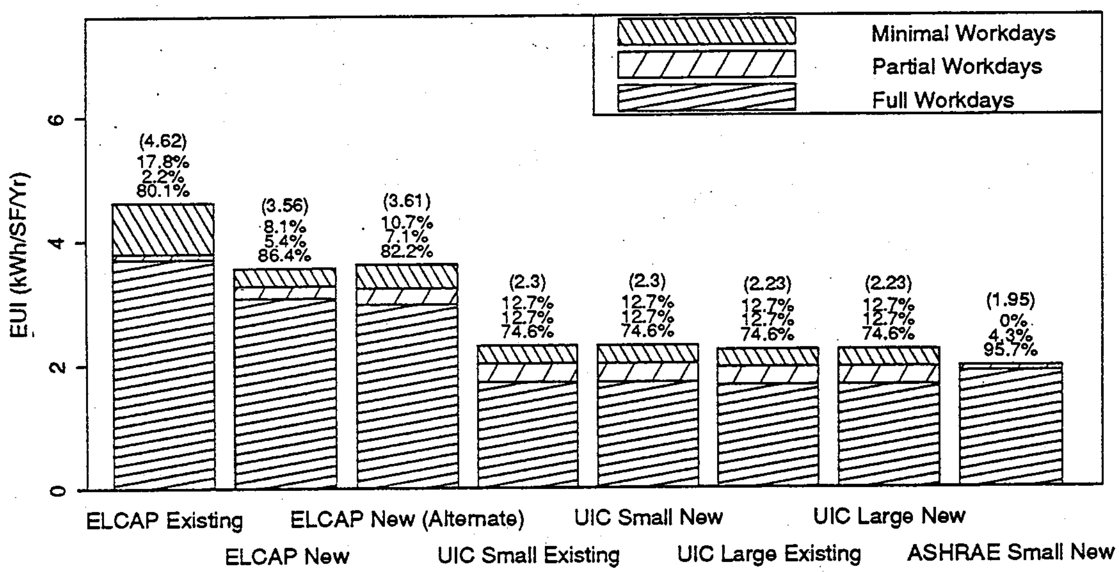
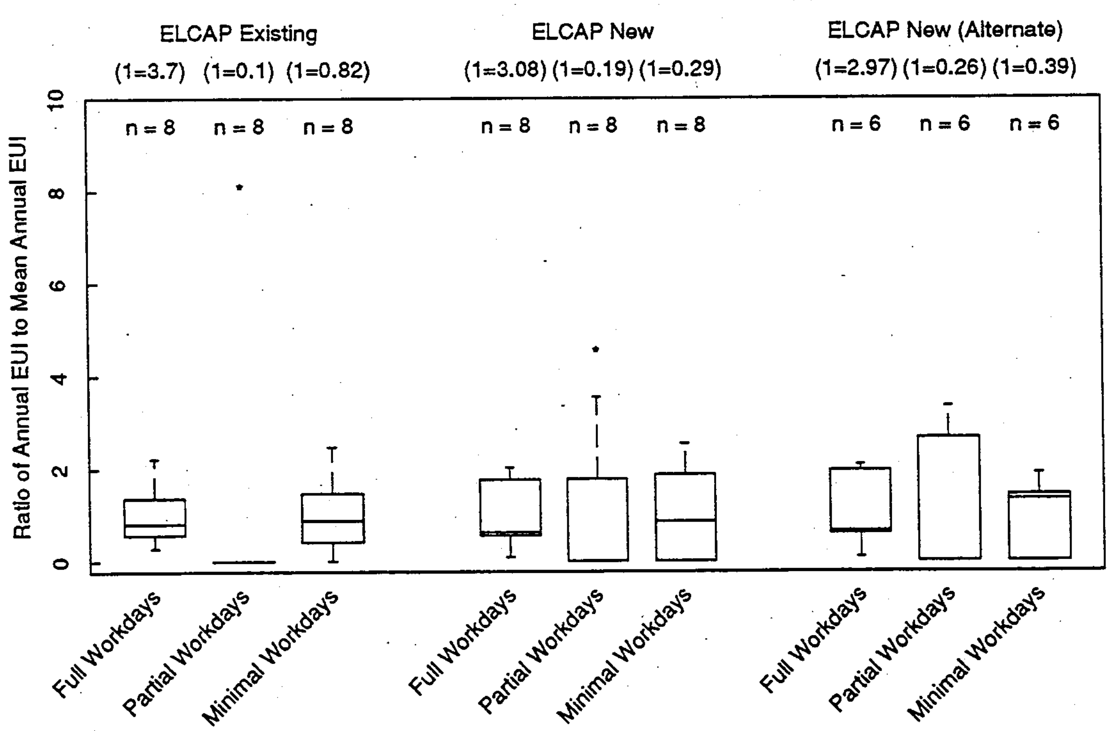


FIGURE 5-9

Estimated Annual Energy Consumption for Equipment in Offices





The equipment load profiles in Figures 5-10 through 5-12 show no major differences between the ELCAP buildings and the UIC prototypes except that ELCAP transitions between occupied and unoccupied load levels are much longer. It appears that plug loads increase gradually as the workday progresses and fall off gradually as closing time approaches. Although very few ELCAP buildings ever operated in the partial workday mode, the characterization of those days is of lower-than-normal usage for a full day in contrast to the UIC characterization of full usage for a short day.

The occupied power levels, as shown in Figure 5-13, are considerably higher in ELCAP buildings than they are in the corresponding UIC prototypes. How much of this power is attributable to lights and HVAC on the equipment circuits is unknown.

Figure 5-14 shows that ELCAP Existing buildings operate equipment about 1½ hours longer than ELCAP New or UIC prototypes, which may partially explain why the ELCAP Existing consumption is so much higher than both ELCAP New and UIC prototypes.

As shown in Figure 5-15, the ELCAP installed capacities are about three times higher than those in the UIC prototype assumptions. However, the average ELCAP daytime usage fraction, about 12%, is less than the 20% factor used in the UIC prototypes. Nonetheless, there appears to be a significant discrepancy between the actual and assumed capacities.

Comparing Existing and New ELCAP buildings, there is an unexpected trend. New buildings show less installed capacity and less energy consumption than do Existing buildings. It appears that the hypothesized growth in office plug loads caused by proliferation of personal computer equipment is equally active in Existing as well as New buildings. Another possible explanation for the New buildings showing lower installed capacities and loads might be that

FIGURE 5-10

Full Workday Equipment Profiles for Offices

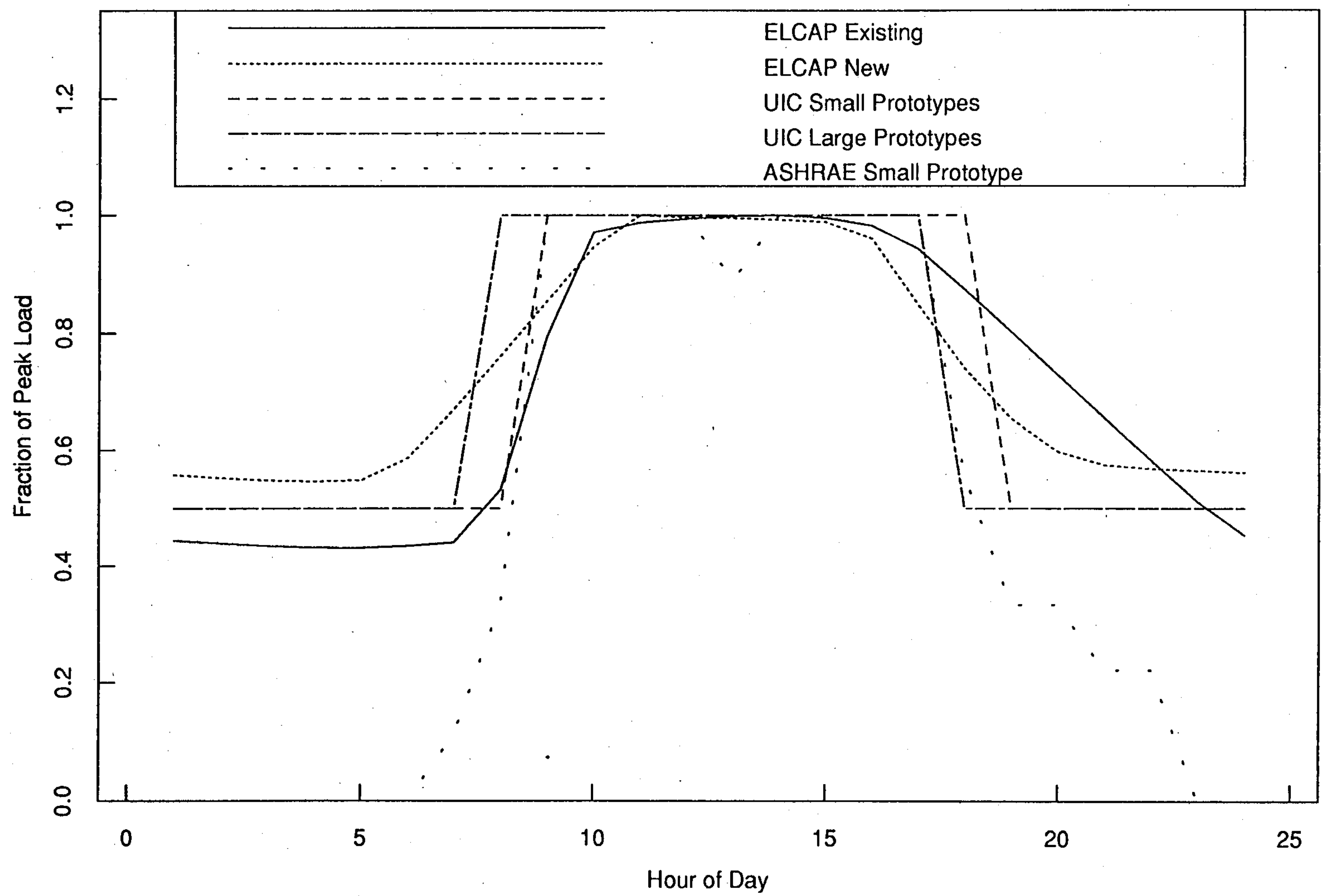


FIGURE 5-11

Partial Workday Equipment Profiles for Offices

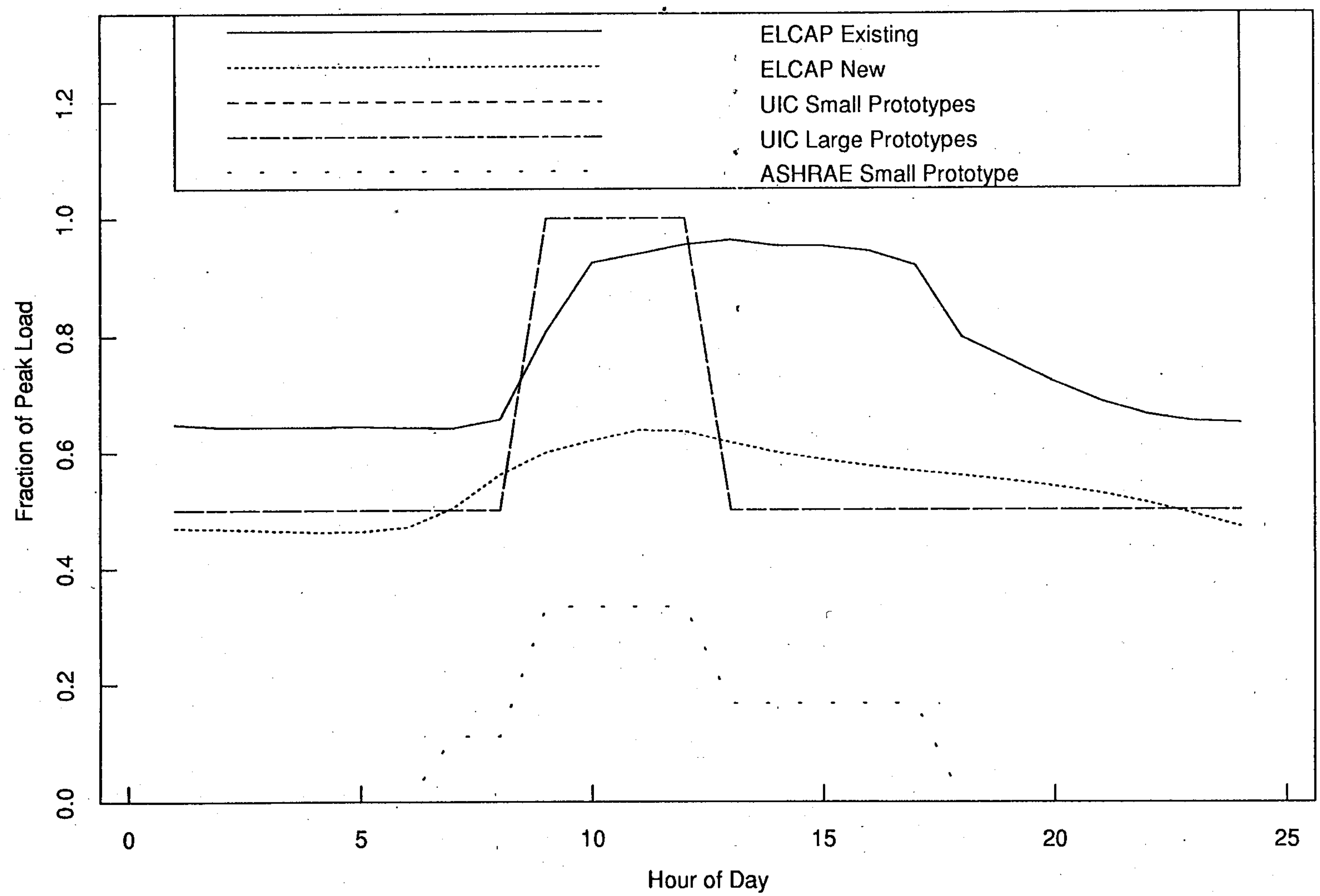


FIGURE 5-12

Minimal Workday Equipment Profiles for Offices

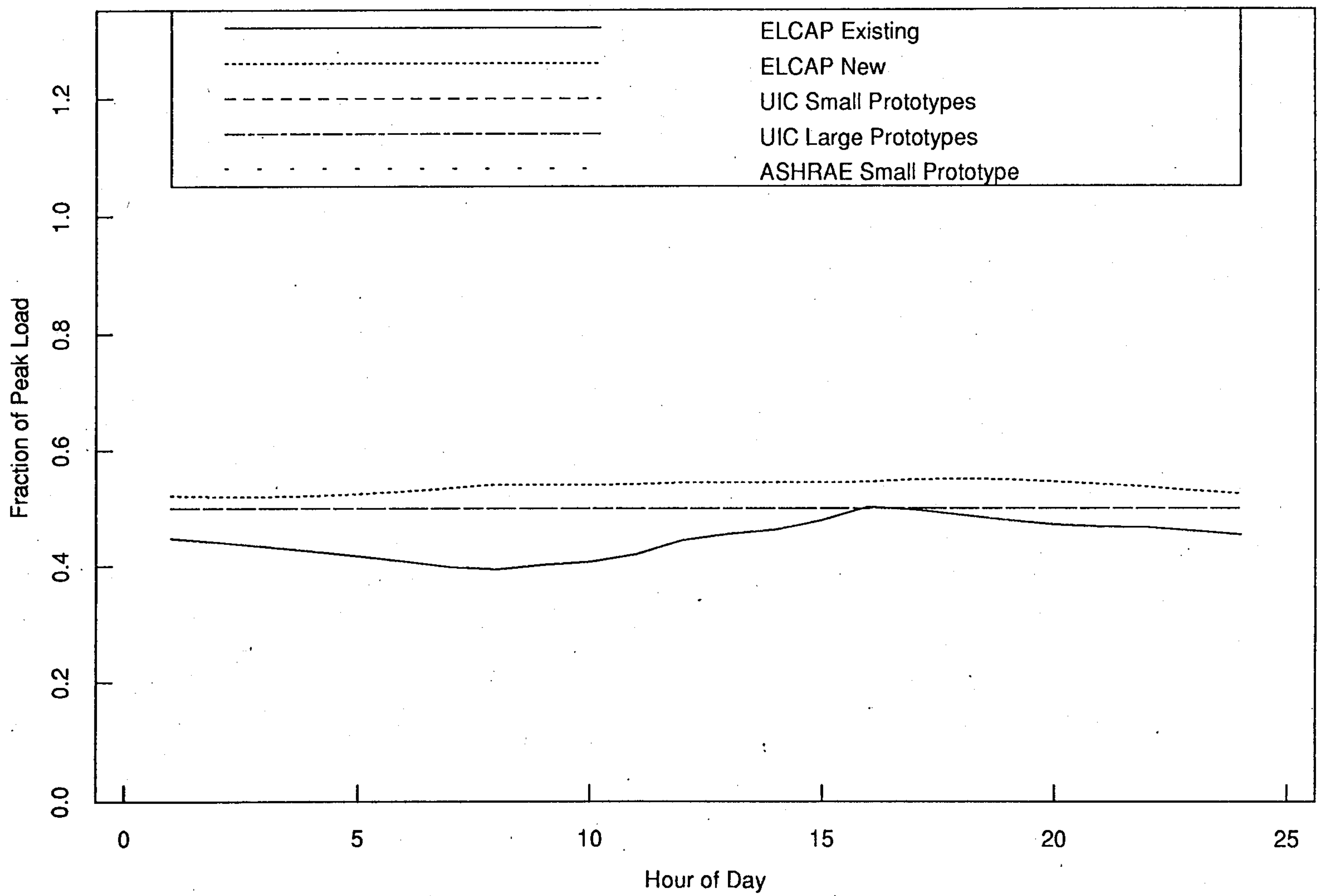
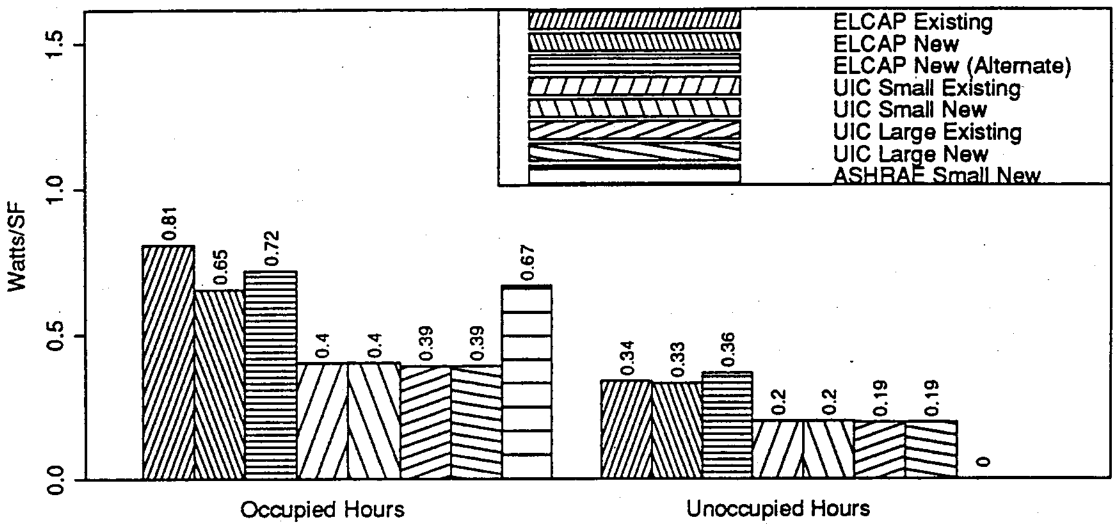


FIGURE 5-13

Mean Occupied and Unoccupied Equipment
Power Levels in Offices - Full Workday



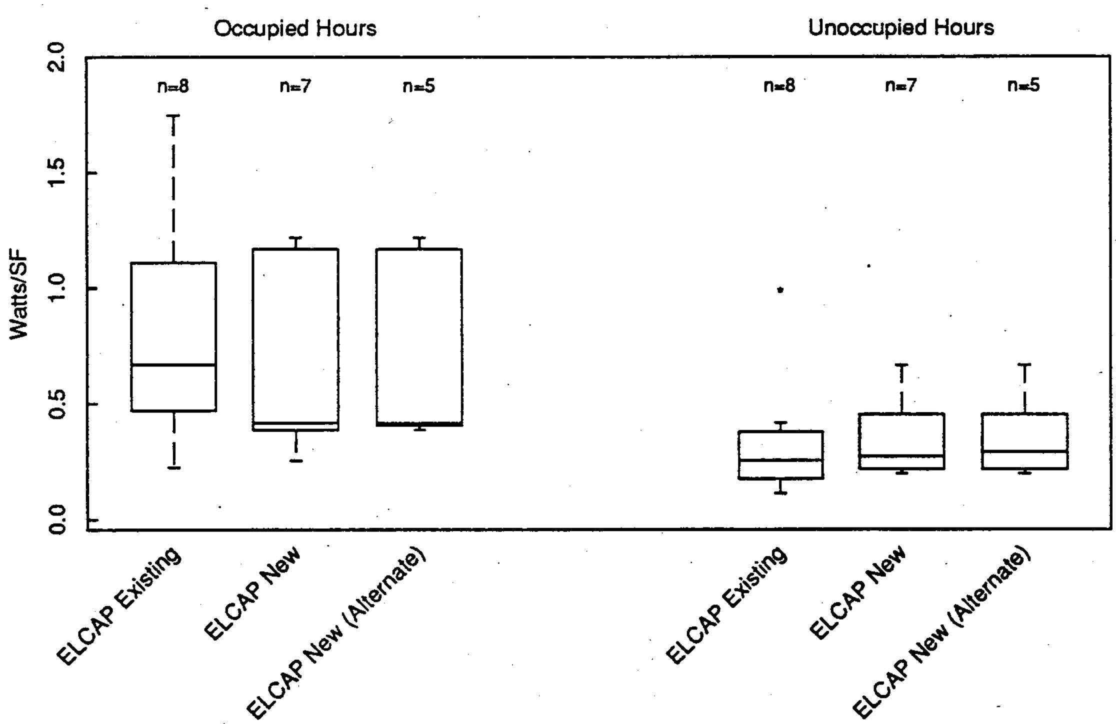
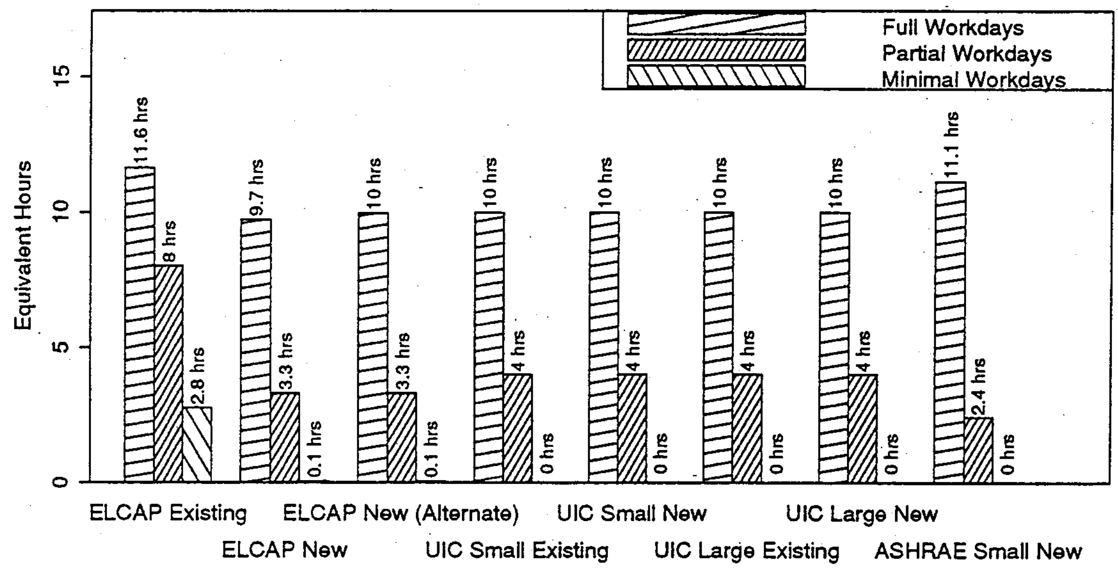


FIGURE 5-14

Equivalent Full-Workday Occupied Hours for Equipment in Offices



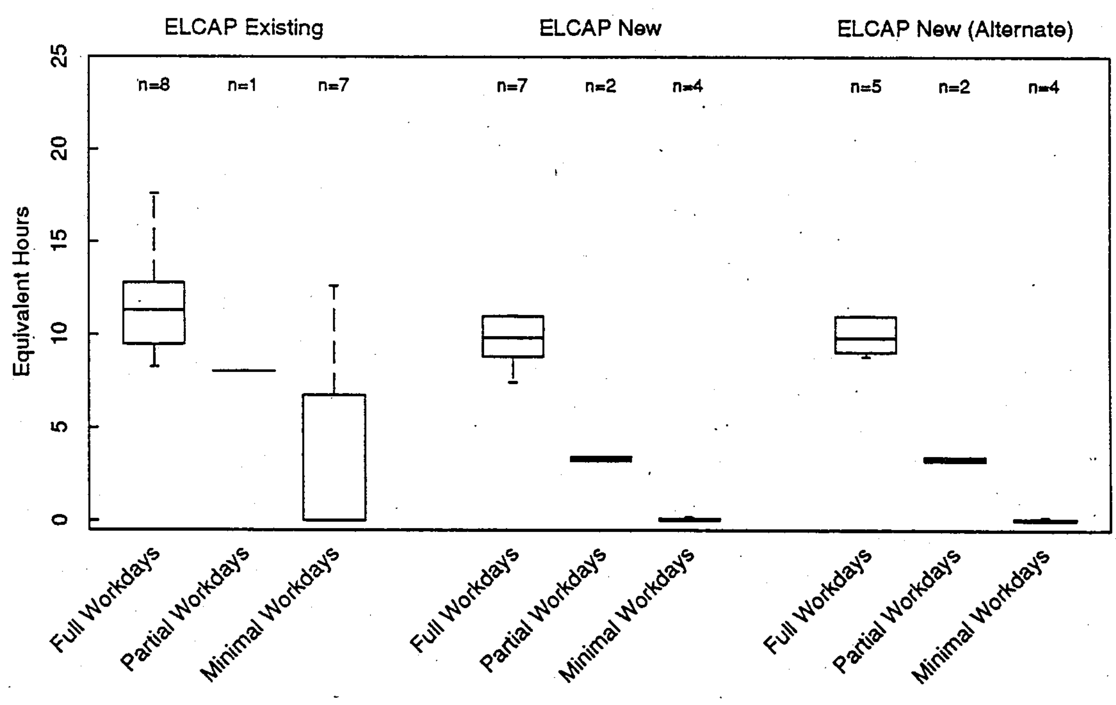
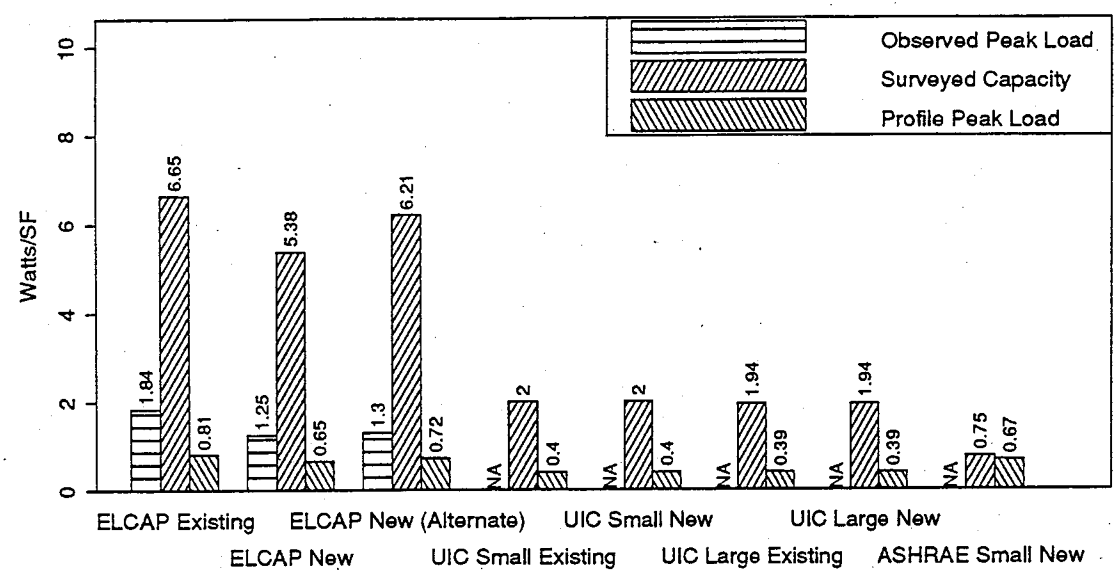
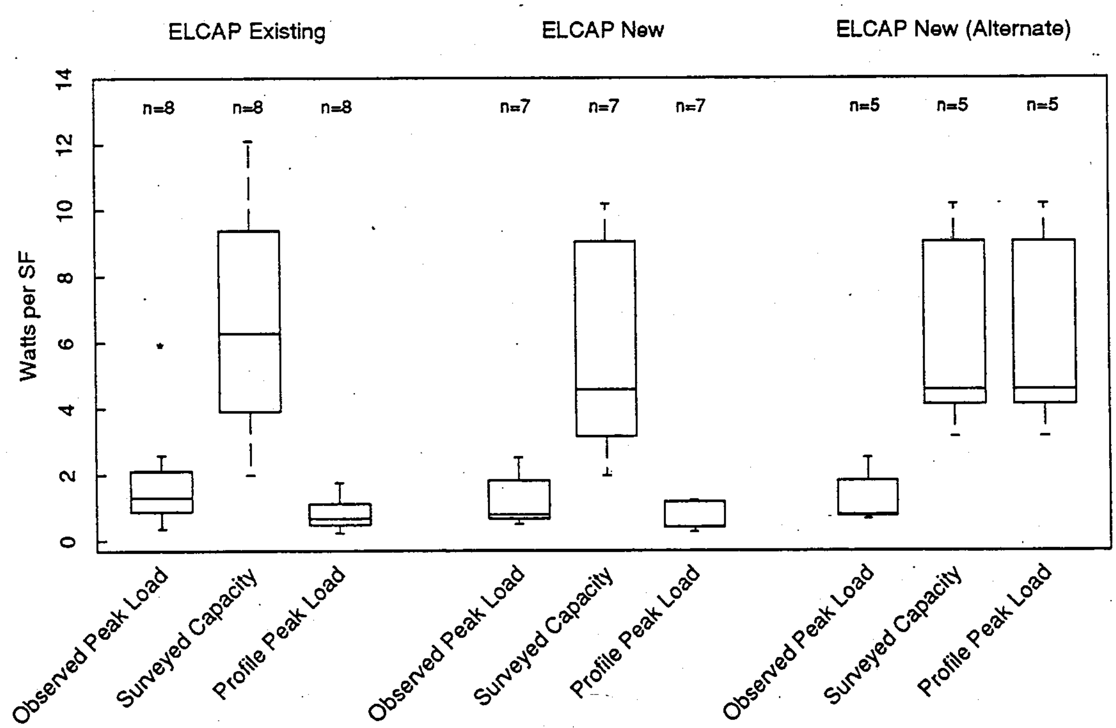


FIGURE 5-15

Equipment Capacities in Offices





they were partially vacant during the monitoring period. However, an analysis of vacancies and tenant changes in the ELCAP sample (Lucas et al. 1990) provided no compelling evidence that New buildings were any more vacant than Existing.

RETAILS

Day-Type Distributions

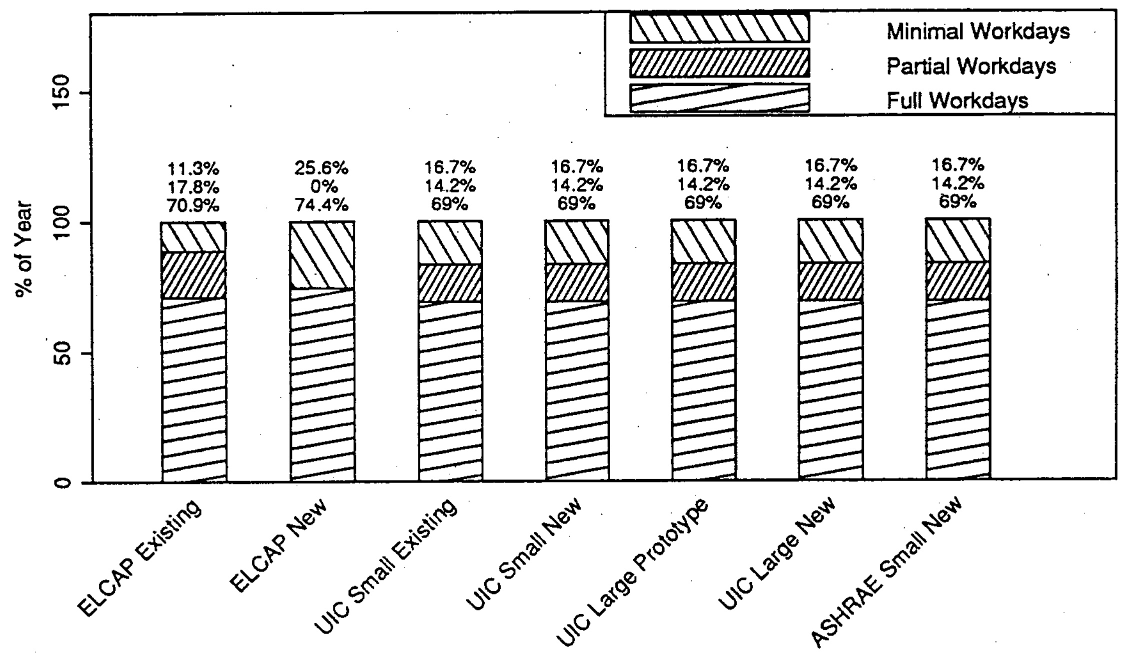
Figure 5-16 shows the annual distribution of day types for each of the retail prototypes. The UIC and ASHRAE prototypes base day-type distributions on the occurrences of weekdays for full workdays, Saturdays for partial workdays, and Sundays and holidays for minimal workdays. ELCAP day-type distributions are based on the actual occurrence of the full-, partial-, or minimal-occupancy operating days. ELCAP Existing day-type distributions match the UIC assumptions very closely, except that there are slightly more partial workdays and slightly fewer minimal workdays. ELCAP New buildings show no partial workdays at all and a slightly higher number of full workdays. However, there are only three ELCAP buildings in the New category. It does not appear that differences in day-type distributions will explain any major energy use differences.

Lighting Observations

Annual Energy Consumption Differences. Figure 5-17 shows the estimated annual energy consumption for lighting in retails. In contrast to the office observations, ELCAP retails use less energy than the UIC prototypes predict. Existing buildings show consumption about 12% less than UIC, while New buildings show almost 50% less than UIC. Compared to the UIC Large prototypes, the differences are even more dramatic. There is a considerable drop in consumption (about 40%) between ELCAP Existing and New buildings, a trend not suggested by the UIC Small prototypes, which show an increase of about 9%, but similar in direction to the trend of the UIC Large prototypes.

FIGURE 5-16

Day-Type Percentages in Retails



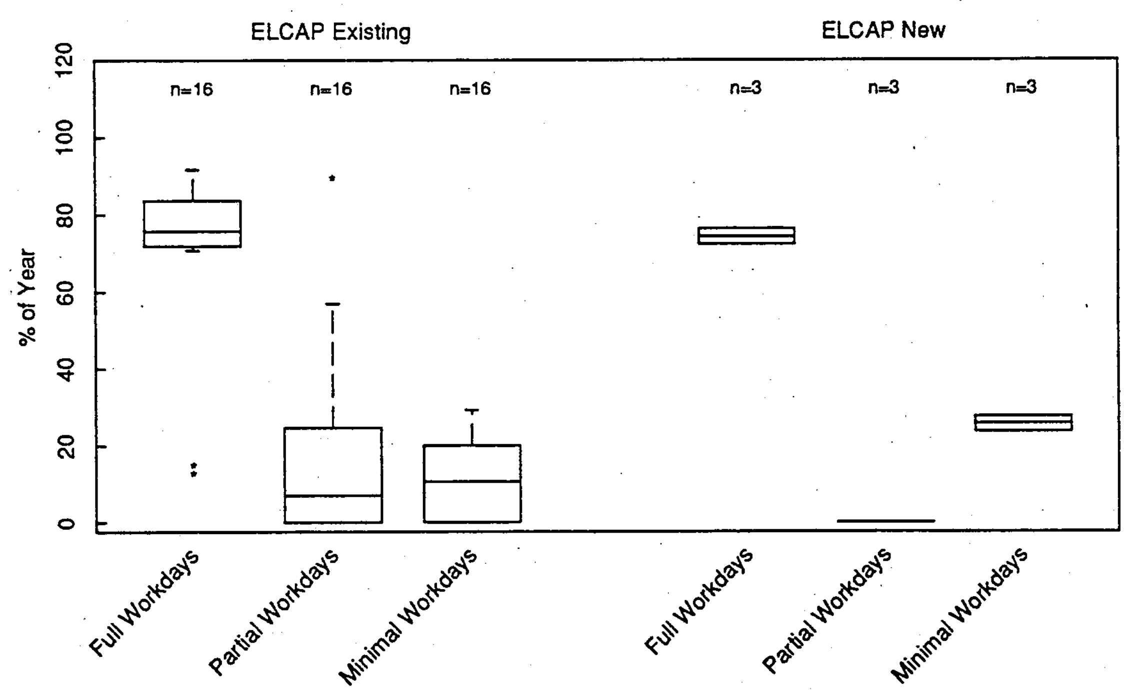
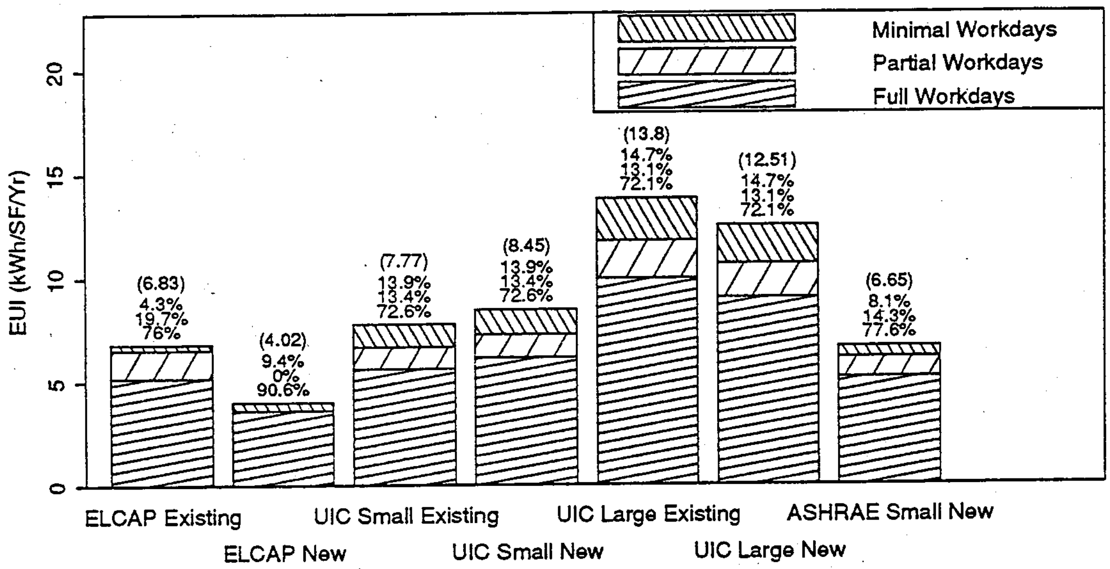
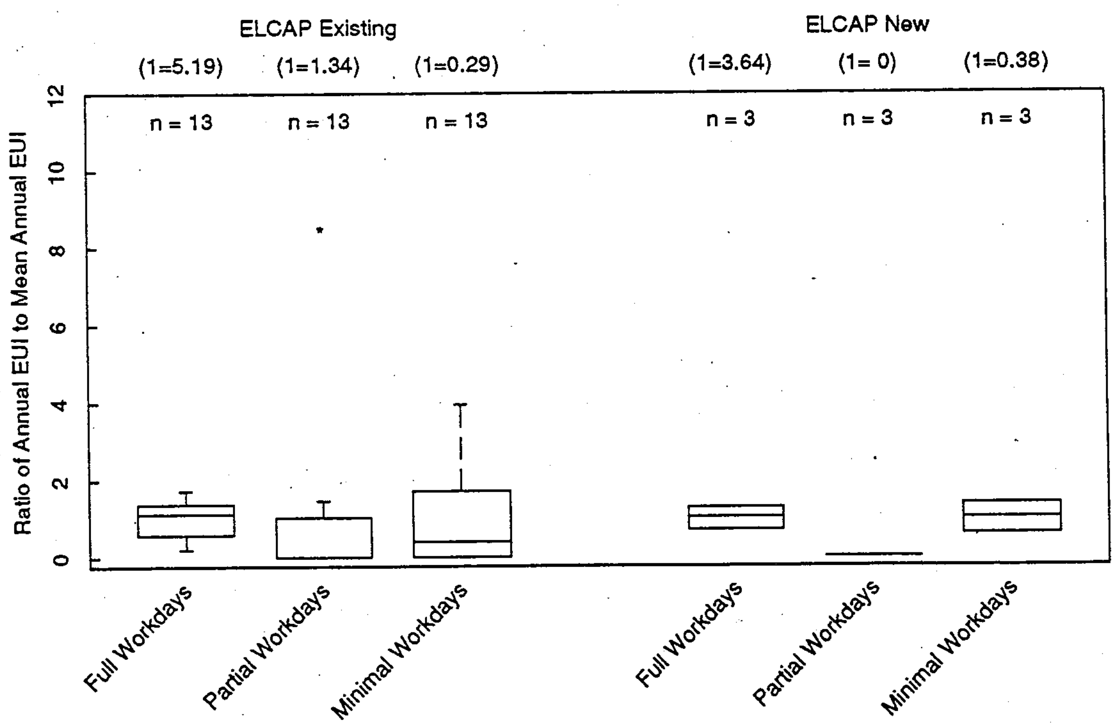


FIGURE 5-17

Estimated Annual Energy Consumption for Lighting in Retails





Explanations of Energy Differences. The full workday retail lighting profiles (Figure 5-18) suggest two major reasons why ELCAP loads are below UIC loads. First, the ELCAP unoccupied load fractions are 20% to 30% lower than those of UIC's prototypes. Second, the length of the workday appears to be shorter in the ELCAP load shapes. This is particularly obvious for the ELCAP New buildings, although the sample size (three) is very small. The minimal workday profiles also show levels of activity considerably less than implied by the UIC profiles, perhaps because the ELCAP retail sample is dominated by small businesses that are less likely to open on Sundays.

The full workday occupied and unoccupied power levels (Figure 5-19) confirm the profile implications that nighttime load levels are a major factor contributing to lower ELCAP loads. For Existing buildings, the ELCAP occupied power level even exceeds that of the corresponding UIC prototype, but not enough to counter the lower ELCAP unoccupied power level.

The equivalent full-workday occupied hours shown in Figure 5-20 confirm that the ELCAP New buildings have shorter workdays, one hour shorter by this measure. ELCAP Existing workdays appear to be about equivalent in length to those of the UIC Small prototypes, but shorter than the UIC Large prototypes. The data in Figure 5-18 also confirm that the ELCAP buildings show less minimal workday (Sunday/holiday) activity than do the UIC prototypes.

In ELCAP Existing buildings, both the observed hourly peak and the profile peak load exceed the surveyed equipment capacity. This is most likely due to errors in the surveys, the addition of new equipment since the surveys, the mixing of lighting and HVAC loads with the miscellaneous circuits, and the absence of ballast loads in the survey data. Figures 5-21 and 5-22 graphically present results of the surveys.

FIGURE 5-18

Full Workday Lighting Profiles for Retails

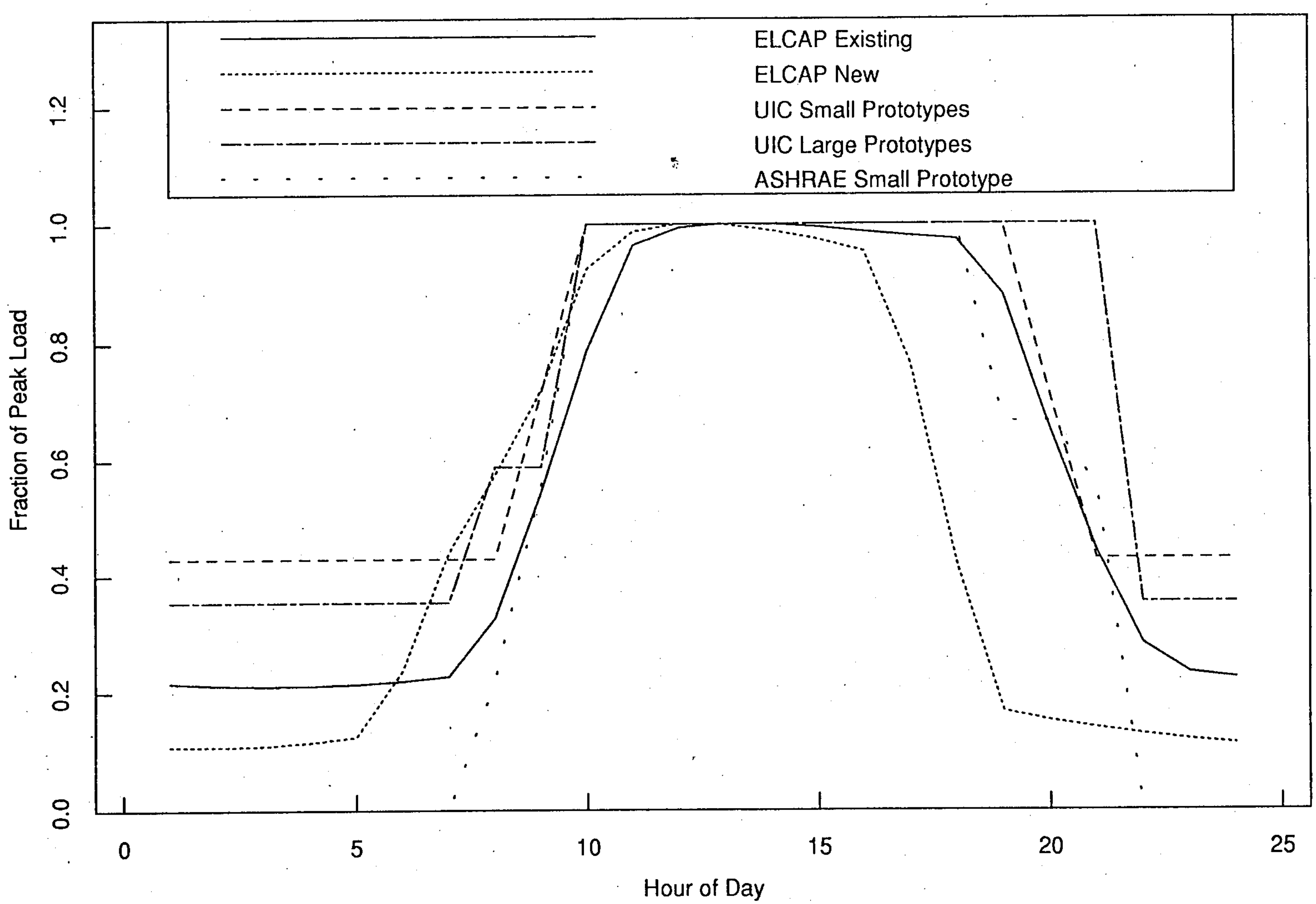
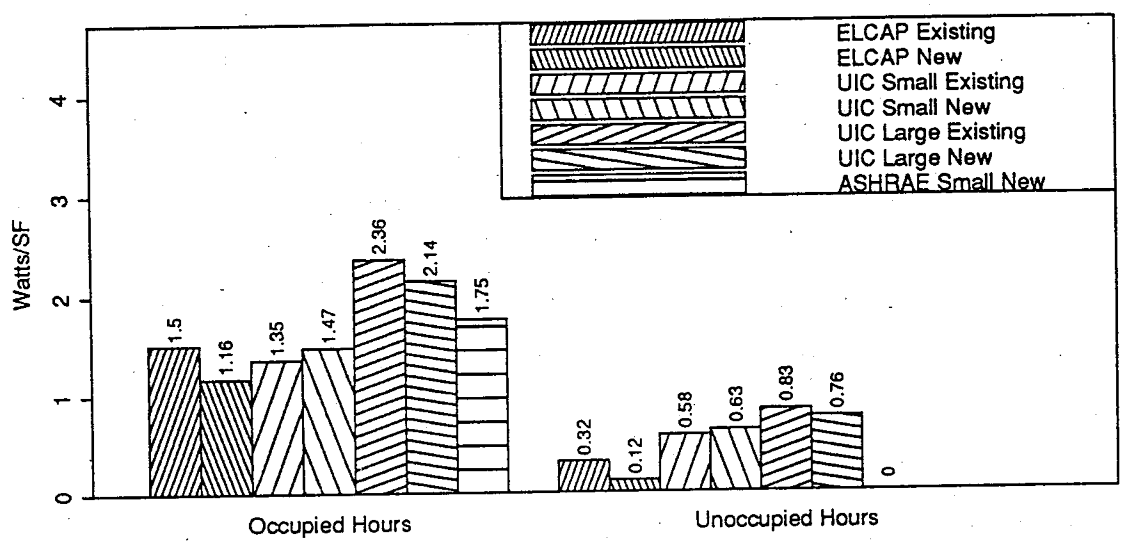


FIGURE 5-19

Mean Occupied and Unoccupied Lighting Power Levels in Retails - Full Workday



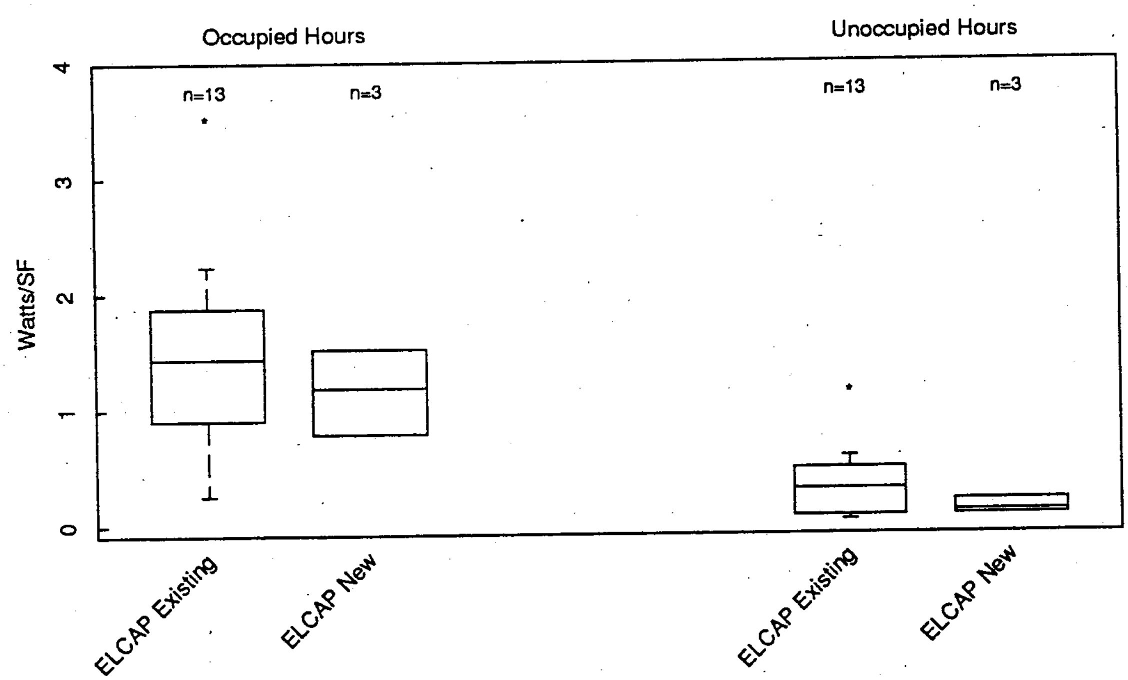
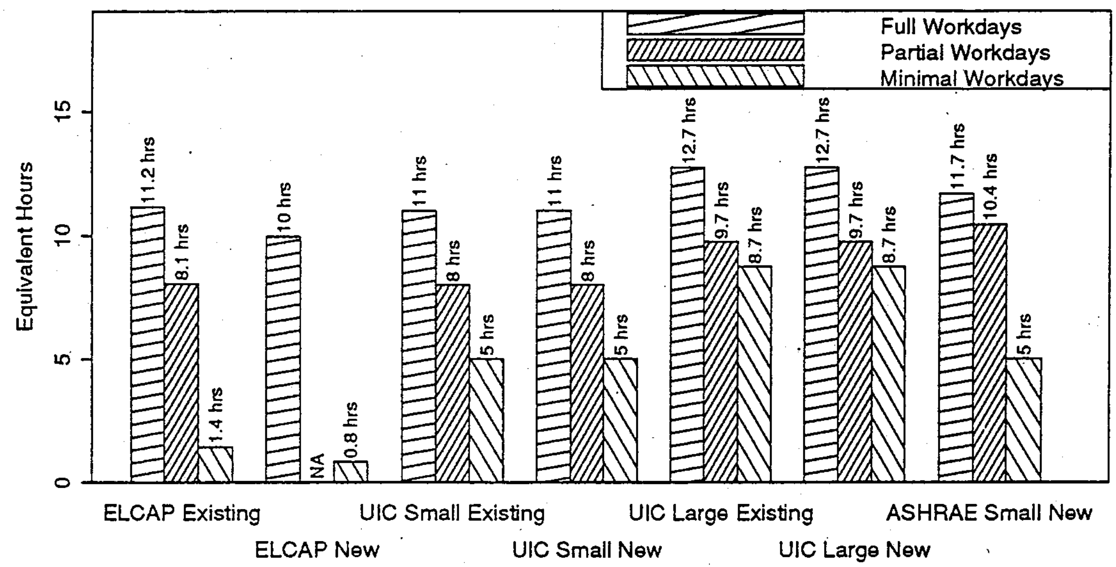


FIGURE 5-20

Equivalent Full-Workday Occupied Hours for Lighting in Retails



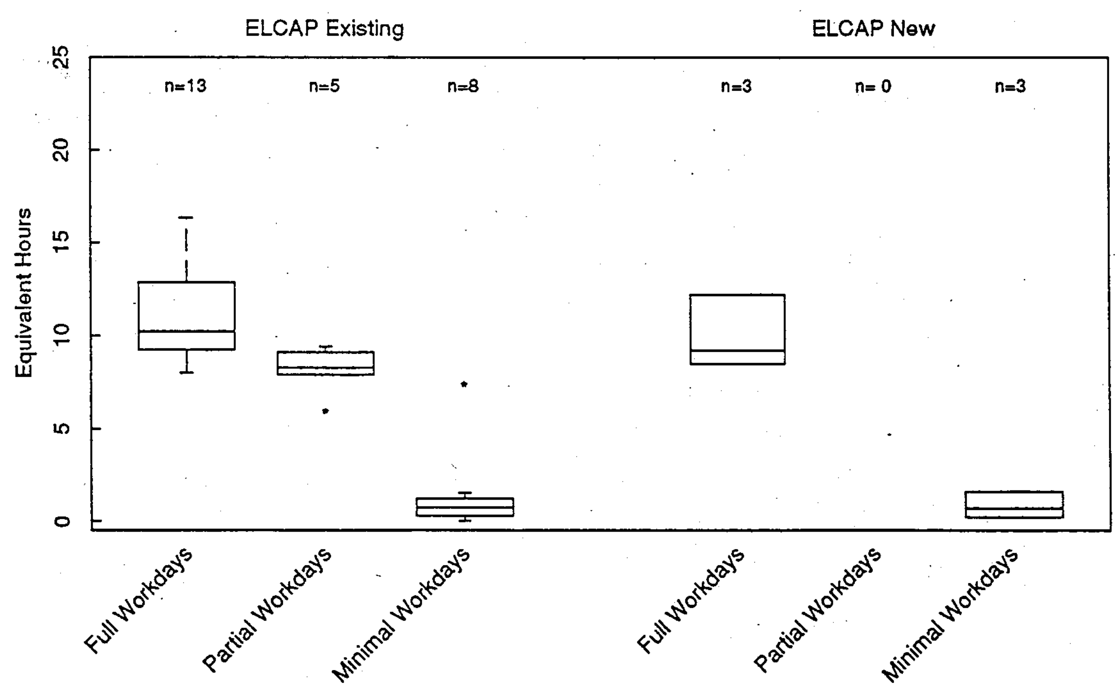
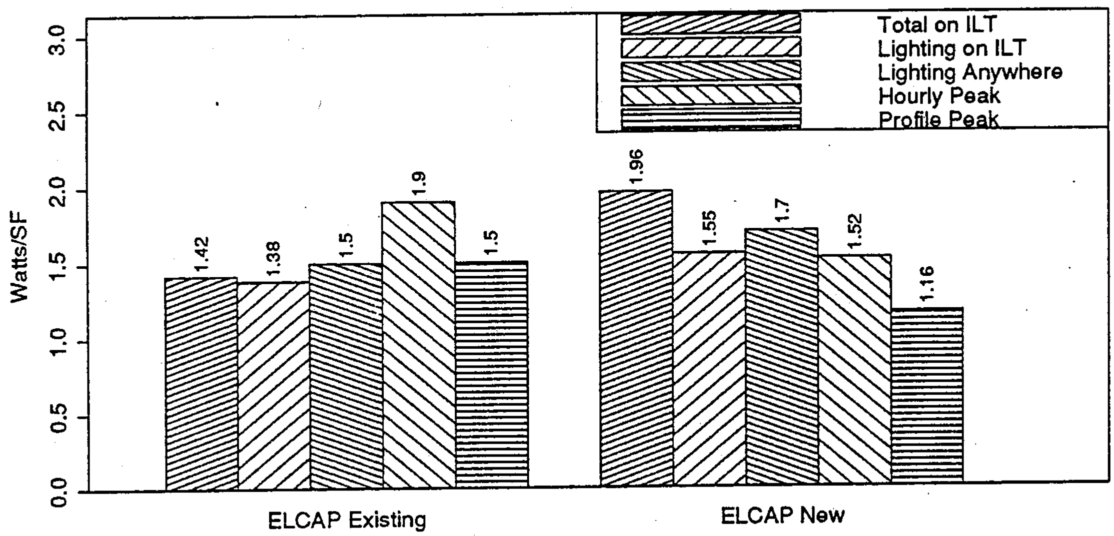


FIGURE 5-21

Surveyed Lighting Capacities in ELCAP Retails



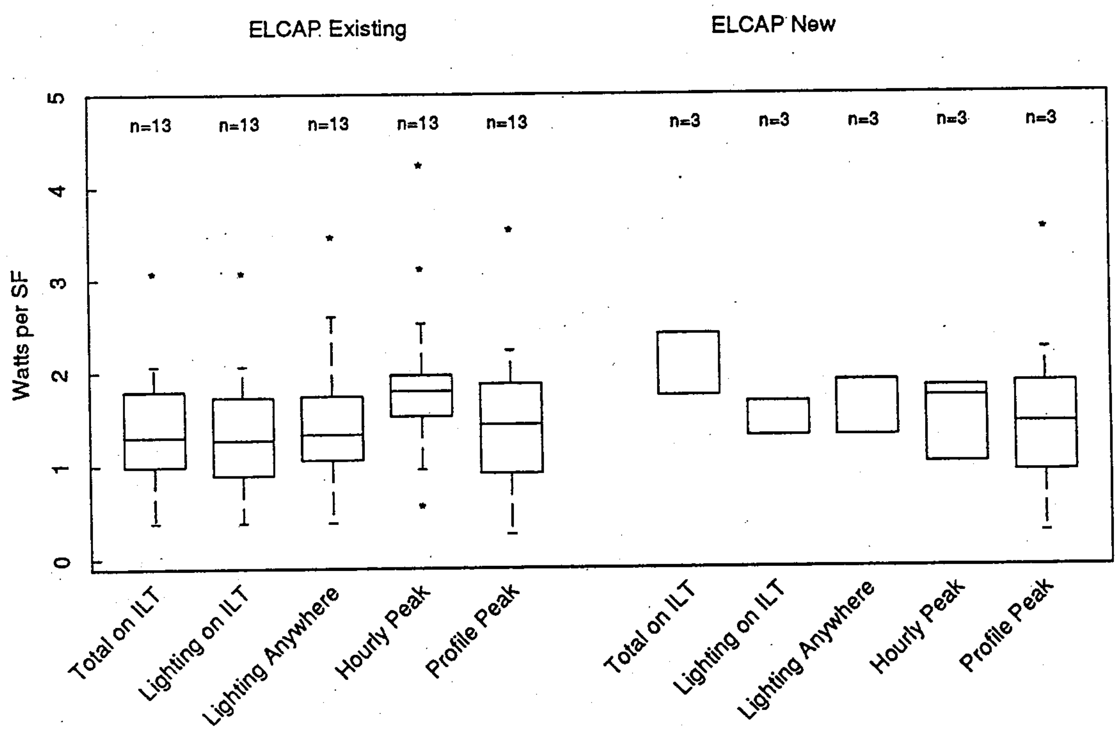
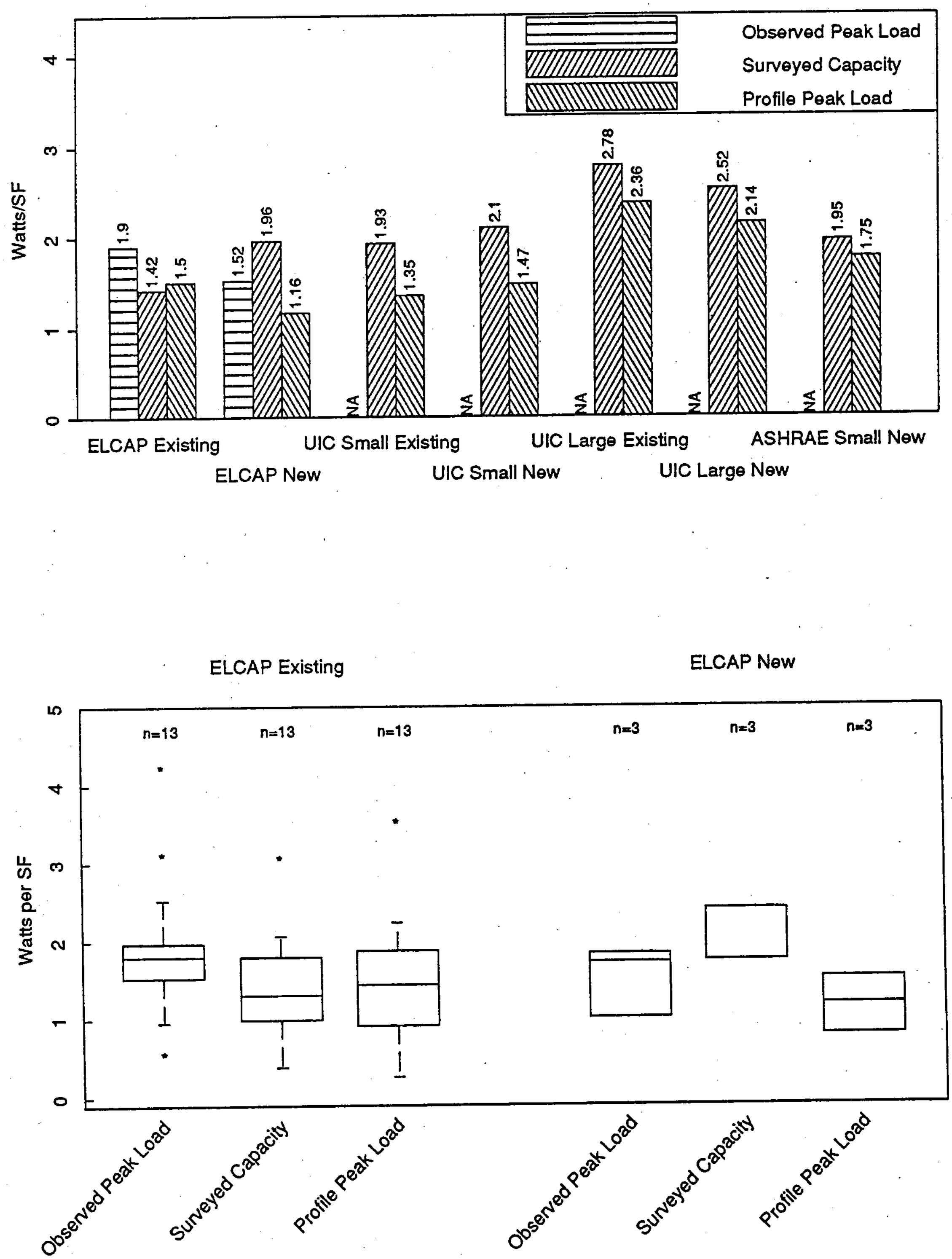


FIGURE 5-22

Lighting Capacities in Retails



Equipment Observations

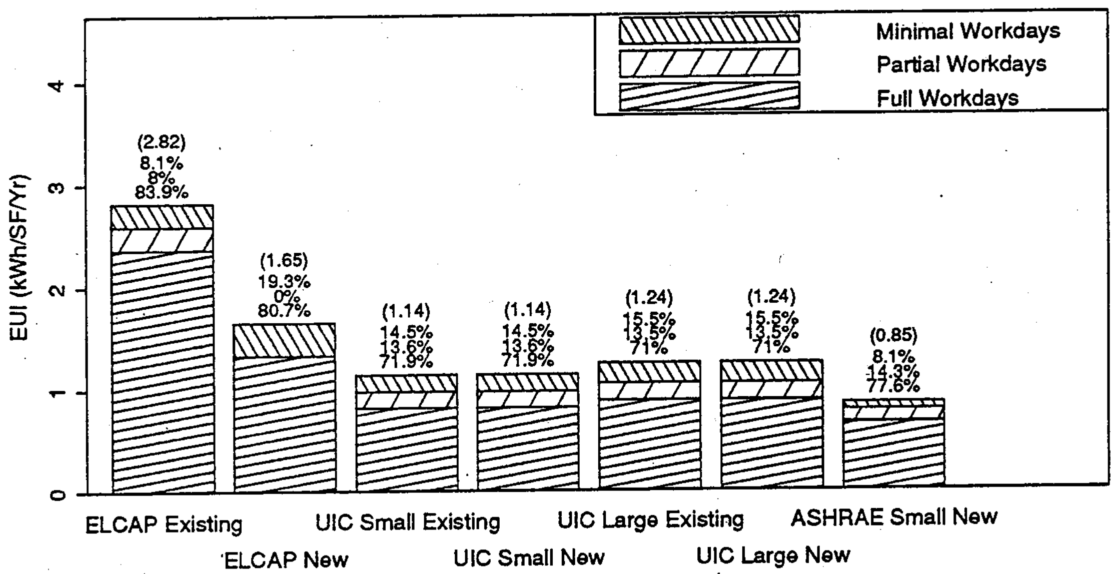
Annual Energy Consumption Differences. ELCAP retail equipment consumptions are high relative to the corresponding UIC prototypes. As shown in Figure 5-23, ELCAP Existing retails consume about 150% more and ELCAP New retails consume about 45% more. ELCAP New buildings consume about 41% less than ELCAP Existing.

Explanations of Energy Differences. The loads metered as *miscellaneous equipment* in the ELCAP buildings often include some lighting and HVAC loads that were not separable to the metering hardware. This suggests that the estimated loads shown in Figure 5-23 might be too high. Previous analyses of the actual loads connected to each metered circuit indicated that the miscellaneous end use in ELCAP Existing retails contains an average of 0.16 kWh/ft^2-yr of lighting and HVAC (largely ventilation) loads. For ELCAP New retails, the value is 0.13 kWh/ft^2-yr. Subtracting these estimates from the ELCAP loads shown in Figure 5-3 would reduce the loads by a small percentage. However, the ELCAP loads would still be considerably higher than those of the UIC prototypes. Figures 5-24 through 5-26, the retail equipment profiles, offer no explanation for the higher ELCAP consumption. ELCAP unoccupied load fractions are reasonably comparable to those of the UIC prototypes, those of Existing buildings being even lower than those of the corresponding UIC prototype. The only obvious difference is that the ELCAP transition periods are considerably longer than those of the UIC prototypes, which alone would suggest that the ELCAP buildings should use less energy rather than more relative to the UIC prototypes.

The plots of occupied and unoccupied power levels (Figures 5-27 through 5-29) explain much of the energy differences. The ELCAP buildings have considerably higher occupied power levels, indicating that there is either more equipment installed than expected or that usage of equipment is more intense.

FIGURE 5-23

Estimated Annual Energy Consumption for Equipment in Retails



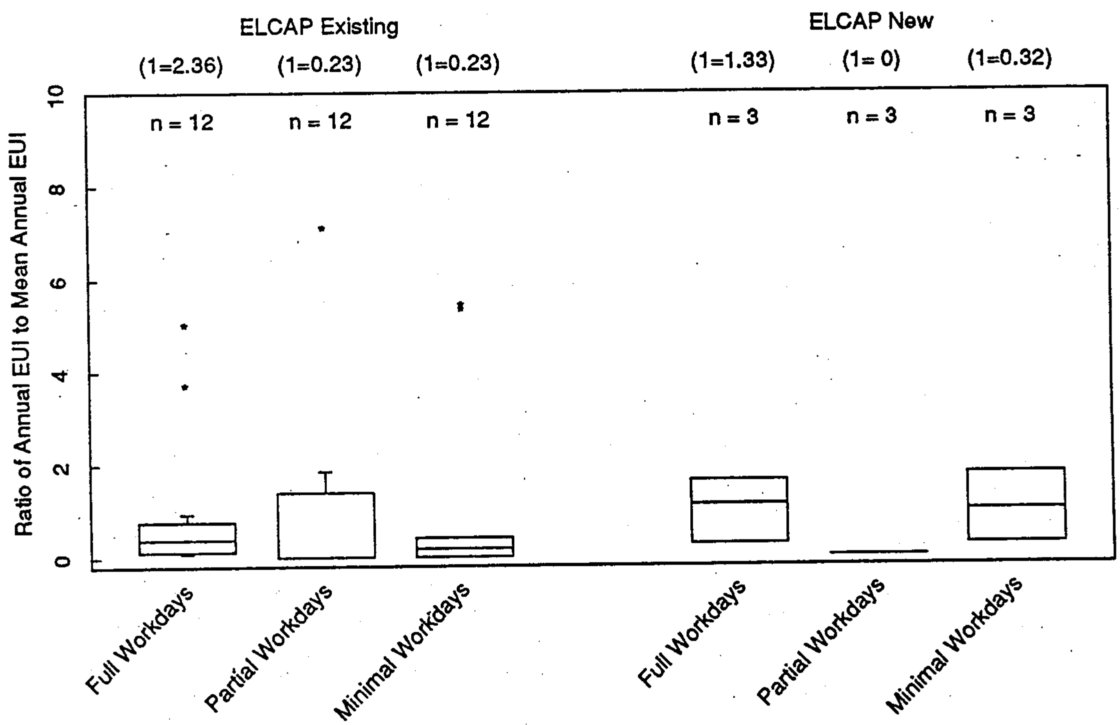


FIGURE 5-24

Full Workday Equipment Profiles for Retails

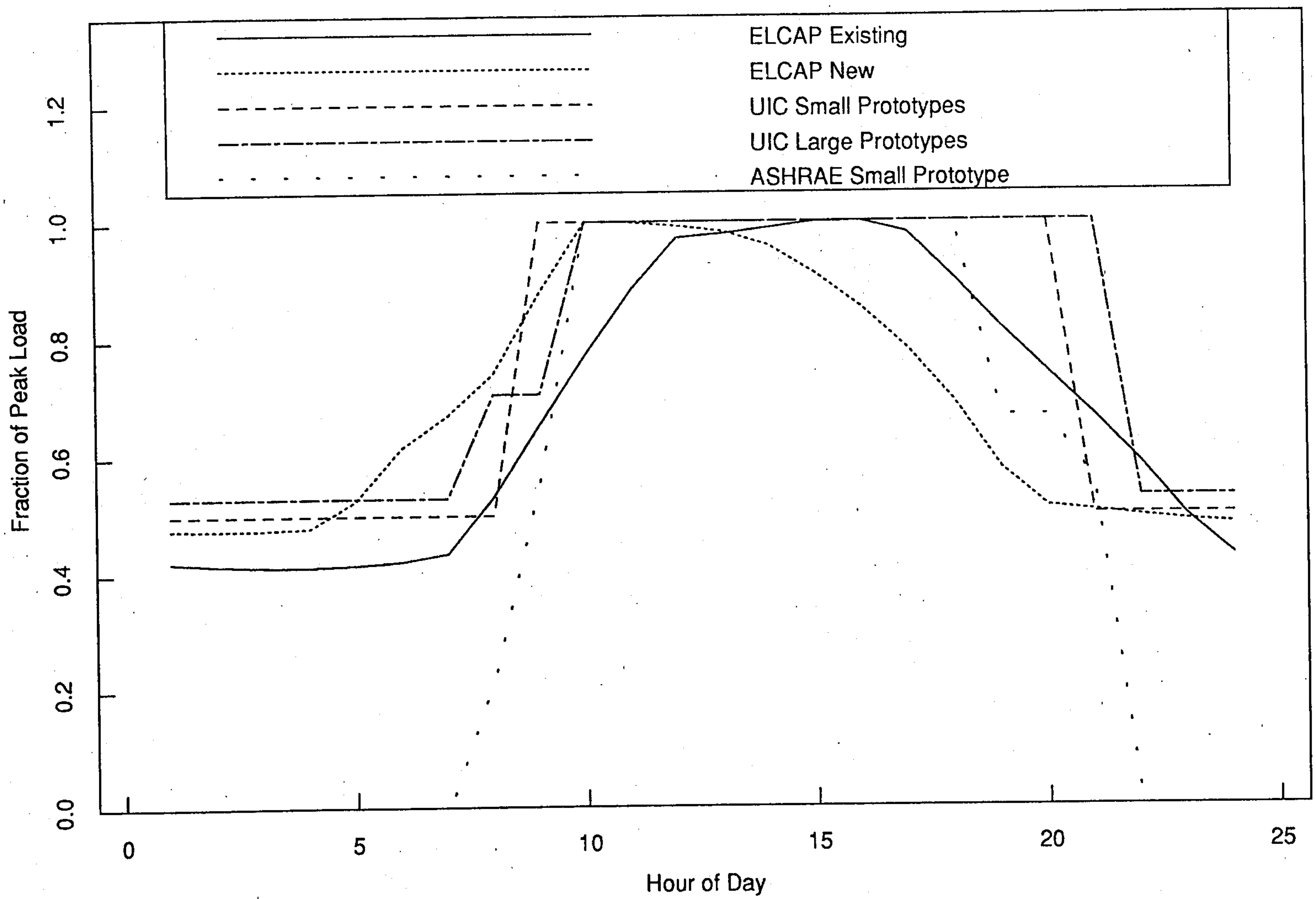


FIGURE 5-25

Partial Workday Equipment Profiles for Retails

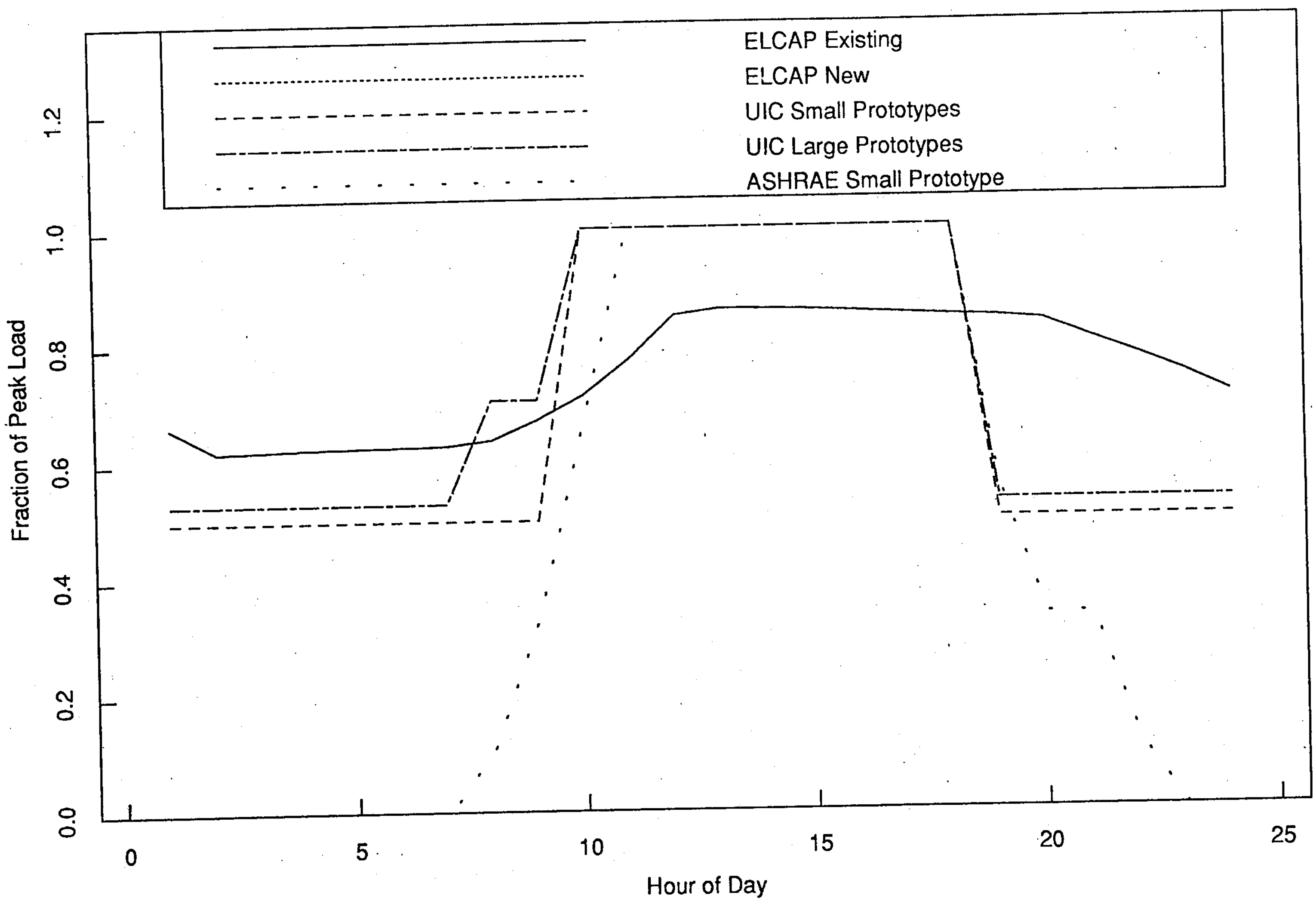


FIGURE 5-26

Minimal Workday Equipment Profiles for Retails

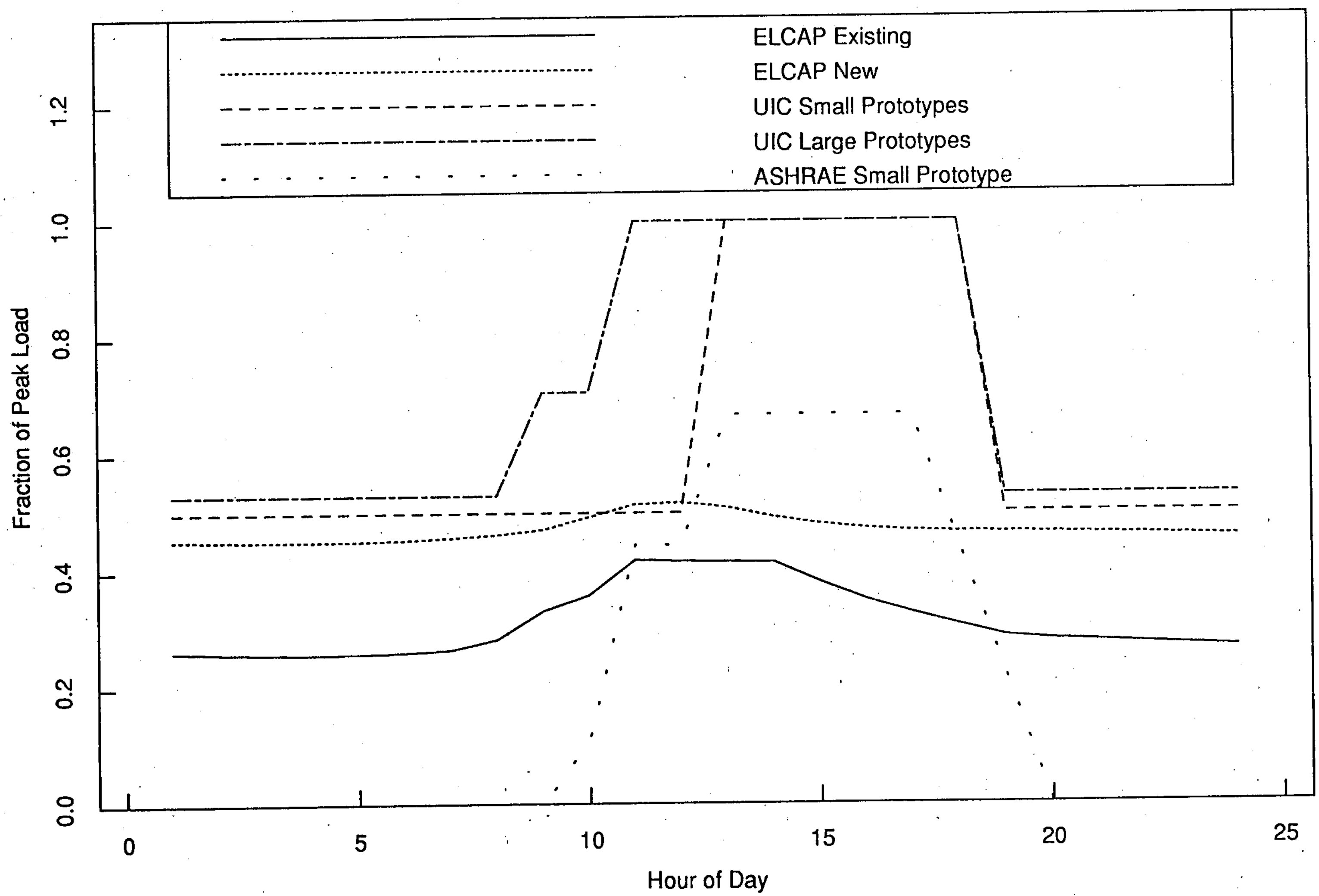
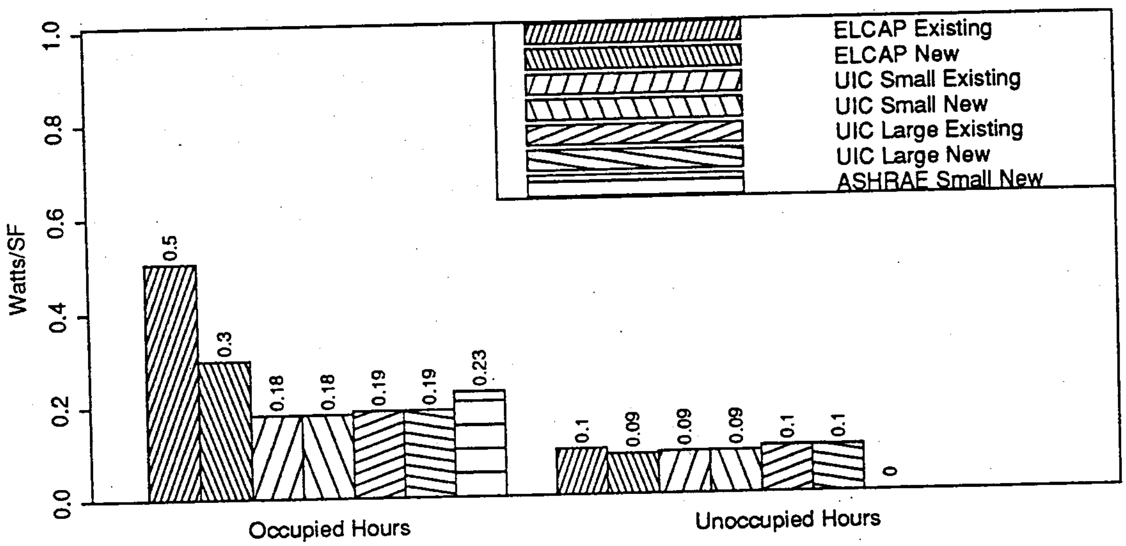


FIGURE 5-27

Mean Occupied and Unoccupied Equipment
Power Levels in Retails - Full Workdays



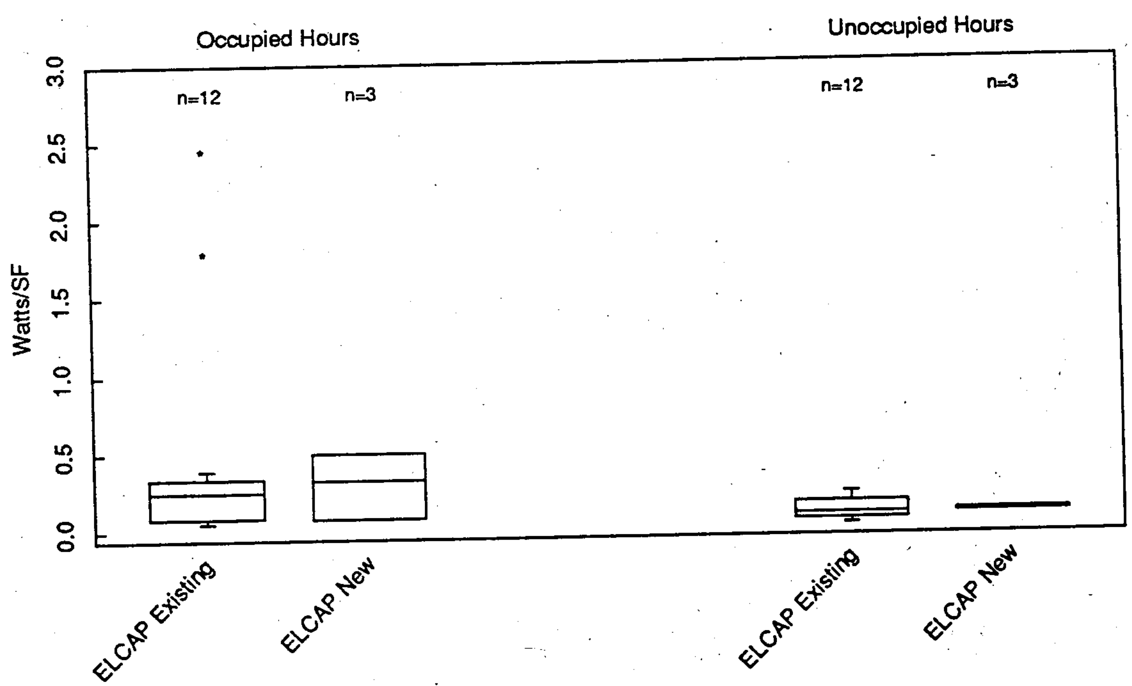
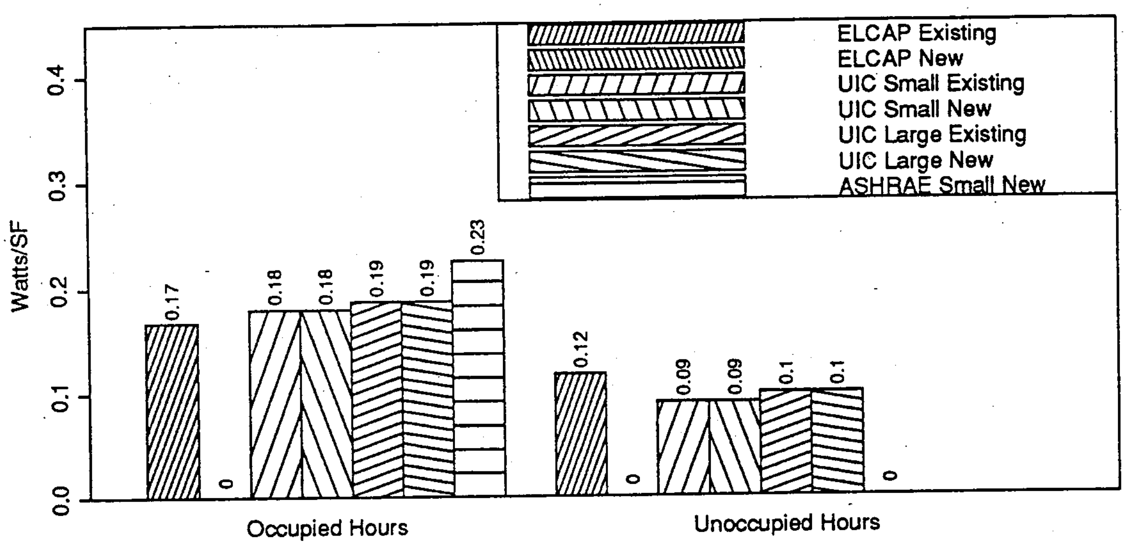


FIGURE 5-28

Mean Occupied and Unoccupied Equipment Power Levels in Retails - Partial Workdays



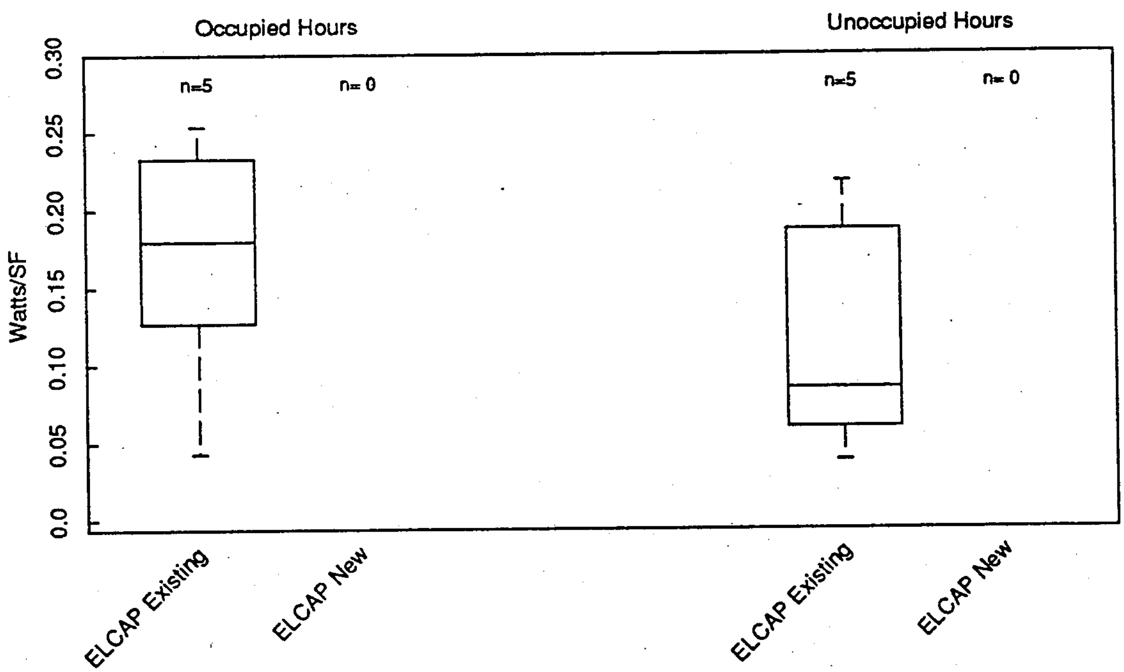
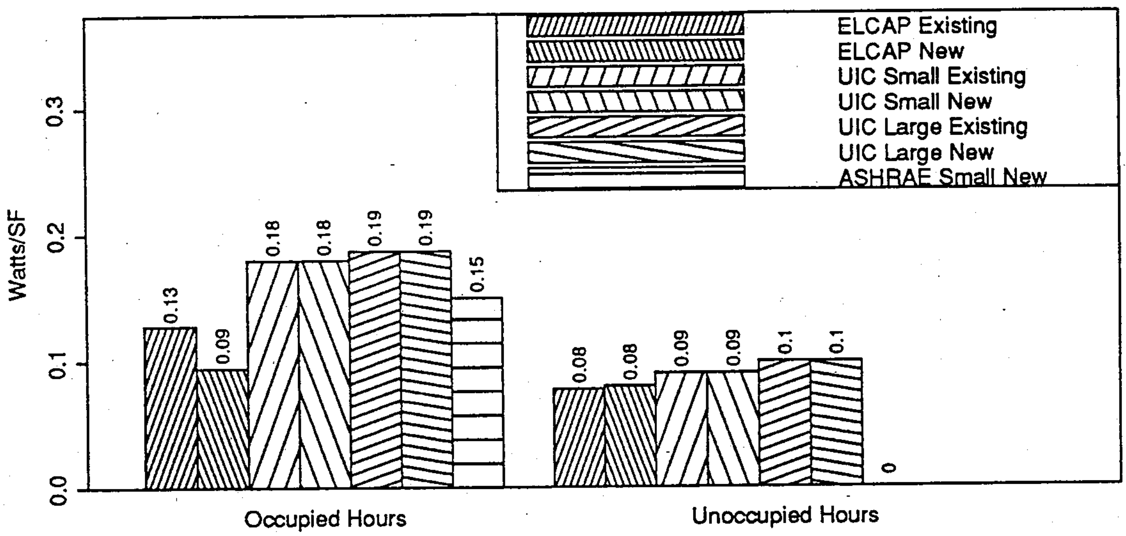
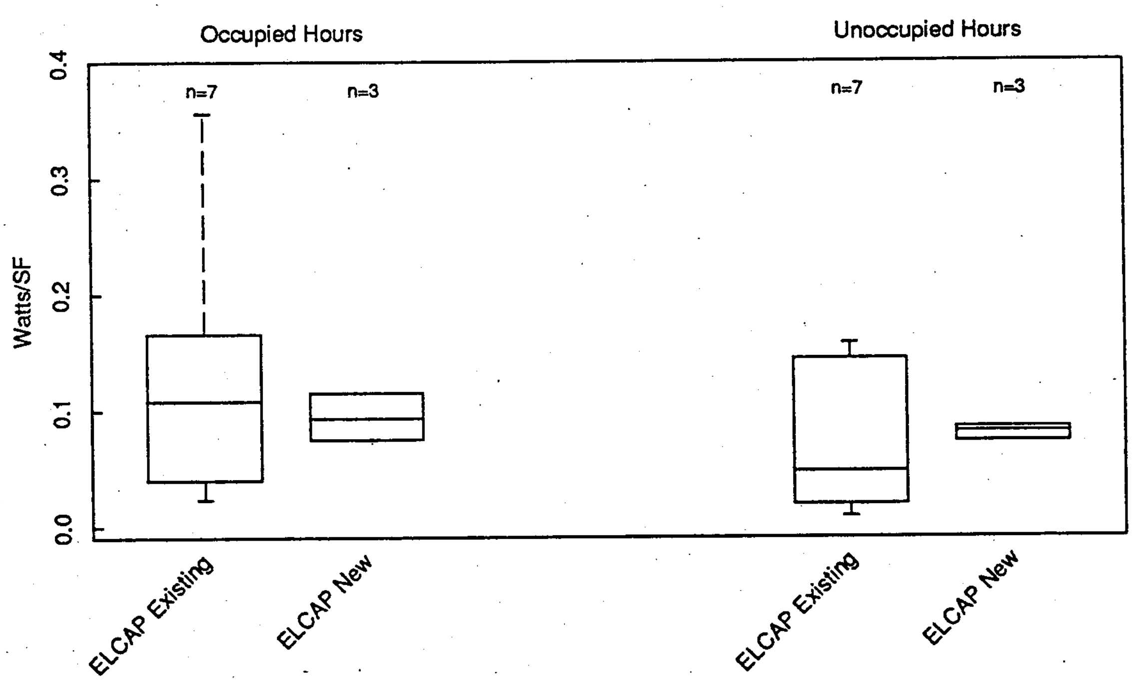


FIGURE 5-29

Mean Occupied and Unoccupied Equipment
Power Levels in Retails - Minimal Workdays





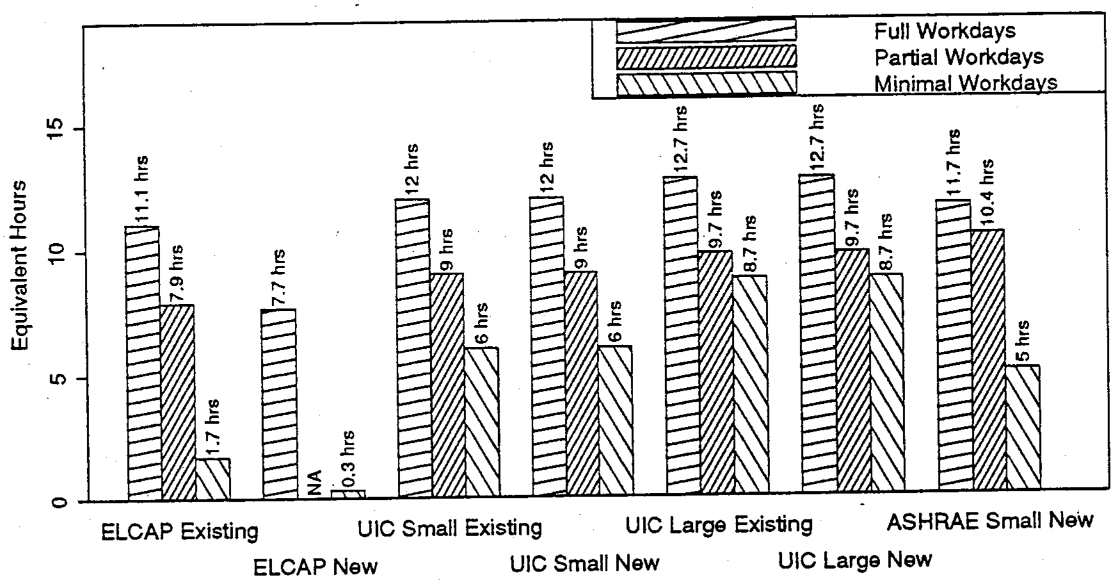
The equivalent full-workday occupied hours, shown in Figure 5-30, do not suggest more intense usage. Confirming the profile observations, the full workday occupied hours are actually less for the ELCAP buildings than for the UIC prototypes.

The surveyed capacities (Figure 5-31) do suggest a higher installed capacity. The tallies of equipment capacities from the ELCAP surveys far exceed the assumptions of installed capacity in the UIC prototypes. While some of this capacity might possibly be due to the mixing of lighting and HVAC loads on miscellaneous circuits, the likely amount is small relative to the observed differences. Also, the peak observed hourly load in the ELCAP buildings is almost as large as the assumed capacity in the UIC prototypes.

Comparing the profile peak loads to the surveyed (installed) capacities, the average usage fractions are shown to be similar between ELCAP buildings and the UIC prototypes. ELCAP Existing buildings, for example, have a profile peak equal to about 11% of the installed capacity, while the corresponding fraction for the UIC prototype is 12%.

FIGURE 5-30

Equivalent Fully-Occupied Hours
for Equipment in Retails



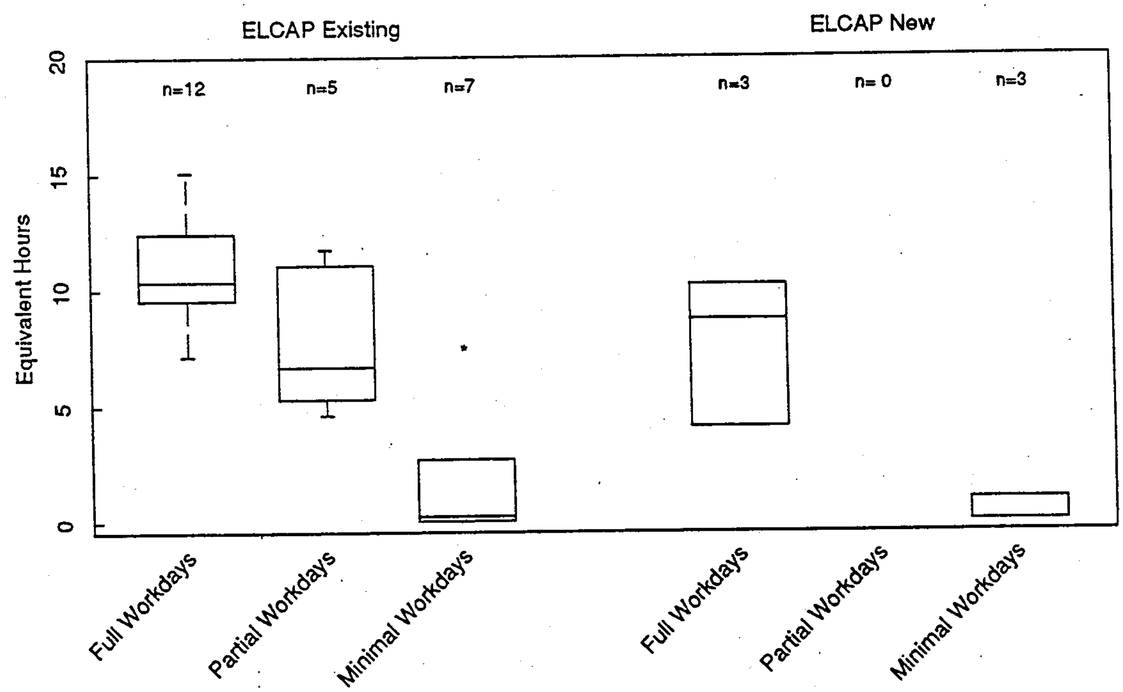
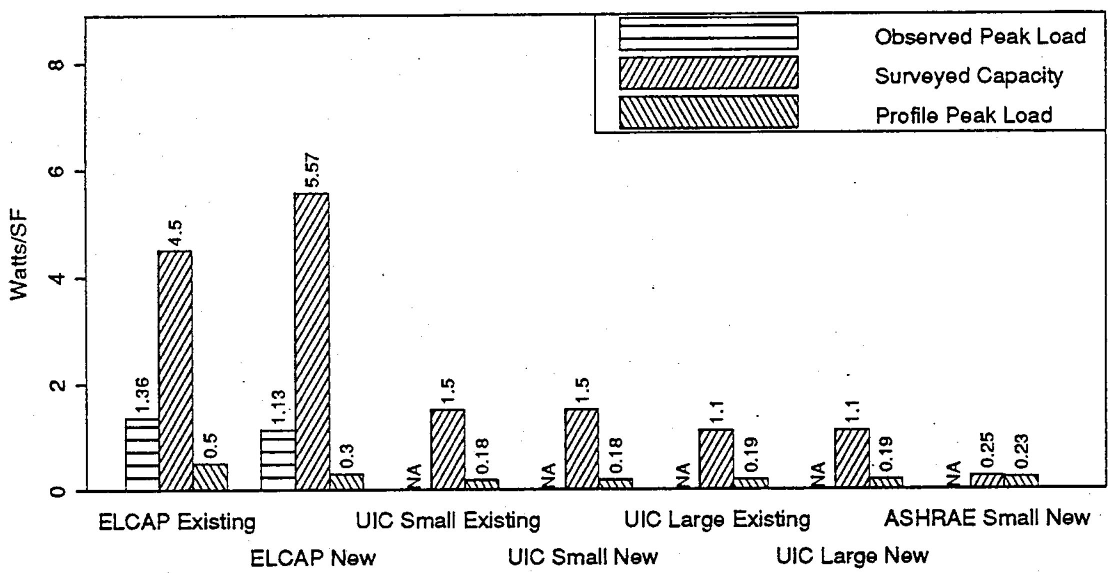
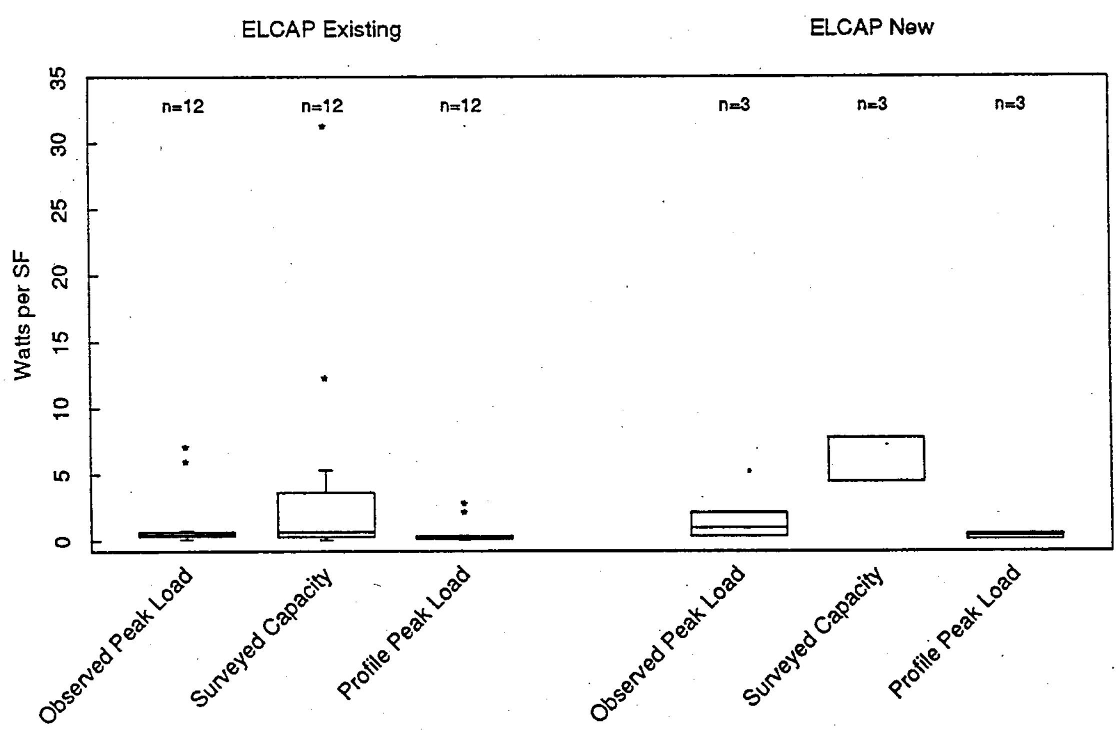


FIGURE 5-31

Equipment Capacities in Retails





Section 6

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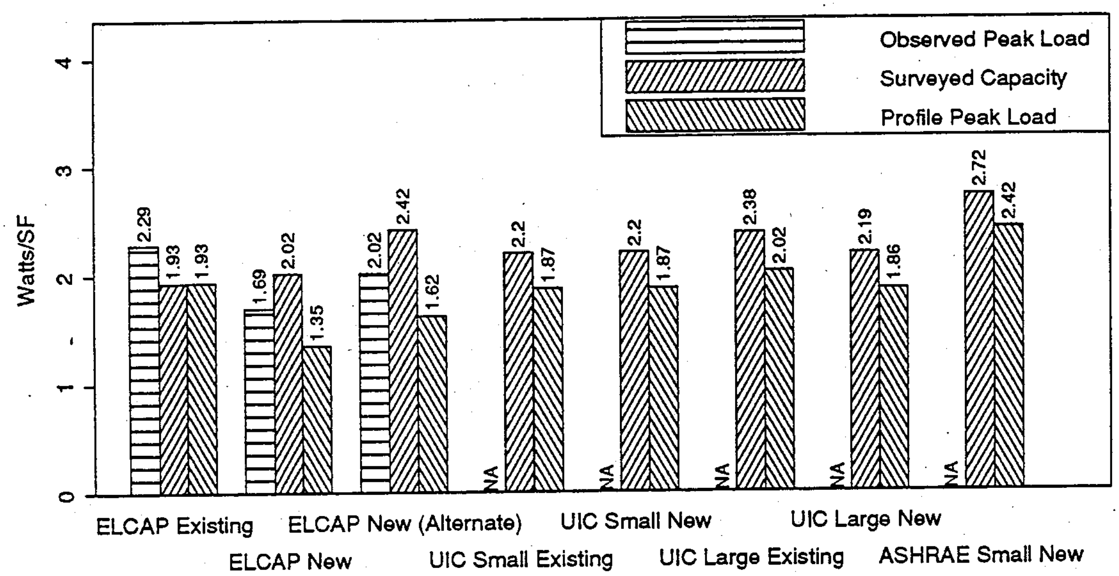
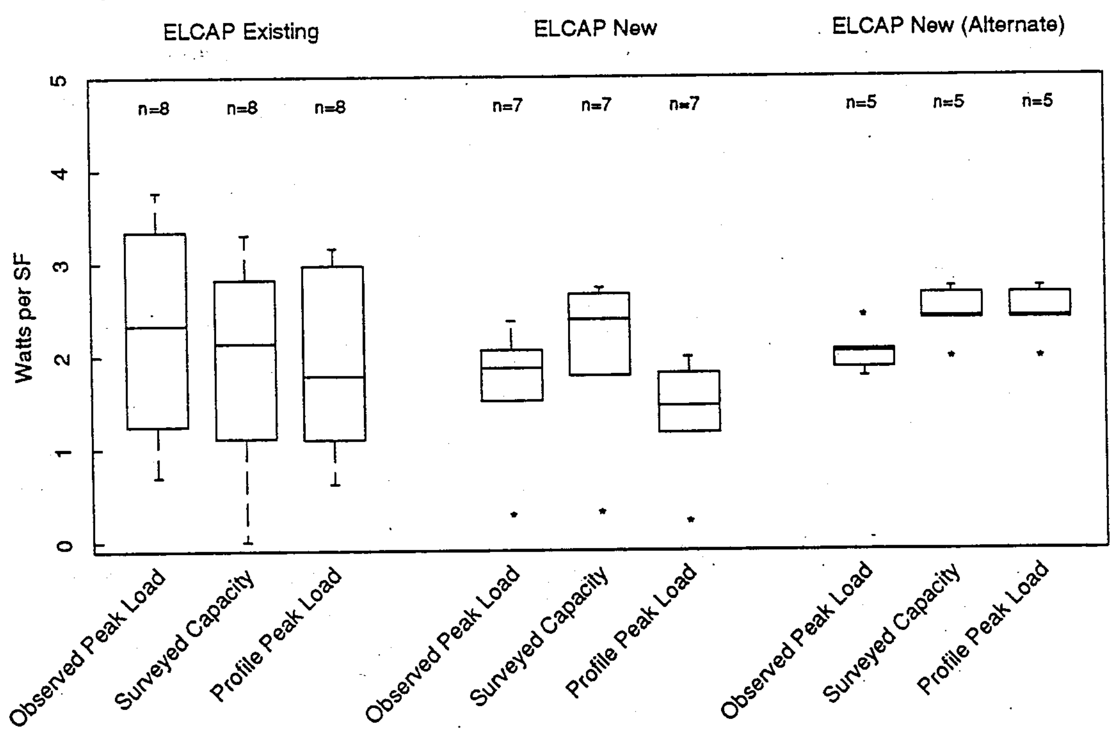
APPENDIX

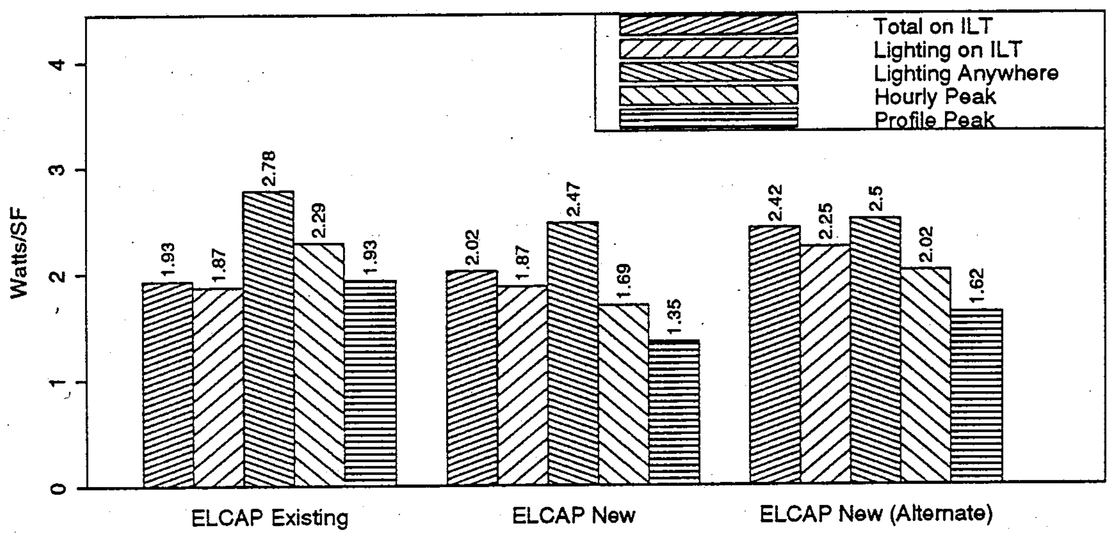
ADDITIONAL ANALYSIS RESULTS GRAPHICS

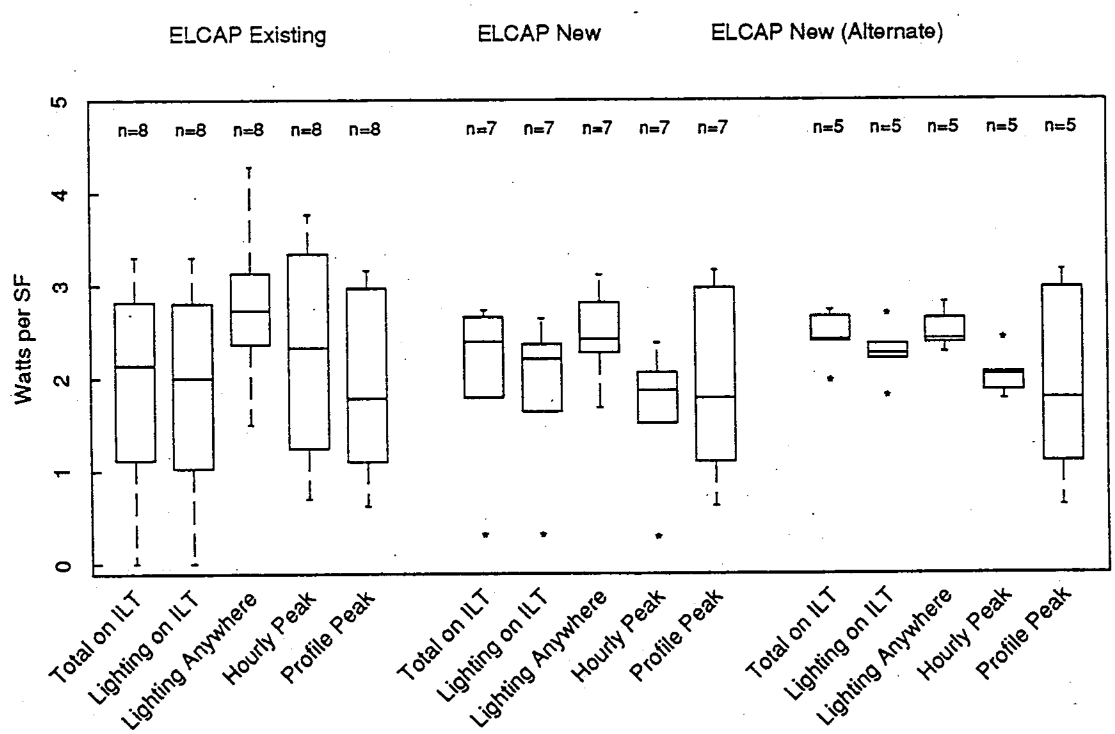
Lighting Capacities in Offices

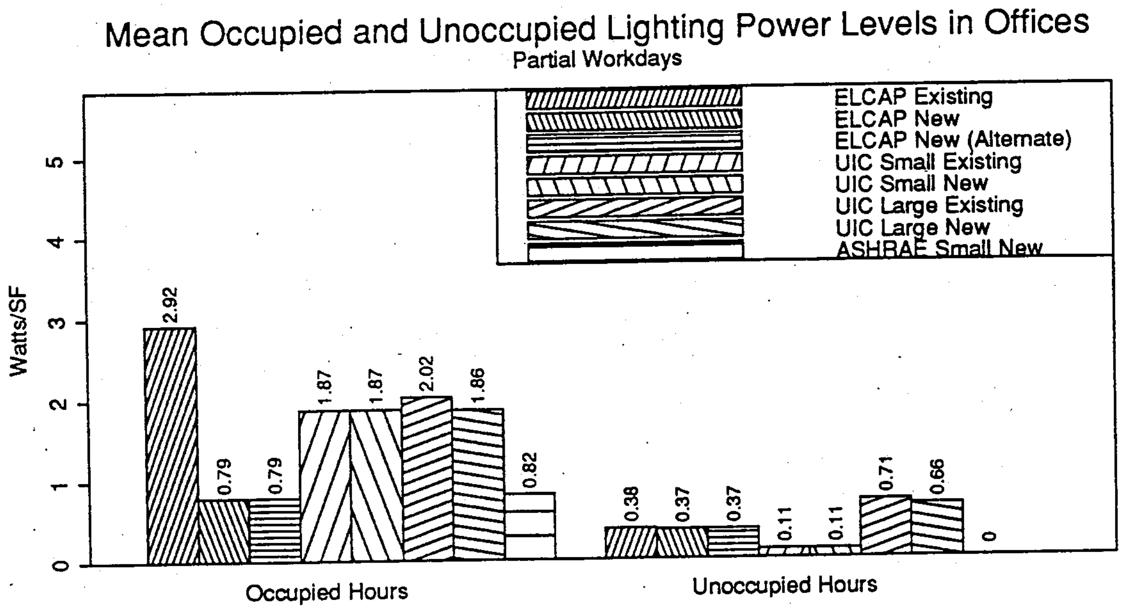


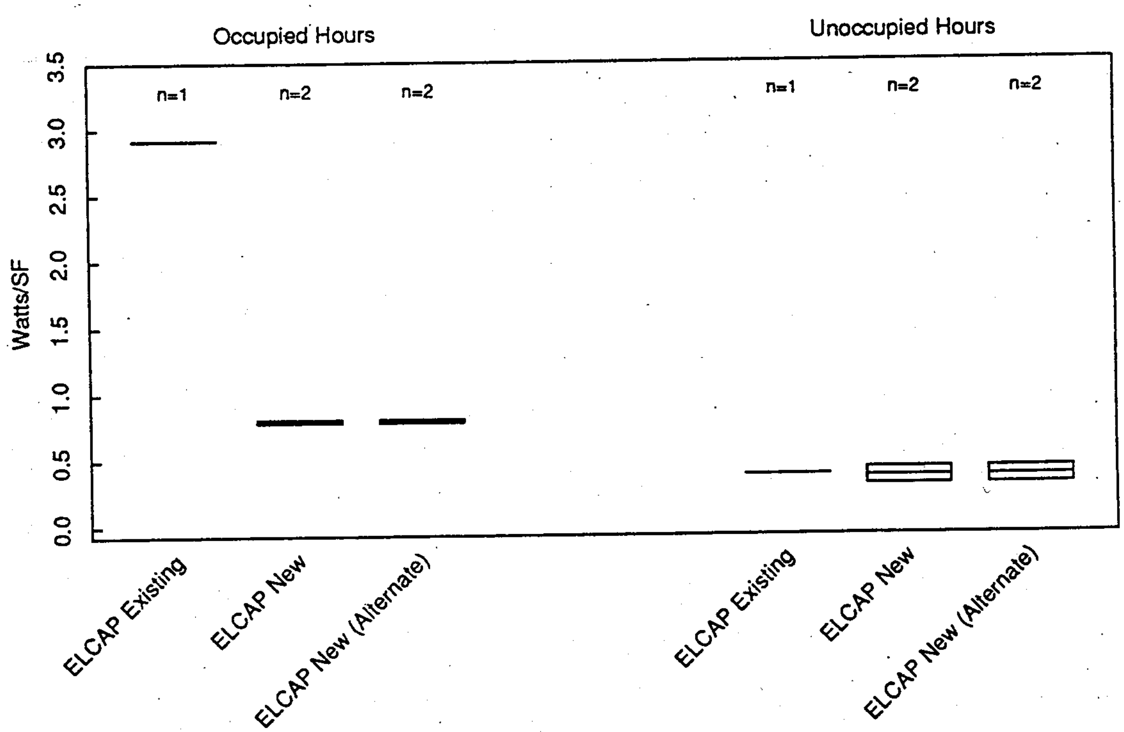


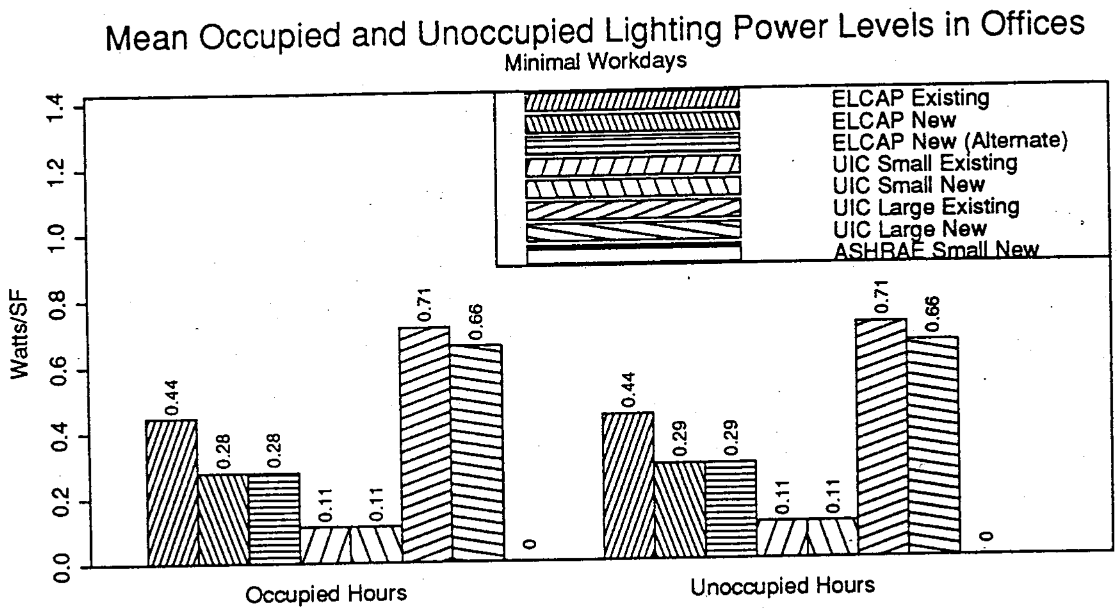
Surveyed Lighting Capacities in ELCAP Offices






Mean Occupied and Unoccupied Lighting Power Levels in Offices
Partial Workdays
ELCAP Existing
ELCAP New
ELCAP New (Alternate)
UIC Small Existing
UIC Small New
UIC Large Existing
UIC Large New
ASHRAE Small New
Watts/SF
2.92
0.79
0.79
1.87
1.87
2.02
1.86
0.82
0.38
0.37
0.37
0.11
0.11
0.71
0.66
0
Occupied Hours
Unoccupied Hours


Occupied Hours
Unoccupied Hours
Watts/SF
n=1
n=2
n=2
n=1
n=2
n=2
ELCAP Existing
ELCAP New
ELCAP New (Alternate)
ELCAP Existing
ELCAP New
ELCAP New (Alternate)



Mean Occupied and Unoccupied Lighting Power Levels in Offices
Minimal Workdays
ELCAP Existing
ELCAP New
ELCAP New (Alternate)
UIC Small Existing
UIC Small New
UIC Large Existing
UIC Large New
ASHRAE Small New
Watts/SF
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
0.44
0.28
0.28
0.11
0.11
0.71
0.66
0
0.44
0.29
0.29
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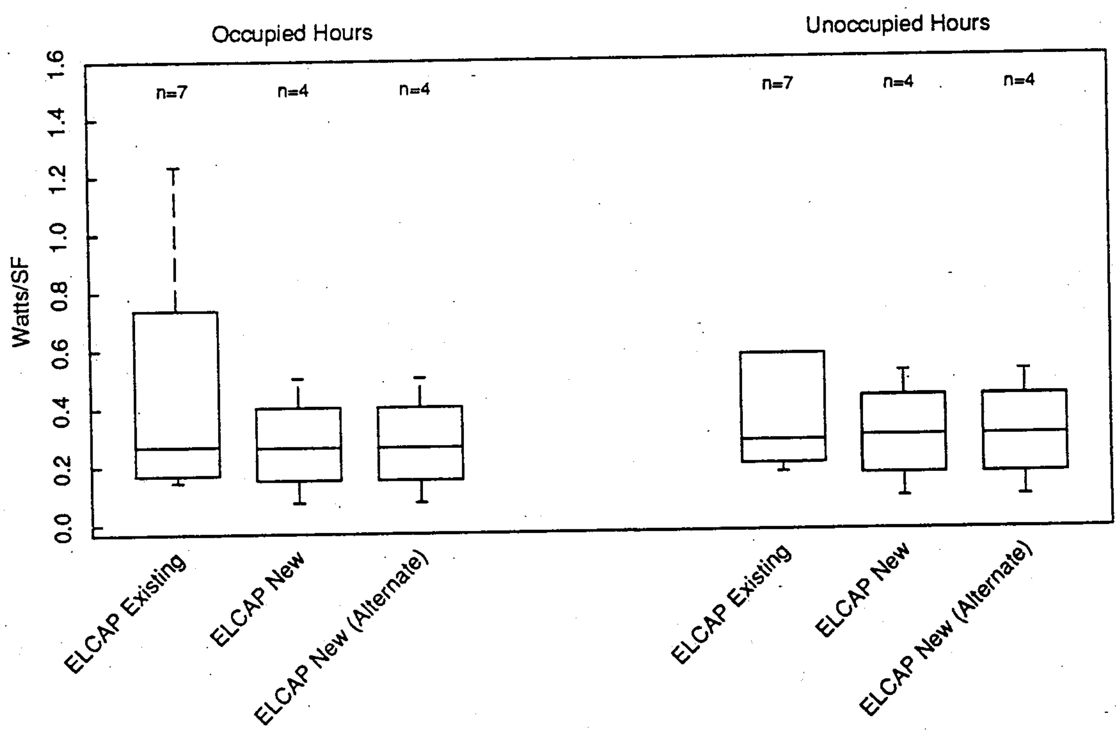
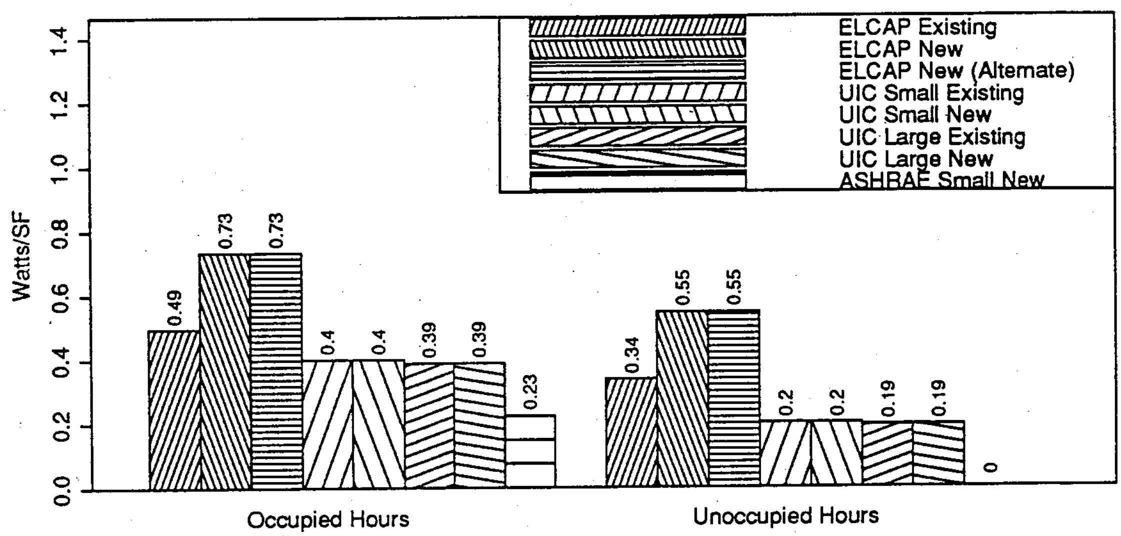
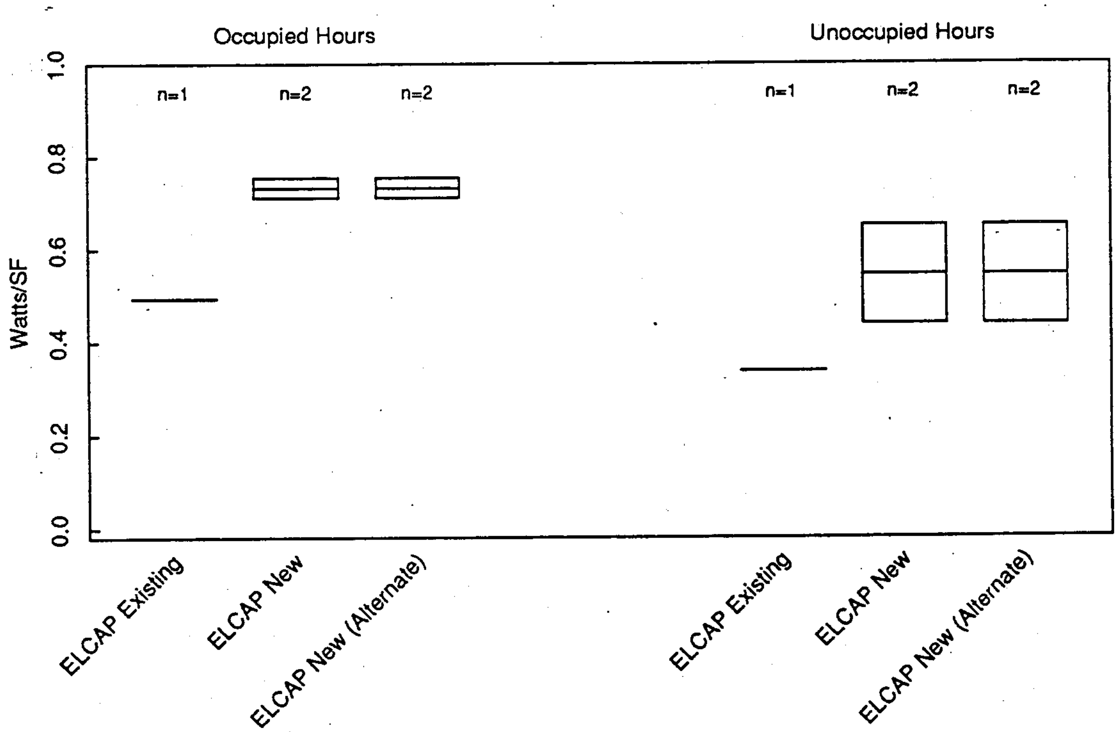
0.71
0.66
0
Occupied Hours
Unoccupied Hours



Occupied Hours
Unoccupied Hours
Watts/SF
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
n=7
n=4
n=4
n=7
n=4
n=4
ELCAP Existing
ELCAP New
ELCAP New (Alternate)
ELCAP Existing
ELCAP New
ELCAP New (Alternate)

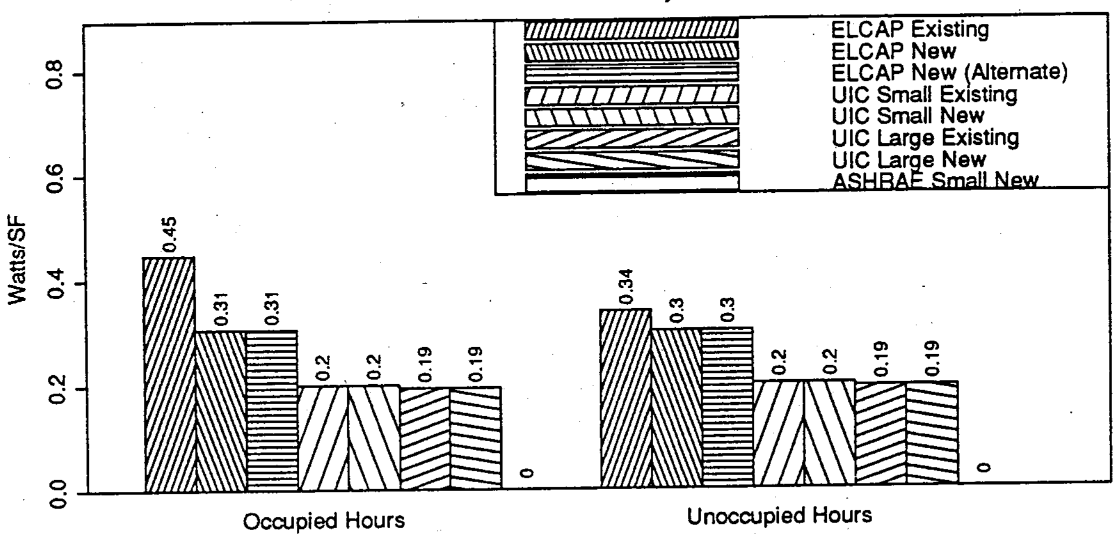
Mean Occupied and Unoccupied Equipment Power Levels in Offices
Partial Workdays

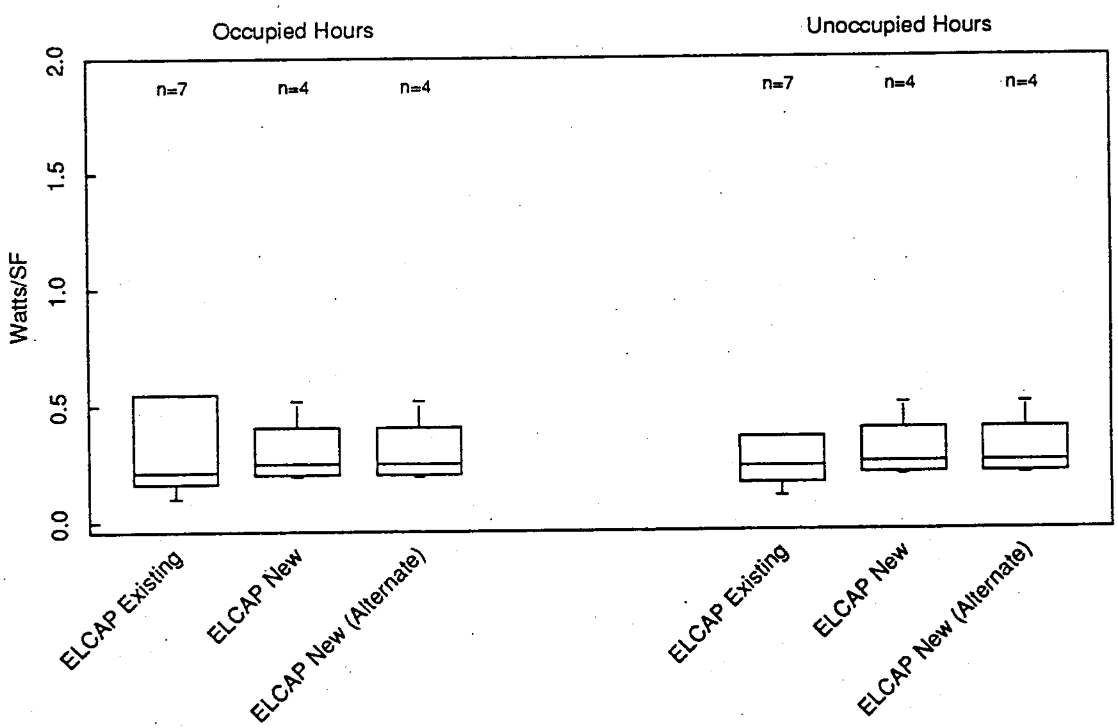


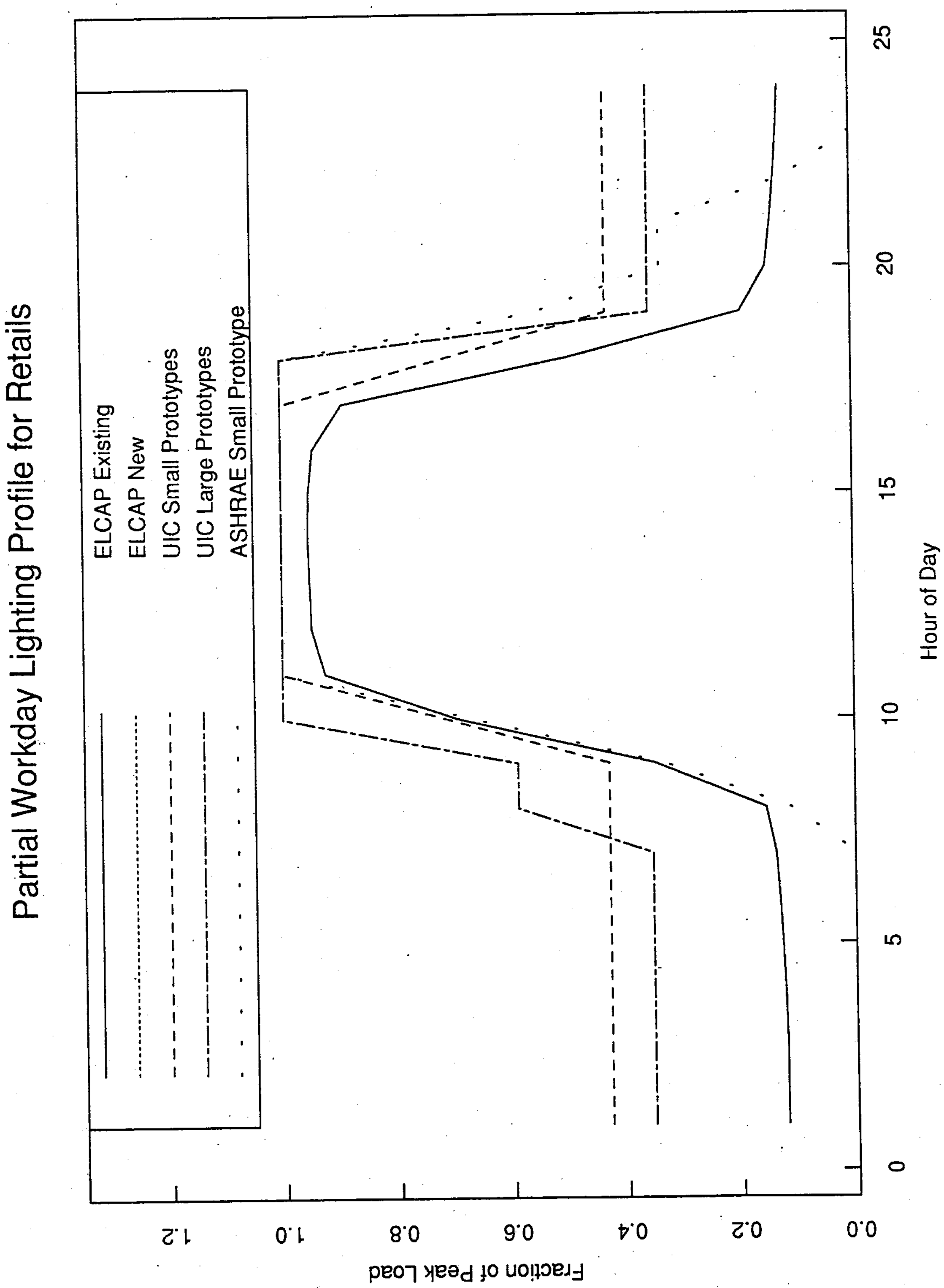


Mean Occupied and Unoccupied Equipment Power Levels in Offices

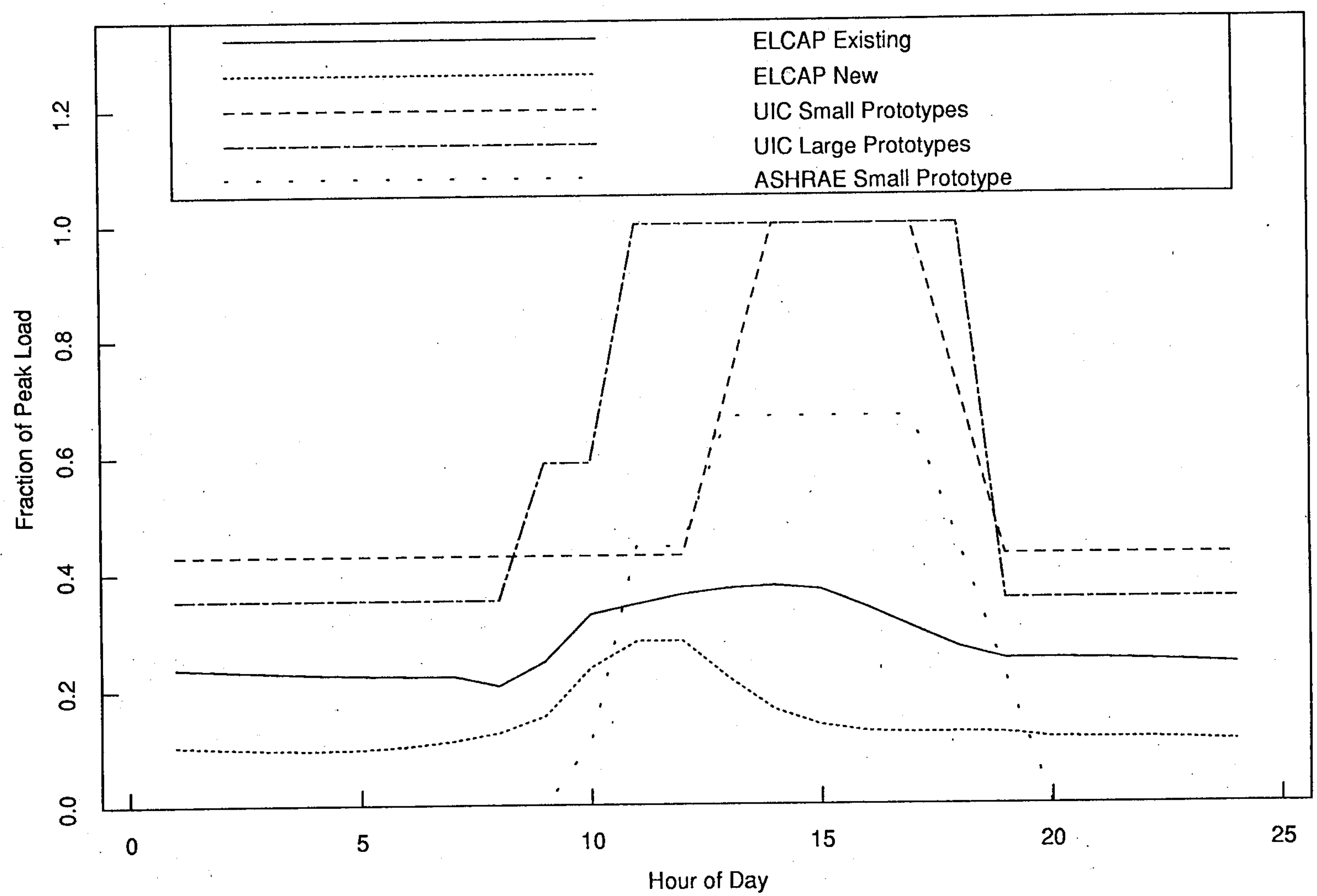
Minimal Workdays

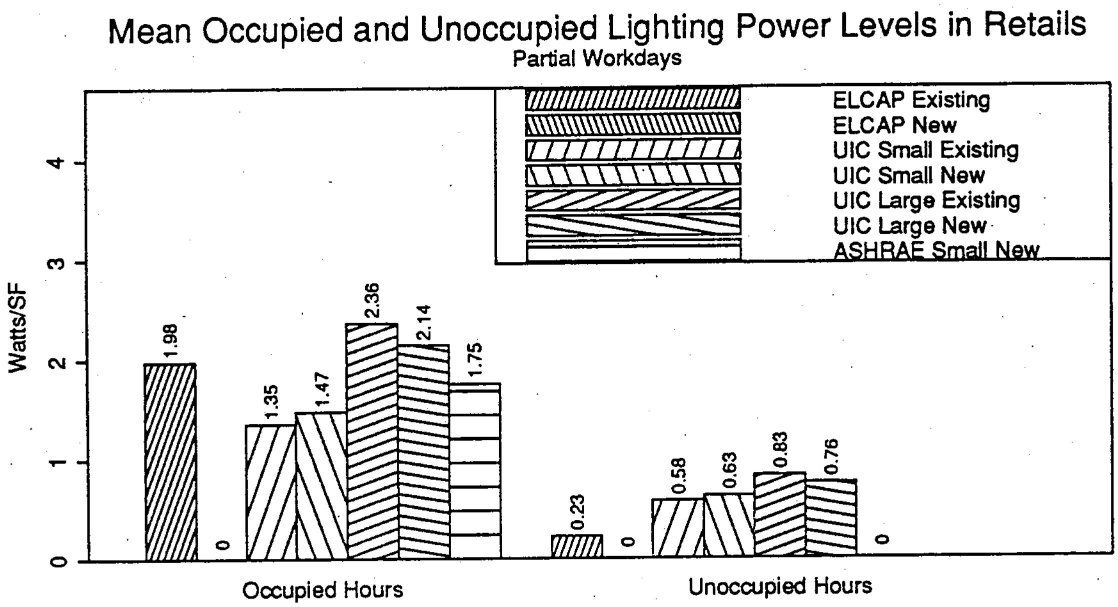




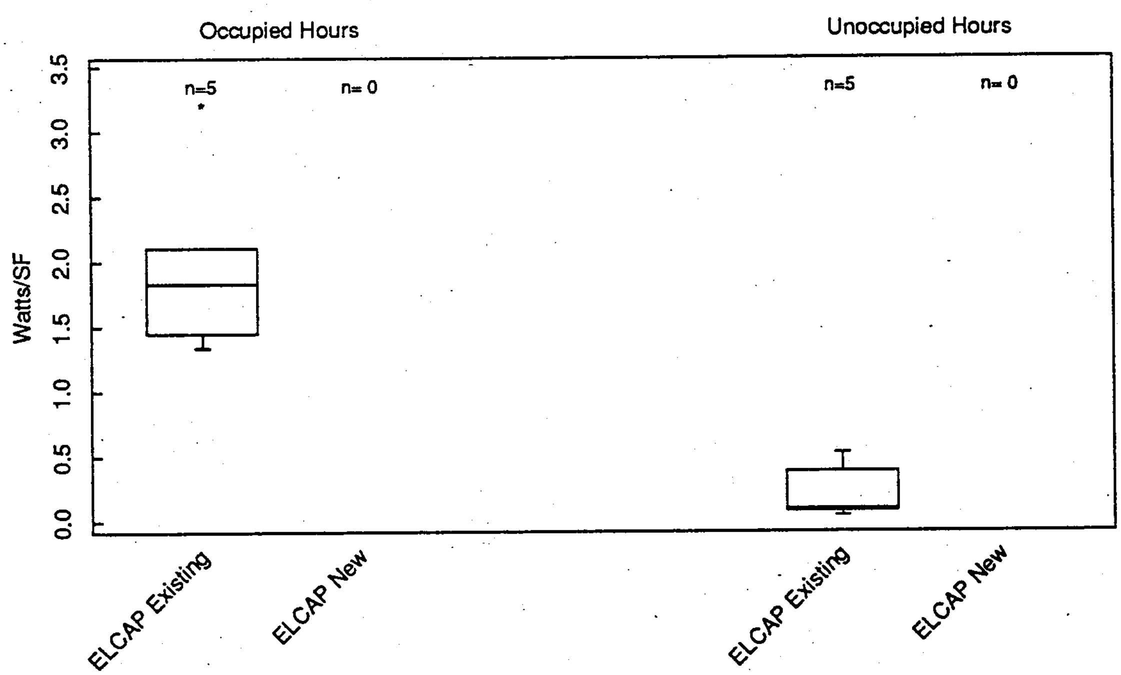

Partial Workday Lighting Profile for Retails
ELCAP Existing
ELCAP New
UIC Small Prototypes
UIC Large Prototypes
ASHRAE Small Prototype
Fraction of Peak Load
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Hour of Day
0
5
10
15
20
25

Minimal Workday Lighting Profile for Retails





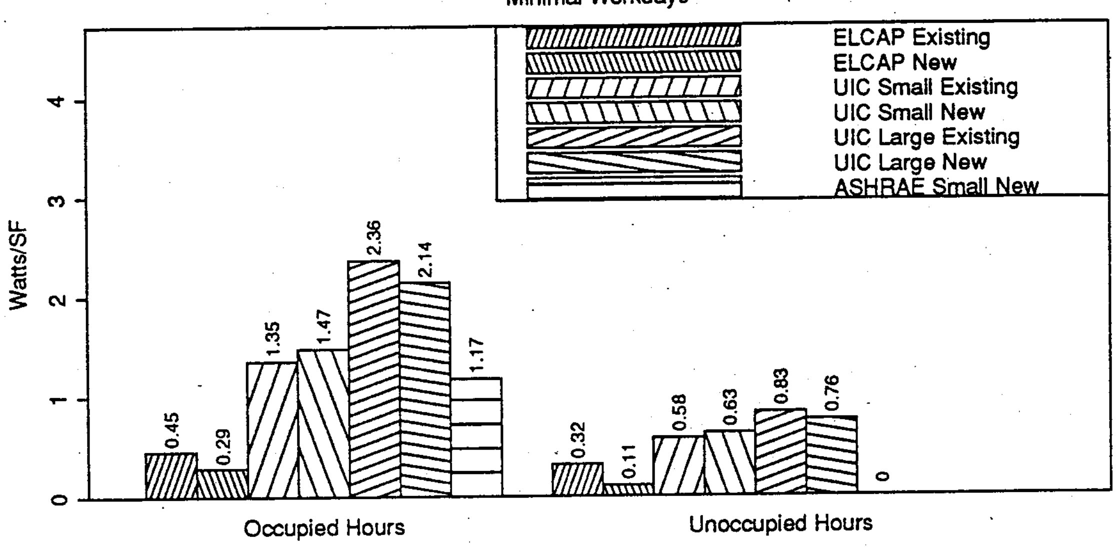
Mean Occupied and Unoccupied Lighting Power Levels in Retails
Partial Workdays
ELCAP Existing
ELCAP New
UIC Small Existing
UIC Small New
UIC Large Existing
UIC Large New
ASHRAE Small New
Watts/SF
1.98
0
1.35
1.47
2.36
2.14
1.75
0.23
0
0.58
0.63
0.83
0.76
0
Occupied Hours
Unoccupied Hours

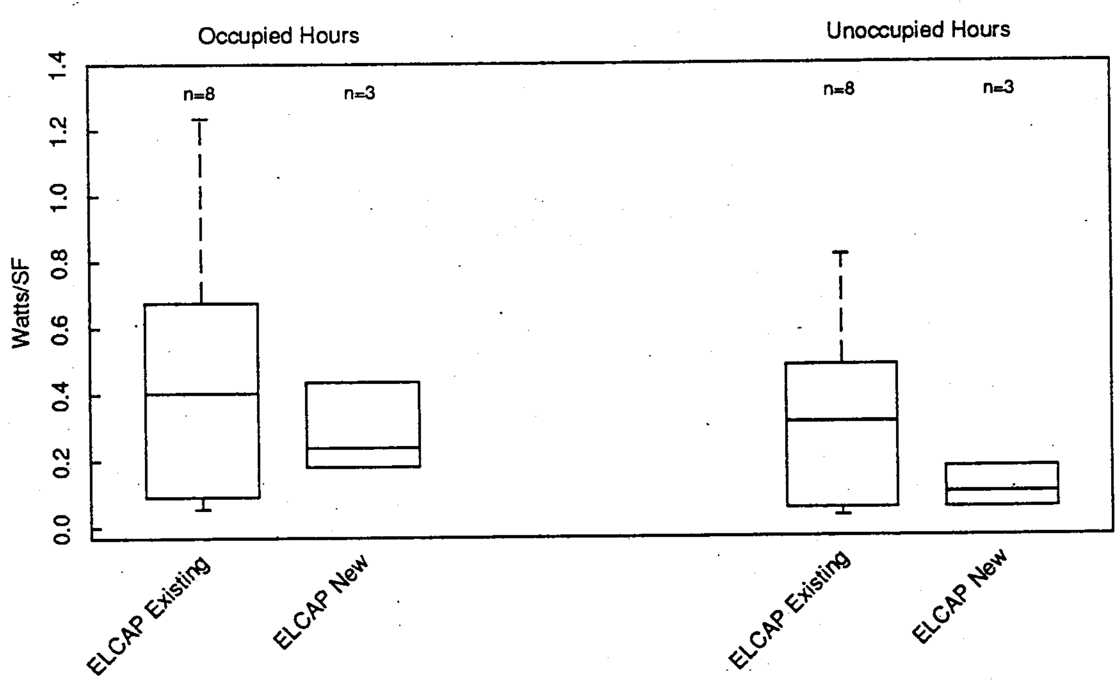


Occupied Hours
Unoccupied Hours
n=5
n= 0
n=5
n= 0
Watts/SF
ELCAP Existing
ELCAP New
ELCAP Existing
ELCAP New

Mean Occupied and Unoccupied Lighting Power Levels in Retails

Minimal Workdays





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