INVESTIGATING AN ANALYTICAL FRAMEWORK FOR IMPROVING COMMERCIAL ENERGY AUDITS: RESULTS FROM A NEW JERSEY MALL

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ABSTRACT

This report describes an investigation of energy use by commercial buildings using results from a case study shopping center in New Jersey. The purpose of this investigation is to discover what problems are occurring in each of the candidate businesses and link these problems to indicators that will lead the energy analyst to those systems that are in need of further attention during the site visit. Useful indices based on whole-building annual, monthly, daily and hourly electricity data are discussed as well as the importance of measurements of internal comfort conditions and lighting levels.(Electricity is emphasized because of data availability).

We show that combined indices (e.g., kW, kWh, size of conditioned space, and occupancy) can provide useful insight and can be used to determine whether certain equipment is over-sized (causing excessive summertime demand), whether equipment is left operating during unoccupied periods and, whether economizers are functioning properly. The results from applying such methods to the case study shopping center, and acting on the problems suggested by the data, could have yielded electricity energy savings in the 5 to 15% range and, of increasing importance, show that cooling-season electric demand could be reduced by 8% (costing about $56/kW) mostly by correcting operation and maintenance problems. We summarize this study by proposing a multi-level approach which utilizes the indices uncovered in this investigation and comment on the usefulness of such an approach.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

1.1. Commercial Building Energy Audits

1.1.1. General

Energy use intensity in commercial buildings continues to grow despite industry efforts to improve efficiency in both new and existing buildings (Brambley et al. 1988, MacDonald et al. 1988). Results from several studies indicate that commercial building energy audits are not being fully utilized, may not be delivering the information that a customer needs to make energy efficiency improvements, and usually do not employ monitoring or feedback procedures needed to track the intended result (ASHRAE 1987c, MacDonald and Wasserman 1989). Although proprietary "canned" commercial building energy audit computer programs are in use by many utilities and state agencies, recommendations can vary dramatically between programs and among different users of the same program (Haberl and Komor 1989). Few, if any, validated, public-domain procedures exist for analysis of energy use in existing commercial buildings.

The traditional energy audit of a commercial building is a complex task requiring the services of building professionals from several fields, including architects, mechanical engineers, electrical engineers, lighting engineers, plumbing engineers, electronic specialists, and others. A traditional energy audit can range in price from $0.02 to $0.05 per square foot of floor space and may require 17 to 68+ hours to complete for a typical commercial building (SMACNA 1985).

A recent assessment of the commercial building energy auditing process performed by ASHRAE for a national laboratory concluded that audits are subject to considerable uncertainty and could benefit significantly from a preliminary analysis of a building's metered data performed prior to the site visit (ASHRAE 1987c). The specific recommendations from the ASHRAE report are listed in Table 1. In summary, we find the recommendations from the ASHRAE survey helpful and have adopted them, and other ideas (Cowan and Jarvis 1984), as a basis to formulate our investigation.

1.1.2. Implications From Two Energy Audits

In order to compare our data-based conclusions to those obtained through a traditional audit, we arranged for a standard utility-sponsored audit to be conducted on the general merchandise store at a case study shopping center which we refer to as the Jersey Mall. We wanted this audit to be as representative as possible, and therefore we followed the steps a building owner might take in arranging for an audit. We called the utility's energy information number, identified ourselves as energy analysts working with the building owner to better understand energy use, and requested a standard energy audit. Due to a (fortunate) error by the auditing firm, two different audits were conducted at the store. These two audits were conducted two weeks apart by two different auditors from the same firm, and neither was aware that the other had audited the building. We therefore have valuable data on what a traditional audit turned up, as well as some indication of the variability caused by different auditors.

The two audits supplied extensive lists of recommended retrofits, estimated costs and savings, and payback periods. In addition, each audit provided a breakdown of energy consumption and energy costs by end-use. The results are summarized in Table 2. As this table shows, the information provided by the audit for the customer is specific and detailed (the full audit report supplies greater detail on the specifics of the retrofits), yet, the discrepancies between the two audits cast some doubt on the accuracy of the information.

For example, audit #1 found a 0.6 year payback on boiler maintenance, yet audit #2 did not make any recommendations for boiler maintenance. Audit #1 estimated energy use for distribution (ventilation) at 30 MBtu, while audit #2 estimated the same value at 672 MBtu. Neither audit mentioned space cooling retrofits nor made any attempt to determine if comfort conditions were being maintained. Both auditors took considerable efforts to count and evaluate lighting, although the conclusions reached were not the same.

In summary, these two audits supply information that is in a usable form, they describe exactly what needs to be done, and the associated costs and savings. However, there are serious doubts as to the accuracy of this information, as suggested by the discrepancy between two seemingly identical audits (they both used the same "canned" computer program approved by the local utility company).

1.2. Objectives of This Study

The objectives of this study are motivated, in part, by the results from the ASHRAE survey and the lackluster performance from the energy audits performed at the Jersey Mall. The objective embraces the development and testing of preliminary metered data analysis procedures that will serve to guide the commercial building energy auditor to those energy conservation candidates most likely to conserve energy and maintain, or better, improve interior environmental conditions.

The proposed, fully developed procedure is composed of several steps and is structured to include an interactive pre-screening followed by several site visits and a post-retrofit monitoring analysis. This paper describes the analysis we performed at the Jersey Mall and presents results, including monitoring efforts, from several small commercial businesses at our case study mall (see the map in Figure 1).

1.3. What's Ahead in This Report

In the sections that follow we describe the case study mall and focus on seven stores (a general merchandise store, a stationery store, a furniture store, and an exercise center that were intensively monitored, and three additional stores that were monitored somewhat less intensively). For each of these stores annual, monthly, daily and hourly indices (based on electricity data) are considered to see what was wrong with each of the HVAC and lighting systems (if anything), and, if something was discovered, if any helpful clues could have been generated (prior to the site visit) that would have helped the building energy auditor.

The additional stores discussed include a drive-up bank, a travel center, and a video store. Following these discussions is a section that describes some thoughts about improving utility billing anomaly identification. In the final section we pull together this diverse study and discuss what type of energy conservation candidates can be observed from historical metered data, determine who can benefit from such an analysis, describe a proposed multi-level analysis, and finish with some thoughts about future research in this area.

Emphasis in this study is on electricity usage, covering air conditioning, lighting and other end uses. Electricity use in the Jersey Mall is metered at the individual store level, and individual businesses are responsible for their electricity bills. On the other hand, heating fuel (primarily natural gas) is mass metered for most of the stores, and only approximately included in the store rents. Since this study focuses on energy audits for individual businesses, and since this metering configuration is fairly typical of small businesses, the analyses in this study are restricted to electricity consumption.

2. THE JERSEY MALL

2.1. General Description

The Jersey Mall contains 52 individual businesses covering 220,000 square feet of conditioned space. The mall, originally built in 1953, consists of an open-air courtyard surrounded by tenant businesses (Figure 1). The businesses in the mall cover a wide range of goods and services, from banks to bakeries. More information on the Jersey Mall can be found in Komor and Katzev (1989), Olsen et al. (1988), Haberl and Komor (1989), Komor et al. (1989), and Reynolds et al. (1990).

Figure 2 presents the monthly minimum, maximum, and average of daily temperatures for the period covering December 1986 through August 1988 (NWS 1989). In addition to the average daily temperatures, minimum and maximum temperatures (i.e., minimum and maximum of average daily temperatures in the billing period) help to provide additional indicators of extreme conditions that occurred during the period of our analysis. For example, in four of the seven stores, during the cooling season, peak cooling-season electric demand is established by operating the air- conditioning system for as little as 30 minutes. Hence, to see this more clearly we find it useful to compare the profile of peak electric demand to the maximum daily temperature rather than to the profile of the average daily temperature.

2.2. Exploring the Jersey Mall: Primary Stores Studied

In this section results are presented from our efforts to conceive and test this method with data from the Jersey Mall. We focus on data from three commercial businesses: a 60,000 square foot general merchandise store, a 3,000 square foot stationery store, a 2,700 square foot furniture store, and an 8,900 square foot exercise center.

For each business selected indices are compared, including: 1) a simple annual energy cost per square foot ($\$/ft^2$); 2) energy usage per square foot of conditioned floor area using power levels (Note: we extend concepts presented by MacDonald [1988] to include average and peak electric whole-building annual and monthly power levels, average daily power levels and average hourly power levels); 3) monthly Electric Load Factors (ELF); 4) monthly Occupancy Load Factors (OLF) (Note: equations for ELF and OLF are contained in Table 3); 5) results from applying the Princeton Scorekeeping Method (PRISM); 6) an evaluation of electricity usage during unoccupied periods; 7) comparative electricity usage profiles (daily and hourly); and 8) an evaluation of interior conditions (i.e., interior temperature measurements and average lighting levels).

For each business the indices are presented together with indications of what could have been obtained from a pre-screening phone survey (i.e., square footage and operating hours). Additional insights are investigated to discover what could have been learned if daily and hourly energy consumption information were available, in advance, from each of the sites. Finally, we summarize the types of energy conservation candidates which could have been uncovered by such a method in order to determine what kinds of data (and how much) are necessary to make informed decisions on energy conservation options.

2.2.1. The General Merchandise Store

The general merchandise store at the Jersey Mall contains a total of 60,000 square feet of conditioned space occupying two floors. The store sells clothing, cosmetics, kitchen equipment and other household items. The walls and roof of the general merchandise store have minimal insulation with only 420 square feet of single pane windows (mostly at two entrance vestibules). The general merchandise store has a loading dock and two daylight stairwells.

The building is heated by a 3.2 MBtu oil-fired, low-pressure steam boiler which provides heat to six 20,000 CFM air-handling units (AHUs) three of which serve each floor. Cooling is provided by a 150-ton ground-water cooled chiller which also utilizes the six constant-volume AHUs for distribution (and two local cabinet-type units above the entrances). Two AHUs on each floor have economizers. Control of the heating system is provided by an open-loop outside-air-reset controller (i.e.,a "Steam Mizer" Controller). Air-handling units are controlled with a recently installed time clock. Control of the cooling system is manual. Domestic water heating is provided by a 75-gallon natural-gas-fired water heater, also recently installed. A salon on the second floor has an additional packaged 5-ton air conditioner.

The store uses about 137 kW for lighting purposes, of which 84% represents fluorescent fixtures, with the remaining 16% primarily consisting of incandescent display fixtures. Measured illumination levels vary from 50 to 60 footcandles. Additional information concerning the general merchandise store can be found in Table 4.

The general merchandise store pays \$1.35/ft^2 annually for electricity, of which electric demand represents 31% of the cost. The annual average power level for electricity usage (calculated by dividing the total annual electricity consumption by the product of the square footage of conditioned space times 8,760 hours) is 1.75 W/ft^2 whereas maximum power levels (peak monthly electric demand) vary from 3.1 W/ft^2 to 4.3 W/ft^2. The average monthly Electric Load Factor (ELF, as defined in Table 3) is 48% which is slightly higher than the Occupancy Load Factor (OLF, as defined in Table 3) of 42% -- an indication that lights and/or equipment may be operating during unoccupied periods.

In other words, the general merchandise building is occupied, on average, 42% of each day. The minimum electric demand power level of 3.1 W/ft^2 indicates an average base-level electricity use. The 4.3 W/ft^2 maximum electric demand power level is smaller than expected and may indicate a very efficient cooling system or an under-cooled building (ASHRAE cites 3 to 7 W/ft^2 for lighting levels in department stores. Energy for cooling would be in addition to this -- ASHRAE 1987a, Chapter 18).

Using two seasons (22 months) of whole-building electricity consumption, we test for weather sensitivity using the Princeton Scorekeeping Method, PRISM. PRISM is a statistical procedure originally developed to provide a weather-adjusted index of energy consumption in residences. PRISM requires whole-building metered data and average daily temperatures from a nearby weather station. PRISM produces a weather-adjusted Normalized Annual Consumption (NAC) that is composed of three primary parameters which describe heating-related and non-heating-related consumption. Details concerning PRISM can be found in (Fels 1986).

Our goal in using a PRISM analysis is to determine statistically the primary functions for which electricity is being used, and how consistent that use is. PRISM allows us to determine heating, cooling and base-level electricity consumption and produces reliability indicators for each of these parameters. One additional step is added, a simple test for determining how "flat" the 12 months of electricity consumption data are. We categorize consumption into five basic categories: 1) base level plus cooling (PRISM Cooling Only, CO), 2) base level plus heating (PRISM Heating Only, HO), 3) base level plus heating and cooling (PRISM Heating and Cooling, HC), 4) base level only (a "flat" consumption profile), and 5) erratic consumption (does not fit any of the above). For a more extensive look at the Jersey Mall using a PRISM analysis see Fels et al. (1990).

A PRISM CO analysis of the general merchandise store indicates that the building consumes electricity primarily for base-level uses (80%), while cooling consumes (20%), and is well determined (i.e., $R^2 = 0.95 > 0.70$, CV(NAC) = 2% < 6%) using the reliability criteria established by Reynolds and Fels [1988] for residential buildings). NAC is defined as the base- level consumption plus the weather sensitive consumption. R^2 is the indicator of the goodness-of-fit. CV(NAC) is the percent standard error of the NAC. PRISM tells us that the majority of the energy is being consumed for lights, fans and other non-cooling related loads.

Next, sliding PRISM CO is applied to 22 months of electricity consumption as shown in Figure 3. Sliding PRISM CO is PRISM CO applied in 12-month increments, sliding forward the estimation period one billing interval (usually one month) at a time. Sliding PRISM CO clearly shows a 5% increase in the area-normalized NAC. There is also a 17% increase in the base-level consumption and a surprising 66% decrease in cooling. Sliding PRISM CO allows us to see that our building has undergone a change. It appears that a significant amount of base-level electricity was added. In contrast, the cooling portion of the electricity consumption has been reduced resulting in a near flat NAC.

Monthly utility records for electricity also contain electric demand information, shown in Figure 4 as peak electric demand power levels (W/ft^2) as described by MacDonald (1988). Peak electric demand power levels for the general merchandise store have risen 6% for non-cooling periods and 2% during cooling periods. When one compares Figure 2 to Figure 4, the high demand levels retained into October and November become evident, even though maximum and average temperatures have declined. This "hanging-on" of the high electric demand in the fall might indicate that the cooling system is being used for only a few days (which sets the peak demand) and might explain the usage drop.

The Electric Load Factor (ELF) and Occupancy Load Factor (OLF) shown in Figure 5 also help to confirm two features; equipment or lights are left operating during unoccupied periods and there is a disparity in peak electric demand and usage in the fall. According to ASHRAE (1987b), when the monthly ELF exceeds monthly OLF there is reason to believe that electricity is being consumed during unoccupied hours. In the case of the general merchandise store ELF indeed exceeds OLF during most months, and especially during the summertime when (according to our hourly measurements) the store manager would leave the 150-ton chiller operating 24 hours-per-day to try to maintain comfort conditions.

Our calculation of ELF varies slightly from that in ASHRAE since ASHRAE calculates ELF using base-level demand and base-level consumption only. We calculated ELF using whole-building demand and whole-building consumption. Although it was not our intent to re-invent this index we did notice that there seems to be some significance when ELF (as calculated with whole- building electricity) dips significantly below OLF. Figure 5 shows that the ELF dips below the OLF in November (while remaining significantly above the OLF during most other months). In the general merchandise store, our site inspections revealed that the economizers were not functioning and that the air-conditioning system was required during periods when free-cooling may have been available, but the system was not capable of taking advantage of ambient conditions. During the spring and fall months, such use of the air- conditioning system sets the peak electric demand at cooling levels without a correspondingly high monthly electricity usage, hence the dip in the ELF. (We also found this to be true in the furniture store.) Because the occurrence is related to the whole-building usage, it would not have shown up in the ELF as ASHRAE defines it.

One can further use monthly OLF, base-level electric demand (kW) and base- level electricity usage (kWh) to construct an hourly base-level model of electricity used for lights and fans (this model is graphically illustrated in Figure 11b). Here the electric demand for a typical non-cooling month (e.g., February 1988 = 186 kW) is assigned to all hours the store is open. The calculated electricity consumption (e.g., 186 kW * 291 hr. = 54,126 kWh) for this estimated portion is then subtracted from the actual electricity consumed during February 1988 (67,050 kWh), resulting in a difference of 12,924 kWh (19%). The 12,924 kWh are then assigned evenly over the remaining 405 unoccupied hours which creates an average unoccupied consumption level of 32 kW.

With this information we can now gain some insight into the hourly operating characteristics of the building during occupied and unoccupied periods. This method is very simple to apply yet seems to yield results similar to more complex methods that require hourly data as input for regression techniques (Akbari et al. 1988) or other sophisticated matrix decomposition methods including Singular Valued Decomposition (SVD) proposed separately by Verdi (1989) and Anderson et al. (1989), and Principal Component Analysis (PCA) used by Hadley and Tomich (1986). This simple method may, in fact, have certain advantages since the primary coefficient (i.e., the occupied period, base-level electricity) represents a physically meaningful parameter (i.e., one parameter that would show the daily electricity used for lights and fans during occupied periods of the non-cooling season).

For energy auditing purposes such information is very instructive. For example, this simple comparison implies that 19% of the base-level electricity (kWh) is consumed during unoccupied periods. With such preliminary information in hand one should certainly investigate what lighting and equipment is left operating during unoccupied periods.

With detailed hourly electricity consumption data we can compare the base- level consumption to the actual consumption to see how consistently the store is operated. One could even iteratively investigate the perceived operating schedule and compare this to the posted operating schedule to see whether lights and fans are being turned-on too early in the morning, left- on too late at night, or both.

Figure 6 illustrates a comparison of the daily base-level model (daily sums of the hourly model) and actual daily electricity consumption (obtained through instrumentation) for the general merchandise store. As expected, our store consumes electricity in a consistent fashion: Mondays through Fridays it uses about 1.5 to 2.0 W/ft^2, and has an expected drop in consumption for Saturday and Sunday since the store is open fewer hours on those two days.

Several of our indices have indicated that electricity consumed for cooling purposes may not be sufficient to provide space cooling in the general merchandise store. To investigate this further measurements of interior conditions were taken. As others have indicated (Nordman and Meier 1988), simple measurements of interior zone temperature can allow for a basic evaluation of comfort conditions. In Figure 7 we illustrate data from simple minimum-maximum thermometers placed near the thermostat and read once per day in the early evening (for the period representing March 1988 to December 1988 for general merchandise). For the general merchandise store we show the data for the first floor in Figure 7. Clearly, this zone has dramatic fluctuations in temperature both during the cooling season and non-cooling seasons -- a strong indication of a lack of thermostatic control and clearly uncomfortable conditions. In mild weather conditions (i.e., ambient temperatures of 30 to 60 F) interior temperatures can rise into the mid-80 F (usually in the afternoon when the chiller was not running) or drop into the 50 to 60 F range (an isolated condition for this store only, occurring during the heating season when the loading dock doors remained open during a delivery).

Finally, we look at how hourly whole-building electricity data and zone temperatures can provide the building energy analyst with additional useful information. Figures 8 through 11 illustrate some techniques for discovering how consistently comfort conditions and operation schedules are maintained.

Figure 8 shows the hourly power levels for the general merchandise store together with the corresponding zone temperatures for the first 41 days of 1989. The hourly power levels reveal what annual, monthly and daily indices have been hinting. In this case, we see that occupied-period hourly power levels consistently reach 3.0 W/ft^2 and drop to about 0.75 W/ft^2 at night. Hence, for this building, peak monthly electric demand power levels do serve as a reasonable indicator for the occupied-period hourly power levels (one would expect this since it is based on a utility meter which records a 30-minute sliding-window electric demand versus a 15 minute demand). The monthly electricity usage power level indicates the average of hourly power levels.

Figure 8 also indicates erratic first-floor temperatures (when compared to the stationery and furniture stores and exercise center); periods when the interior temperature reached almost 80 F as well as periods when it dropped to almost 60 F. The erratic first-floor zone temperatures were also indicated in the daily minimum-maximum temperatures in Figure 7. (The site visits to the stores revealed that fluctuations in the interior temperatures were due to a lack of thermostatic control. Also, the first floor is often subjected to cold air coming in through the adjacent loading dock doors during deliveries -- one reason for the abnormally low minimum temperatures in Figure 7).

Figure 9 displays the hourly energy use for the general merchandise store as a 3-D profile. The time-of-day and day-of-the-year form the x-y plane and the electricity use is displayed as a surface above the temporal x-y plane. Hourly electricity use (kWh/h) is measured along the vertical z- axis. Figures 9 (a) and (b) show 366 days of electricity use at the general merchandise store beginning on March 14, 1988 (day 73) and continuing through the first of the year and ending on March 13, 1989. Figure 9 clearly exhibits features that remain hidden to us when viewed in daily, monthly, or annual graphs.

One of the methods reported by Reiter (1986), and others, provides us with a means of classifying the spatial profiles that can be seen in Figure 9. Figure 10 illustrates such profiles. When we examine Figure 9 again, keeping these profiles in mind, we can obtain some additional insights as to how our building is consuming its electricity when compared graphically (using the profiles) to similar buildings (see Haberl et al. 1988a, or Akbari et al. 1988). We can clearly see that we have a dominant, scheduled daily electric base-level profile which represents lights, fans and electrical receptacles. What we do not see is an archetypal profile for cooling. This might be indicating to us that our cooling system is operating more like a scheduled process load. This can be caused by several conditions, namely: that the building does not have a refrigerative cooling system; that the building's refrigerative air-conditioning system is significantly under-sized; or that the building's refrigerative air- conditioning system is operating under severe constraints.

Our site inspections and conversations with contractors and the owners reveal that the building's chilled water system is operating with severely clogged pipes -- caused by 36 years of fouling by ground-water being circulated directly through the cold-deck in the air-handling units. This is one reason why uncomfortable cooling-season interior conditions exist, the other is the presence of paneled-over return-air vents which occurred during a previous remodeling.

Several additional features are worth pointing out in Figures 9a and Figure 9b. First, around-the-clock operation of the chiller can clearly be seen about day 223. Immediately following this, notice the new "smoothness" of the early morning hours -- the effect of a newly installed time clock which turns the air-handling units on at about 7 a.m. Finally, the around-the- clock operation of the air-handling units during the heating season can be seen starting shortly after day 283. Days where the consumption falls to zero are missing data.

Figures 11a-d illustrate some additional important points about how the building is being operated. (see Haberl and Vajda 1988 for other applications of this type of graphical display) To obtain these plots the base-level model (Figure 11b) is subtracted from the measured hourly electricity consumption and sorted into residuals representing positive (Figure 11c) and negative groups (i.e., absolute value of the negative residual, Figure 11d. Technically speaking, Figure 11d is actually the absolute value of the negative residual). Doing so reveals several features that remain hidden to traditional techniques of unraveling the actual hourly electricity profile plot.

First, the goodness-of-fit for the base-level model can be readily observed, specifically, electricity is being used, during unoccupied hours for lights and fans -- in this case the staff are turning lights on about 30 - 60 minutes before the posted opening time of 10:00 a.m. and sometimes leave lights and fans on in the evening past the posted closing time of 9:00 p.m. On Sundays, lights and fans tend to be turned on at, or slightly after, the scheduled opening time (hence the negative spike). Also visible are periods when the building was closed when the schedule indicated it should have been open (i.e., January 2, 1989, and January 6, 1989, holidays that we were not aware of).

SUMMARY - GENERAL MERCHANDISE: In summary, the general merchandise store is an average consumer of electricity compared to the other businesses at the mall. The lights and fans in the general merchandise store are controlled in a reasonably consistent fashion and most (but not all) loads are extinguished at night when the store is closed. The store may be somewhat uncomfortable as indicated by the indoor air temperature data (due to inadequate delivery of the chilled water to the air-handling units), and therefore further information needs to be obtained about the HVAC systems. One significant finding that arises from a preliminary look at the store's metered consumption data is that 19% of the store's electricity is being consumed when the store is closed. Had these conclusions been available to the energy auditor, a guided site visit could have been performed with results much improved over those seen in the commercial building energy audits performed on the store (Haberl and Komor 1989).

To confirm our hypothesis drawn from the data, we made numerous site visits to the store. Indeed, we found: 1) a lack of thermostatic control, 2) fouled chilled water piping (which might account for the decreasing cooling related energy usage), 3) air-handling units running in the evening (wintertime), 4) malfunctioning economizers and abandoned control systems, 5) blocked return-air grilles, and 6) slightly above-average illumination levels. A night walk-through revealed about 10 kW being used for lighting, 3 kW being used to power 24 cash registers (that must be left running to maintain their internal computer program), and 15 kW being used to idle a 50-horsepower D.C. motor-generator set used by the freight elevator, with the remaining 4 kW being used for telephone switchgear and electric receptacle loads. Most of these problems were suggested by a careful preliminary look at the monthly energy consumption data.

2.2.2. The Stationery Store

The stationery store contains 3,000 square feet of conditioned space and about 2,900 square feet of unconditioned basement used to store the stationery and office supplies sold by the store. The store has minimal insulation in the roof and walls (three of the four walls are exposed to the environment). The stationery store has 502 square feet of single-pane windows. Two entrances are located on opposite sides of the stores, neither has vestibules.

Heating is provided by a 250,000 Btu/h natural-gas-fired rooftop package furnace. Cooling is provided by a 7.5-ton air-conditioning system contained in the rooftop package unit. A separate 100,000 Btu/h duct heater provides occasional heat for the basement storage area. Control of the heating and cooling system is provided by a combined heating-cooling system without night setback.

The total lighting load (i.e., the first floor fluorescents plus basement incandescents) represents 9.5 kW. Fluorescents account for 68% of the total lighting load with the remainder representing incandescents that occasionally illuminate the basement storage area. Measured illumination levels vary from 50 to 80 footcandles. The store does not have a domestic water heater. Further information concerning the stationery store can be found in Table 4.

The annual indices indicate that the stationery store is a low energy business consuming only \$0.65 of electricity annually per square foot, of which 40% is demand-related electricity costs. Annual electricity usage is a low 0.78 W/ft^2, although peak monthly electric demand appears surprisingly steady at 2.47 to 2.87 W/ft^2. An average monthly ELF of 27% is almost the same as the average OLF of (29%) which indicates that the store is only open for business, on the average, about seven hours each day (i.e., an average 24 hours times 28% equals 7 hours-per-day). When a base- level model is constructed (using information from the OLF, monthly base- level [kW], and monthly base-level [kWh]) only 2% of the store's monthly electricity appears to be consumed when the store is closed.

This store is clearly a low energy business (0.78 W/ft^2) and a simple look at annual W/ft^2 or \$/ft^2 could have indicated this (i.e., \$0.65/ft^2). However, several of the annual indices yield some additional hints as to why. First, the 2% unoccupied base-level electricity consumption indicates that very little electricity is consumed when the store is closed. Further, near equal minimum monthly peak electric demand (2.47 W/ft^2) and maximum monthly peak electric demand (2.87 W/ft^2) indicate little or no variation in electricity during cooling or heating seasons -- a possible indicator that the store does not have electric cooling (or heating) or that it is provided from another source.

A further look at the monthly electricity consumption and demand data reveals a clear lack of cooling season sensitivity -- a possible lack of air-conditioning. When we apply PRISM the PRISM CO analysis fails to detect any increase in the electricity consumption during the cooling season. This is indicated by the low R^2 and a negative cooling slope (a physically unreasonable number). A test which differentiates between "flat" and "erratic" base-level consumption can also be applied to the monthly data. In its simplest form such a test takes the mean and standard deviation of 12 months of electricity data and is slid forward in one-month increments (in a similar fashion as sliding PRISM) as shown in Figure 12. From this plot one can see that the stationery store has experienced a gradual reduction in electricity use of about 7% and a corresponding 23% decrease in electric demand. The monthly OLF indicates a relatively consistent 28% occupancy. Since cooling season influence is not apparent, the fluctuations in the ELF (Figure 14) would most likely be due to very minor differences in kW and kWh levels and are probably not meaningful in the case of the stationery store.

The monthly data (Figure 13) help to confirm what was indicated from the annual indices -- a lack of air-conditioning. The monthly data also clearly indicated decreasing electricity usage and demand levels.

Daily electricity consumption data for the stationery store continue to clarify the picture of the store's electricity usage (Figure 15). First, the store is consistently operated on a fixed schedule. Second, the low annual indices are confirmed by the fact that on Sundays virtually no electricity is consumed by the store. The store was closed an extra day (Monday, January 2, 1989), hence the -1 W/ft^2 negative residual consumption spike (i.e., absolute value of the negative residual).

The minimum-maximum zone temperatures for the store add a new dimension to the picture (Figure 16). First, in contrast to the temperatures for the general merchandise store (Figure 7), this store appears to have some type of cooling system as evidenced by the flattening of the maximum temperatures when ambient temperatures rise above 60 F. Second, during the heating season, maximum temperatures remain in the 70 to 75 F range and minimum temperatures level-off in the 60 to 65 F range -- an indication that the store is unheated (or that the thermostat is may be consistently setback at night) when unoccupied.

The hourly data allow us a chance to begin to confirm the indications from the annual, monthly and daily data. Figure 17 shows daytime power levels that are about 2.3 W/ft^2 and an absence of electricity consumption when the store is closed. The hourly zone temperatures confirm the indications from the daily minimum-maximum readings -- specifically, the store is conditioned during occupied hours and is either placed in a nighttime setback mode or is not conditioned during unoccupied hours.

Finally, hourly comparative profiles of electricity usage reveal how consistently the store is consuming electricity (Figures 18a-d). Remarkably, actual electricity consumption (Figure 18a) has a shape almost as consistent as our base-level model (Figure 18b), with only a few exceptions. First, in

Figure 18c we see that on a few occasions loads are left on for as much as one hour after closing (in the case of this store all lights are switched off at one panel when the owner leaves -- hence this load could also represent the total load for only part of an hour). Likewise, in Figure 18d actual consumption is now consistently below the level of the base-level model (which was calculated with information from March 1988). The store seems to open slightly late on Fridays (and sometimes Thursdays). Finally, the store was closed for the entire day on January 2, 1989, and one hour early on January 6, 1989.

SUMMARY - THE STATIONERY STORE: In summary, we see that the stationery store is a low energy business, mainly because there is no apparent air- conditioning load being recorded by the utility meter assigned to the store, yet there is evidence of air conditioning in the zone temperature data. The lighting and fan levels have been consistently reduced, as shown by the decrease in electric demand and usage levels over the 22 months under observation. The store owner is remarkably consistent in operating the manual night set-back. Any energy analysis conducted with only the electricity recorded by this one utility meter would require more information about where the connected load for the air conditioning is being recorded before meaningful conclusions could be made concerning cooling-related (or heating-related) energy usage.

Site visits to the store confirm the preliminary indications. First, the store is air conditioned. However, a new rooftop air-conditioning unit was recently added and the unit was circuited through another utility meter (the additional cost is part of their lease arrangement). Second, over time, the owner has not re-lamped 38% of the fluorescent fixtures, thereby reducing the lighting-related electricity demand from 3.5 W/ft^2 to 2.2 W/ft^2. This does not seem to have adversely affected the lighting levels since illuminance measurements taken during the site visit indicate adequate lighting levels of 50 to 80 footcandles are being maintained.

In contrast to the general merchandise store (and the other stores studied), few if any, rapid payback energy conservation candidates could be identified for the stationery store. Subsequent visits did identify several envelope measures (e.g., a partially shut outside-air vent, inadequate insulation levels in re-paneled exterior walls, and an abandoned ventilation hood that needs to be sealed up). However, since the electricity consumption of the air-conditioning unit was being recorded by a separate meter (which included other electrical loads not serving this store) these measures could not have been foreseen from a preliminary analysis.

2.2.3. The Furniture Store

The furniture store at the Jersey Mall contains 2,700 square feet of conditioned space with about 1,000 square feet of unconditioned storage space located directly below the store. The furniture store is located in the same building as the stationery store with only the front, back and roof of the store exposed to environmental conditions. Single-pane windows account for 178 square feet of the exterior envelope. Two entrances are provided on opposite sides of the store, neither has vestibules.

The store is heated by a 180,000 Btu/h duct furnace and cooled by a 15-ton rooftop air-conditioning unit (which has two separate 7.5-ton compressors). The air-handling unit contains an economizer. The store requires 9.9 kW for lighting purposes. Fluorescents represent 94% and incandescents, used occasionally to illuminate the basement, represent the remaining 6%. Measured illumination levels varied from 70 to 110 foot-candles. The store has a 66-gallon electric water heater. Further information concerning the furniture store can be found in Table 4.

The annual indices for the furniture store tell a dramatically different story than either the stationery or general merchandise store. First, the $1.77 per square foot electricity cost is high compared to similar businesses at the mall. This cost incorporates a 49% electric demand portion (one of the highest at the mall). The annual electricity power level (kWh) of 1.46 W/ft^2 is moderate, but monthly peak electric demand (kW) power levels vary from 4.3 to 11.3 W/ft^2. This range suggests that there is a high base-level daytime electric demand and high maximum (cooling season) peak electric demand. The 5% electricity consumption during unoccupied hours indicates that the owners are turning equipment off at night. The annual OLF of 26% indicates that the store is open slightly less than the stationery store. The average monthly ELF of 23% closely matches the OLF and reinforces the indication that lights and equipment are being turned off during unoccupied hours.

For the furniture store a PRISM CO analysis indicates that the building consumes electricity for base-level uses (77%) and cooling (23%) and is also well described (i.e., $R^2 = 0.97$, CV(NAC) = 2%). Sliding PRISM CO shows us that the store has been reducing the overall electricity usage (Figure 19); specifically, NAC has dropped by 5%, base-level electricity has dropped by 10%, while electricity used for cooling has risen by 15% from September 1986 to July 1988.

The monthly power levels begin to reveal the story behind the furniture store's high electric demand (Figure 20). First, peak electric demand levels (kW) are almost three times those of the general merchandise store. Yet, the electricity usage power levels (kWh) for these two stores remain similar to each other. Erratic electric peak power levels are present during February 1988 and March 1988 without any corresponding increase in electricity usage (possibly a winter-time use of air-conditioning system?). Finally, peak demand electric levels have decreased by 15% (both cooling and non-cooling periods) which implies a decrease in base-level energy consumption.

The monthly comparison of ELF and OLF for the furniture store (Figure 21) seems to be a better indicator of excess electrical demand than it is for either the general merchandise or stationery store. ELF dips below OLF during spring and fall months when the air conditioner may be required only for a few days. Hence, peak electric demand rises to cooling season levels without the corresponding rise in consumption which causes the ELF to decrease (similar to the general merchandise building).

In the case of the furniture store the ELF-to-OLF comparison may be more consistent than that shown for the general merchandise store for several reasons. First, the electric demand for the air-conditioning system adds about 6 W/ft^2 (a 17 kW jump!) to the store's already high 5 W/ft^2 base-level electric demand which decreases the ELF ratio. Second, no other electrical device in the store has this large of a rated load. Hence, using the air-conditioning equipment for infrequent periods (as small as 30 minutes) during the fall or spring months sets the monthly peak demand level without a corresponding increase in electricity usage. This forces the ELF ratio to dip, as shown in Figure 21.

The daily power levels (Figure 22) reveal yet another dimension to the furniture store -- unscheduled use of the store during closed periods and variations in weekday usage. Subsequent interviews showed that the new owners were redecorating on Sundays and experimenting with new lighting arrangements and remodeling the store.

The daily minimum-maximum zone temperatures for the furniture store reveal slightly erratic temperatures (Figure 23). Also, the flattened minimum temperatures indicate that the store is being heated (to at least 65F) during unoccupied periods and that night setback (to temperatures below 65F) is not occurring on a frequent basis.

The hourly electricity consumption profiles reveal a new wrinkle not seen in the stationery or general merchandise stores: the presence of a 250-to 500-watt "noise" level (corresponding to the 0.25 to 0.50 W/sqft scale used) during both occupied and unoccupied periods (Figure 24). Several types of electrical equipment can be causing this noise. Some possible candidates for further investigation with sub-metering include checking to see if the furnace is cycling unnecessarily during unoccupied periods and an electric domestic water heater (recently installed in the basement) that may be serving several stores.

Finally, the comparative hourly profiles in Figures 25a-d confirm what our previous indicators have hinted. First, the use of the store on Sundays can be clearly seen in Figure 25c as well as the extended hours in the evening. Figure 25d shows us an unexpected new detail -- sometimes the store opens later than scheduled, as witnessed by the ragged 10 a.m. negative residual "ridge" (the absolute value of the negative residual). Figure 25d also confirms earlier indications (the decreasing slope of the sliding PRISM CO plot in Figure 19) that daytime electricity use has declined when compared to the April 1988 values used for the hourly base-level model -- hence the presence of the 1 kW negative residual "noise" (directly behind the 10 a.m. ridge) during most occupied hours.

SUMMARY - FURNITURE STORE: In summary, the furniture store seems to suffer from a sizable base-level load (even though it appears to have declined somewhat). Several site visits reveal that lighting levels are the main culprit. Fixture counts and illumination measurements during the site visit confirm what a preliminary look at the data revealed (i.e., calculated lighting levels of 3.4 W/ft^2 and illumination levels of 70 to 110 foot- candles). A quick inspection of the rooftop air-conditioning units revealed the primary source of the store's high peak electric demand, namely, 15-tons of air conditioning for 2,700 square feet or 180 square feet per ton of air conditioning, about 1/2 the recommended 250 to 400 square feet per ton (ASHRAE 1987a). The furniture store also had an economizer that was not operational. Hence, the occupants were forced to use the air-conditioning system (or leave both front and back doors open) when they could have been taking advantage of free cooling through the use of the economizer.

2.2.4. The Exercise Center

The exercise center contains 8,900 square feet of conditioned space. About 2,800 square feet is located on the first floor and 6,100 square feet is located in the basement. There is minimal insulation in the roof and walls. Single pane windows represent 223 square feet of the exterior envelope. The exercise center has double doors located in one entrance vestibule.

The exercise center contains a complex arrangement of heating and cooling systems which serve as a record of the evolution of the facility. The 2,800 square feet of conditioned space on the first floor are heated with 2- 120,000 Btu/h duct furnaces. Cooling is provided by a 10-ton rooftop air conditioner located above an adjacent store. The air-handling units that services the first floor contain an economizer. Inspections during the site visit reveal that the economizer was not working. Control of the heating and cooling system is provided by a combined heating/cooling thermostat without night setback.

The 6,100 square foot basement is heated and cooled with three separate systems serving the left exercise room, central locker room and right exercise room, each of which is about 2,000 square feet. The left exercise room is heated and cooled with a 5-ton air conditioner that contains electric resistance heating coils. The HVAC system contains an economizer. However, a 50-foot length of duct work which supplies outside air to the economizer is too constrictive to allow for the passage of fresh air. Control of the system is provided by a combined heating-cooling thermostat without night setback.

The 2,000 square foot central locker area is heated and cooled with a 5-ton air-conditioning system that also has electric resistance heating. This system has an economizer (which appears to have adequate duct work). Two 500 CFM exhaust fans serve the central system. Control of the system is provided by a heating/cooling thermostat without night setback. An elaborate individual, duct-damper control system (to control individual rooms) has also been installed. Neither the controls for the economizer nor the duct-damper controls could be verified (conversations with the contractor indicate that they are not functioning).

The 2,000 square foot right exercise room is cooled only by a 2.5-ton air- conditioning system. The system that serves this room is a cooling-only system and has no provision for make-up air. Control is provided by a cooling-only thermostat without night setback.

The exercise center requires 6.3 kW for lighting purposes. Fluorescent lighting represents 61% of the total with the remaining 39% being used for incandescent lighting. Average illumination levels varied from 5 to 30 foot-candles. The exercise center has numerous other electrical devices including two 30-gallon electric water heaters (used to heat the spas), one 15-gallon electric water heater, two electric saunas and various other equipment. Further information concerning the exercise center can be found in Table 5.

The annual indices for the exercise center indicate that it is a moderate energy consumer (when compared to the seven businesses studied) at $1.51 per square foot total electricity costs. This cost incorporates a 32% demand portion (one of the lowest of the seven businesses analyzed). However, the average annual electricity power level of 1.94 W/ft^2 is the highest of the seven stores studied. The minimum and maximum peak monthly electric demand begin to tell us why since they are almost flat at 4.11 W/ft^2 and 4.81 W/ft^2, respectively. Basically, the electricity consumption profile for the exercise center exhibits a "flat" profile for both the average monthly electricity used (mean = 12,373 kWh, S_{dev} = 11%) and the monthly peak electric demand level.

The OLF of 50% tells us that the store has the highest occupancy rate of the stores studied (on average, the store is occupied more than 12 hours per day). When we consider the next two indices we are given a preliminary hint at what may be causing the high electricity usage and constant electric demand.

First, the average annual ELF of 41% is 19% below the average annual OLF (60%). Previously, when the ELF dipped below the OLF, as in the general merchandise store and in the furniture store, it may have been indicating that the air-conditioning systems were being used only a few days which set the peak monthly electric demand at a high level without a corresponding rise in the electricity usage which forces a drop in the ELF. Since we do not see a significant increase in electricity during the cooling season, we cannot draw a similar conclusion for the exercise center. However, we have another indicator which may be more revealing.

When we calculate the base-level electricity usage model we notice a curious feature -- the calculated amount of electricity consumed (413 hours x 37.6 kW = 15,528 kWh) exceeds the amount recorded for the chosen base-level month (in this case January of 1988 = 11,970 kWh). One possible explanation for this is that electrical load(s) are consistently setting the electric demand at a higher rate than the calculated average level obtained by dividing the total monthly amount by the occupied hours during the month under consideration (i.e., 11,970 kWh / 413 hours = 28.98 kW). Luckily, we have hourly electricity consumption profiles that help us to confirm this conjecture.

Figure 26 helps reveal the picture that the annual indices were indicating: that the monthly electricity consumption and demand are basically flat. Electric demand during the last 22 months has decreased about 20 percent while electricity usage remained almost unchanged. The slight perturbation that occurred in December 1986 and January 1987 is thought to be a billing error (this will be discussed in a following section).

Figure 27 shows us graphically what a PRISM CO analysis reveals -- a lack of cooling-related electricity consumption, specifically, a low $R^2 = 0.09$ and a negative cooling portion (a physically unreasonable number).

The monthly comparison of ELF and OLF for the exercise center (Figure 28) yields further details about the mismatch in the ELF and OLF. The consistent 60% OLF indicates that the building is occupied, on the average, 14 hours per day. When one considers that the there is a 40 to 50% OLF for this customer it implies that the peak daily electric demand is being set consistently above the average occupied-period electricity usage level. Our hourly electricity consumption profiles will also help us confirm this conjecture.

Figures 29 and 30 imply as yet another feature -- use of energy to heat domestic water is correlated to two primary variables; the amount of water consumed and the average daily temperature. In Figure 29, daily normalized logbook readings of natural gas consumption are displayed against the average daily ambient temperature. Figure 30 shows the natural gas consumption displayed against the daily water usage. Although it does not surprise us that the consumption varies with ambient temperature and with the amount of water heated, we do not expect the consumption to vary by as much as what the data indicate.

Since the water that is being heated is primarily being used for showers, towel washing, etc. (the two spas in the facility are heated by separate electric water heaters) one can imply that the water consumption (and hence the natural gas consumption) are related to the number of people using the facility on a given day. Clearly, to obtain an understanding of the energy use required to heat water at the exercise center (or in similar facilities) one should also obtain a measure of the number of persons using such a facility. Previous studies have revealed this type of relationship for a large 100,000 ft^2 recreation center (Haberl and Claridge 1987, Haberl et al. 1988b, 1988c). Nonetheless, it was reassuring to see this correlation for a smaller exercise center.

Measurements of the interior comfort conditions at the exercise center reveal yet another problem that faces this facility. Figures 31, 32 and 33 display the daily minimum and maximum temperatures versus average daily ambient temperature. In the upper zone (Figure 31) we can see that the temperature is maintained at 75 F or less throughout the year (our conversations with the staff reveal that their customers prefer to exercise in a cool room). It is also evident that the temperature drops down consistently to 50F whenever average daily temperatures fall below 40F -- a clear indication of night setback.

Figure 34 shows hourly zone temperature measurements for the upper zone at the exercise center for the period February 10, 1989 through March 10, 1989. Figure 34 confirms what Figure 31 suggested, namely, that the zone temperatures are maintained within a 60 to 70 F range and that temperatures are allowed to drop in the evenings with the minimum temperature somewhat dependent on the minimum ambient temperature, falling infrequently falling below 60F. When compared to the hourly zone temperatures for the previous stores (Figures 8, 17, and 24) the lower average zone temperature and its consistency (between 60 to 70F) are evident.

Figures 32 and 33 show the daily minimum and maximum temperatures for two of the three basement zones. Surprisingly, the interior temperature varies little for either of these zones, rarely dropping below 65 F or rising above 75 F. The HVAC system in the left zone (Figure 32) contains air- conditioning equipment and electric resistance heating. The system in the right zone (Figure 33) contains air conditioning only. Clearly both zones are maintained in a narrow 65F to 75F temperature range. The left zone seems to be more consistent than the right zone. One possible explanation (which we discovered during our site visits) is that the return grills to the right system often become completely blocked with particulate matter (most likely carpet fibers and lint that are kicked-up during the aerobics classes) which has the effect of reducing the air-conditioning system's effective cooling capacity. This may be contributing to the scatter in Figure 33.

Unfortunately in the case of the exercise center we find that interior temperature measurements do not completely reveal the deteriorated quality of the interior air. Specifically, the exercise center suffers from a severe lack of ventilation. For typical occupancy rates which vary from 12 to 80 people during any given instant, the air-handling systems should be supplying ventilation rates which vary from 600 CFM to 4000 CFM (assuming 50 CFM per person). Our site inspections revealed that the store has adequate equipment for supplying fresh air but that all but one system had been allowed to fall into total disrepair. Hence, only minimum ventilation rates (an estimated 200 to 600 CFM) could be observed for the entire exercise center.

Figure 35 gives us some hint of the deteriorated indoor air quality at the exercise center. This figure shows relative humidity measurements displayed against average daily ambient temperatures for the general merchandise (GM), furniture store (FU), stationery store (ST), travel center (TR), upper level exercise center (EX^) and lower level exercise center (EXv). Although we did not perform tests that would have indicated the validity of indoor humidity measurements as an indicator of indoor air quality we do find indoor humidity measurements to be useful. For example, indoor relative humidity tends to decline with decreasing ambient temperature in all the stores, which is expected since the amount of moisture available in the outside air also diminishes with cooler temperatures. In this figure it is clear that the relative humidity at the exercise center is, on average, twice that measured in the other stores. Since the source for the majority of the increase in relative humidity at the exercise center is human perspiration and respiration one can obtain a rough sense of how the exercise center compares to other stores by viewing the difference in indoor humidity levels. When we combined humidity measurements with (subjective) odor levels observed during the daily site visits and inspections of the systems, the lack of ventilation becomes evident.

Figures 36 and 37a-d show the hourly electricity usage for the exercise center for the period January 1, 1989 through February 10, 1989. Figure 36 shows the electricity usage as an hourly power level displayed as a time series plot. Figures 37a-d shows the comparative electricity usage where Figure 37a shows the actual electricity usage, Figure 37b shows the base- level model for the exercise center, Figure 37c shows the positive residual and Figure 37d shows the absolute value of the negative residual.

In the case of the exercise center the base-level model represents the average electric demand calculated by dividing the base-level electricity by the operating hours (i.e., January 1988, 11,970 kWh / 413 hours = 28.98 kW). This differs from the general merchandise, stationery and furniture stores where the base-level model was calculated by multiplying the base- level electric demand by the operating hours and subtracting the difference from the base-level electricity usage. Visually, this can be confirmed when one notices that the base-level model for the exercise center does not assign any electricity consumption to the unoccupied periods.

At the exercise center multiplying the base-level electric demand by the operating hours yields a value higher than the amount of electricity used during the month (i.e., 413 hours x 37.6 kW = 15,528 kWh > 11,970 kWh). The 8.6 kW disparity indicates that the electric demand level for the exercise center is significantly above the average electric demand during base-level months -- Figures 37c and 37d show us why. The exercise center has a number of large electric loads (i.e., two saunas, three water heaters, one clothes dryer, one 10-ton A/C, two 5-ton A/Cs, one 2.5-ton A/C). The un- regulated cycling of these loads can clearly be seen in Figure 37d as the variation in the absolute value of the negative residual, occurring during occupied hours.

SUMMARY - EXERCISE CENTER: In summary, the exercise center contains a complex arrangement of interacting HVAC systems that documents the evolution of the facility (our conversations with the contractor indicate that the facility started with the upstairs and lower locker rooms and then separately added the left and right aerobic exercise rooms in the basement). Although the exercise center has minimal insulation and single pane windows, the impact of any environmental influence (including ventilation) cannot be detected. Poor maintenance, abandoned controllers and frequent remodeling have contributed to a deteriorating indoor air quality. Significant increases in ventilation rates are required to restore indoor air quality to acceptable levels.

Although the per-square-foot cost of electricity is about average at $\$1.15/\text{ft}^2$ (when compared to the other stores we studied), the store has several counteracting features that are not revealed in such a simple index. First, below-average energy use for lighting (illumination levels of 5 to 30 foot-candles) is offset by large, infrequent power requirements for several saunas, spas, air-conditioning equipment and electric resistance heating devices.

Second, the historical monthly electrical consumption can be characterized as flat, varying only 11% from one month to the next. A 50% OLF indicates that the facility is in use about 12 hours per day. Calculated base-level electricity usage exceeds actual electricity use which indicates that electric demand is being consistently set at 8+ kW above average daily levels, making the store a good candidate for electric load shedding (a potential 7% savings in annual electric costs). In contrast to the other stores, energy use at the exercise center is strongly influenced by the number of persons visiting the facility. Unfortunately, when and if the exercise center improves the badly needed ventilation, the electricity usage portion of their energy bill will probably increase.

2.3. Exploring the Jersey Mall: Other Stores Studied

2.3.1. The Drive-Up Bank

The drive-up bank at the Jersey Mall is a small 322 square foot building located in a remote corner of the shopping center. The self-standing building has a flat built-up roof and masonry walls, both of which are minimally insulated. The facility has a 30 square foot bullet-proof window and one entrance door opening directly outside.

Heating and cooling are provided by a 1.5-ton heat pump, along with auxiliary electric resistance heating. Control of the system is provided by a combined heating/cooling/emergency heating thermostat without night setback. One small exhaust fan services the bathroom. Infiltration is the primary means of ventilation. The drive-up bank has about 2 kW of lighting evenly divided between fluorescent and incandescent fixtures. The drive-up bank has several appliance loads including a small portable electric resistance heater, a 15-gallon electric water heater, a small cabinet-type refrigerator, coffee pot, and toaster. Further details are included in Table 6.

The drive-up bank consumes a significant amount of energy for its size. At $5.73 per square foot and 5.92 W/ft^2 it has the largest consumption per measure of conditioned area of the seven stores studied. Several reasons contribute to this high rating. First, the store is the smallest of the seven stores studied. Self-standing structures that are this small tend to have higher energy intensities than larger structures with similar functions. Second, since the store is in a remote location of the mall it does not have any common walls and must carry the entire, fully exposed, envelope load. Third, the electricity consumed by the drive-up bank provides heating, cooling and base-level functions, whereas our measurements of electricity in the other stores mostly excluded heating. Clearly the base-level electricity use at the drive-up bank is high (relative to the other stores) but clearly within range of the other stores.

Peak monthly electric demand varies from 9.6 to 38.8 W/ft^2. Electric demand accounts for 44% of the annual electric utility costs. The drive-up is occupied only 24% of each day, with 37% of the electricity being consumed when the store is closed. A PRISM Heating and Cooling (HC) analysis reveals that the store consumes electricity primarily for heating purposes (52%), followed by base-level purposes (35%), and cooling purposes (13%). In addition, the PRISM HC analysis shows that the analysis is well described ($R^2 = 0.82 > 0.70$, CV(NAC) = 7%).

Figure 38 shows the monthly electricity use (kWh) and peak monthly electric demand (kW) for the period December 1986 through September 1988. Figure 39 shows the monthly electricity use and peak monthly demand displayed against average ambient temperature. Both Figures 38 and 39 indicate that the drive-up bank exhibits a consistent electricity use (this is also confirmed by the PRISM HC analysis) yet both figures show a very curious peak electric demand profile -- a probable kW utility billing error which we attribute to a mechanical failure in the kilowatt-hour meter demand register. This is discussed further in Section 3.4 of this report. In Figures 38 and 39 we also show the probable kW usage for those months affected by the mechanical malfunction.

Using the estimated kW readings one can see that the heating-season, peak monthly electric demand (at 38 W/ft^2, 12.5 kW) is three times greater than the demand during other periods (10 W/ft^2, 3.4

kW). Although this is a small amount of electricity (when compared to the general merchandise demand of 270 kW) when we combine this with information gathered during the site visit we can begin to understand what energy conservation opportunities are available for the drive-up bank -- namely, demand load shedding and turning off equipment during unoccupied periods.

Also noticeable in Figure 38 is a correlation between minimum heating- season temperature (Figure 2) and peak monthly electric demand. For example, both February 1987 and March 1987 had minimum average daily temperatures in the 10F to 20F range compared to the monthly average temperatures in the 30F to 40F range. April 1987, however, only had minimum temperatures in the 30F to 40F range compared to the monthly average temperature of 48F. This tends to explain better the shape of the electrical demand during this period which seems to depend more on the minimum (or the maximum during the cooling season) rather than the average daily temperature.

The load shedding option is confirmed by our field notes which indicate a 3.4 kW appliance load (a toaster, coffee pot, portable electric heater and refrigerator), a 4.0 kW electric water heating load, a 1.5 kW heat pump load and a 5 kW electric resistance heating load. Although the savings would be small (about $12 per month for each 1 kW reduction at $10/kW- month), clearly several load shedding strategies exist, for example: removing one of the two 2-kW electric heating elements in the electric water heater; rewiring the electric water heater and electric resistance space heater to prevent both from being on simultaneously, or improving the wall-insulation under the teller's booths (which is the reason for the portable heater to keep their feet warm).

The second option, reducing the electricity consumption during unoccupied hours is suggested because the base-level electricity consumed during occupied hours (June 1988, 178 hours x 3.4 kW = 605.2 kWh) is only 63% of the actual electricity consumed during the same month (June 1988, 960 kWh) leaving the remaining 37%, which we interpret as being was consumed during unoccupied periods.

This second option is further confirmed by considering the daily electricity readings (taken during our site visits by recording daily electricity use in a log book) as shown in Figures 40 and 41. Figure 40 shows the daily electricity usage and daily average temperature for the period January 1, 1989 through February 10, 1989 displayed as a time series plot. Figure 41 shows the daily electricity use displayed against the daily average ambient temperature for the period September 1988 through March 1989. In Figure 40, the lack of a weekday-weekend cycle (compared with Figures 6, 15, and 22) indicates that the building mechanical system is being operated without regard to occupancy.

Further, in Figure 41, the high levels of electricity consumption that prevail during heating periods (and during cooling periods to a lesser extent) drop to levels nearer to that observed for the remaining stores during non-heating, non-cooling (or base-level) periods between 60F and 70F. Finally, in Figure 41, during the base-level and cooling periods, we can begin to detect a weekday-weekend difference by noticing that daily electricity consumption on Sundays (data marked by a capital S) appears to be at about one-half to two thirds that of Monday through Saturday levels - - an indication that lights and appliances (excluding the water heater) are being turned off.

SUMMARY - DRIVE-UP BANK: In summary, the drive-up bank suffers primarily from a mechanical failure in the kilowatt-hour meter which could be costing $300+ per year in false electric demand readings. The drive-up bank could further reduce electricity costs by implementing a load-shedding program that would prevent simultaneous use of electricity by several systems in the building. It could further reduce electricity costs by implementing a procedure that would allow for the main space heating system to be turned down or turned off during unoccupied periods. Most likely this would involve some additional insulation to the building envelope and a careful inspection of plumbing to insure that there would be no freezing. All of these features could have been identified by a preliminary analysis of the building's metered data.

2.3.2. The Travel Center

The travel center is a 720 square foot business located beside the furniture store. The store has a 108 square foot, single pane window and one entrance (that does not have a vestibule). The store is heated by a 60,000 Btu/h natural gas fired duct furnace. Cooling is provided by a 5-ton packaged air conditioner which was installed during the summer of 1988, replacing an older 5-ton water-cooled system. Control for the system is provided by a combined heating/cooling thermostat without night setback.

The HVAC system for the travel center does not have an economizer or make- up air capabilities. Lighting in the store requires about 1 kW of which 400 W represent fluorescent fixtures and 0.6 kW represent incandescent fixtures. Measurements of illumination vary from 55 to 75 foot-candles. The store is provided with hot and cold water from an adjacent store (therefore we did not account for water heating energy). The travel center contains 4 microcomputers, 2 high-speed printers and telecommunication equipment which is left operating 24 hours-per-day. Further information can be found in Table 6.

The travel center is an average consumer of electricity, using $1.69 per square foot in electricity each year. Demand represents 42% of the total electric costs or $0.71 per square foot each year.

The travel center consumes 1.76 W/ft^2, which almost equals that of the larger general merchandise store. Peak monthly electric demand varies from 3.1 W/ft^2 to 10.4 W/ft^2 which is also average for a store that appears to use electricity for cooling and base-level purposes. The store is occupied, on average, 29% of each day and has an ELF of 34%. A significant 50% of the electricity consumed by the travel center is consumed during unoccupied hours.

A PRISM HC analysis indicates that the store consumes electricity primarily for base-level purposes (63%), followed by heating purposes (20%), and cooling purposes (17%). The PRISM HC analysis shows that the analysis is only moderately described ($R^2 = 0.63 < 0.70$, CV(NAC) = 7%).

Figures 42 and 43 show the monthly electricity use (kWh) and electric demand (kW) for the travel center. Figure 42 displays the consumption in a time series format and Figure 43 displays the consumption against the average monthly ambient temperature. A closer look at Figure 42 reveals several features that begin to tell us what has happened at the travel center. First, there is a slight increase in peak monthly demand from 1987 to 1988. Second, and more importantly, cooling-season electricity consumption almost doubles from 1987 to 1988. Interviews with the store owner shed some light on a possible reason -- namely that an older, water- cooled, air conditioner was replaced with a rooftop air-cooled air conditioner. The raw data tend to indicate that this newer unit creates a similar electric demand profile (about 10 W/ft^2) but consumes about twice the electricity as the previous unit. Unfortunately, limited utility data did not allow us to perform a PRE-POST PRISM HC analysis to confirm the indications in the raw data.

A closer look at Figure 43 indicates that the owners might be using the air-conditioning system earlier in the year (notice that A87 = April 1987, is significantly below A88). We speculate that an increased internal heating load from newly purchased microcomputers might be a contributing factor.

Daily electricity consumption for the travel center is shown in Figures 44 (time series) and 45 (displayed against daily average ambient temperature). Figure 44 reveals a relatively flat consumption profile with a modest decrease in electricity use during Sundays (although not consistent). The grouping of the data in Figure 45 confirms what the PRISM HC analysis indicated -- that electricity is consumed mostly for base-level purposes.

However, since the daily data cover a period more closely related to the change in equipment, we now see that electricity consumption for cooling purposes may be exceeding that for heating purposes (the PRISM HC analysis did not include this period). Also, we can note that the space conditioning systems seem to be left operating only during extreme heating and cooling periods. This is evidenced by the presence of the Sunday (S) outliers which only appear below the main group of data during temperatures between about 30F and 65F. Interviews with the store owner revealed that he specifically was instructed by the microcomputer supplier that the equipment must be left in operation 24-hours-per-day and must be in a space maintained at or near room conditions. Hence, the owner leaves the space conditioning system in operation during the heating and cooling season but not during the base- level (fall and spring) season when comfort conditions can be accomplished by opening the front door.

Figure 46 shows the minimum and maximum interior temperatures displayed against average daily ambient temperature. One striking feature of this graph is that minimum zone temperatures infrequently drop to 65F during average ambient temperatures between 30F and 65F. This would appear to confirm that space conditioning systems are shut-off during swing season periods, which would cause the temperatures to drift in the evening and set the minimum as shown.

SUMMARY - TRAVEL CENTER: The energy consumption profile seems to reveal that the travel center primarily is dominated by internally generated heat from microcomputers used for passenger bookings. This is also somewhat confirmed by our field notes which reveal that the travel center is only exposed to external conditions at two surfaces -- a front display window and entrance door and the roof.

The travel center is an average consumer of electricity. However, over 50% of its electricity is being consumed by the computer equipment during periods when the store is unoccupied. The owner was instructed to leave the computers on during unoccupied periods since the "boot" program for the computers takes about 30 minutes to run and sometimes data are lost -- an inconvenience for which the owner is willing to pay about $1.35 per day.

The travel center seems to also suffer from an oversized air conditioner (144 ft^2/ton versus ASHRAE's recommended 250 to 400 ft^2/ton). However, unlike the furniture store, the travel center has only one compressor and could have replaced the 5-ton unit with a more economical 2-or 3-ton unit (which would have given them 360 to 250 ft^2/ton). Choosing a 2-ton to 3-ton unit could have saved them about $240 per year in electric demand charges.

2.3.3. The Video Store

The video store is a small 550 square foot business located in a separate building south of the building which houses the other stores. The video store has only one exposed exterior surface which is comprised of 108 square feet of single pane glazing and a single pane glazed door (no vestibule). The store is heated by two 2-kW wall-mounted, electric resistance heaters, each containing its own thermostatic control panel. Cooling is provided by a 1-ton window air conditioner located above the entrance doorway. Control of the window air conditioner is accomplished by a control panel which is mounted on the air conditioner. The store was previously served by duct work (now blocked-off) from an adjacent store. Further information concerning the video store can be found in Table 6.

The video store consumes, on average, \$2.24 per square foot of electricity 48% of which are demand charges (as high as the furniture store's 49%). The store consumes 2.04 W/ft^2 with peak monthly demand varying from 7.8 W/ft^2 to 14.7 W/ft^2. The video store is occupied 29% of each day and has an ELF of 19%.

In a similar fashion to the exercise center the base-level model calculation (i.e., November 1987, 342 hours x 4.3 kW = 1470.6 kWh) exceeds the actual electricity consumed during the month (576 kWh). This suggests that the base-level electric demand (4.3 kW) is 2.6 kW above the average demand of 1.7 kW, which means that the electric demand for the store is consistently being set 2.6 kW above the average consumption rate of 1.7 kW. Our field notes reveal the presence of appliances (a coffee pot, VCR, TVs, a computer, electric bottled water heater-cooler) using about 2 kW, which we suspect are the source of the 2.6 kW spikes that set the electric demand level each month.

A PRISM HC analysis indicates that the store consumes electricity primarily for base-level purposes (67%), followed by heating purposes (21%), and cooling purposes (12%). The PRISM HC analysis shows that the analysis is well described ($R^2 = 0.80 > 0.70$, CV(NAC) = 5%).

Figures 47 and 48 show the monthly electricity consumption for the video store. Figure 47 illustrates the electricity use (kWh) and electric demand (kW) in a time series plot. Figure 48 displays the electricity use (kWh) and electric demand (kW) against the average monthly ambient temperature. In a similar fashion to the drive-up bank, one can notice how certain of the irregularities in the electric demand correlate to the minimum average daily ambient temperature (Figure 2). For example, notice that minimum temperatures during February and March 1987 are lower than those recorded for January 1987 which corresponds to higher demand levels for February 1987 and March 1987; also note that electric demand for April 1987 falls significantly, corresponding to a significant rise in minimum average daily temperature during that month.

Figures 47 and 48 reveal a possible candidate for a simple cost-saving measure. Our site visit to the store shows that the video store receives heating from two, wall-mounted, electric resistance heaters. Both heaters are allowed to cycle on and off independently, which is the main cause for the 4-kW increase in peak electric demand during the winter months. Installation of a simple switching relay would eliminate 2 kW from the heating season electric demand -- a savings of \$100 per year (about 8% of their total bill). Further inspection of appliances and equipment may also identify base-level loads that could be eliminated to reduce the non- heating season electric demand.

SUMMARY - VIDEO STORE: In summary, the video store is a small business with limited exterior wall exposure. Heating is provided by two 2-kW electric resistance heaters and a window mounted air-conditioning unit. The video store has slightly above average electricity costs ($2.24/ft^2) and usage (2.04 W/ft^2). However, a closer look at the monthly utility bills, combined with information from our site visit reveals that a simple measure can save the store owner 8% of the annual electricity bill without sacrificing interior comfort. This measure involves the installation of a simple switching relay that would prevent both 2-kW electric resistance wall heaters from cycling at the same time and thus setting the electric demand for the month.

Finally, the video store was vacated by the tenants in August 1988 (who moved to another location). The new tenants performed some remodeling but plan to use the same HVAC equipment from the previous owner -- in effect, inheriting the problems of the former tenant. The study at the Jersey Mall has shown us that small commercial customers move often and receive little or no instructions about how to operate their HVAC systems. Improved communication between customers, HVAC contractors and utility companies could help eliminate such problems.

2.4. Improving Utility Billing Anomalies

Utility billing information, the heart of our analysis, is provided by a utility company (for the most part) from periodic readings obtained by utility company personnel. Electric kilowatt-hour meters (and other meters) commonly have cyclo-meter, dial-and-pointer or sweep-pointer displays that must be carefully read to extract the energy usage (kWh) and demand (kW) that has occurred since the meters were last read (Dranetz 1983, EEI 1981). During the process of analyzing the utility billing information at the Jersey Mall we have noticed several types of anomalies occurring in the utility bills. Since we are aware of new types of utility meters that would eliminate such problems, through automated reading, we also realize that the current generation of kilowatt-hour meters will be with us for some time. This section reviews several probable anomalies we have seen at the mall with the intent of discussing possible methods for detecting anomalous utility billing information.

Figures 49 through 52 illustrate three probable utility anomalies we witnessed at the Jersey Mall. Figures 49, 50 and 51 show the utility billing information as usage (kWh - figure a.), monthly Electric Load Factor (ELF - figure b.) and electric demand (kW - figure c.).

Our first example (Figures 49a-c) involves a probable misreading in the electricity usage (kWh) for the month of February 1987. Since electricity usage (kWh) readings are essentially taken from a "runtime" (continuously increasing) dial-and-pointer decade display, any misreadings tend to be compensated for in the following month. In this case we see an unusually low February 1987 kWh reading followed immediately by an unusually high March 1987 kWh reading. Electricity (kWh) billing errors of this type can cause an overcharge (or undercharge) if the seasonal rates differ for the months when the error occurred.

Figure 50 indicates a probable electric demand (kW) reading error for the month of July 1987. Electric demand errors of this type can cause a one- time over-charge in the customer's electric demand (kW) portion of the bill. Clearly, for this customer the 150% (15 kW or about $150) increase in electric demand should have been cause for concern.

Figure 51 shows a probable compound electric demand (kW) billing error. First, during the month of March 1987, a single anomalous demand (kW) reading (4 kW above normal) can be clearly seen.

This probable demand billing anomaly incorrectly increased the customer's electric demand portion of the utility bill for that month by 144% above the electric demand rate normal for March.

The second type of error is hidden to us in the monthly data. However, our daily inspections of the kilowatt-hour meters during the course of our study reveal yet another error. Figures 52a-b indicate the pointer-and-dial displays used in the demand register which utilize three decade register dials. Figure 52a indicates the beginning period demand reading (dial reading = 0.945). Figure 52b indicates the end-of-period readings (dial reading = 1.945). Our daily inspections revealed that register C mechanically slips from the position shown in Figure 52a to that shown in Figure 52b without any corresponding movement in decade registers B or A yielding an incorrect reading of 1.945. Re-inspection of Figure 51a-c indicates that readings for March 1987 through June 1987 and October 1987 through December 1987 most likely suffered from this mechanical failure of the demand registers (in Figure 38 and 39 we illustrate corrected demand). Figures 38 and 39 illustrate the most likely electric demand for this store (the drive-up bank) where we have removed the offending digit from the meter reading and recalculated the demand as if the mechanical failure had not occurred.

Improved metered data analysis methods, with an emphasis on anomaly detection, should be further researched. Such methods could improve the useful information the utility company provides to their customers by enhancing the quality of utility bill. Although anomaly detection was not the purpose of this study we found it necessary to carefully review each customer's utility bill prior to performing the analyses methods we have discussed so far. If the Jersey Mall is any indication of the total customer base, such anomalies may be occurring frequently.

3. DISCUSSION

3.1. General

We have studied commercial building energy use using seven case studies from businesses at the Jersey Mall. In this study we have confined our analysis of metered data to whole-building electricity data (except for one presentation of natural gas usage), temperature, humidity and lighting measurements and data gathered from several site visits. For each of the seven businesses similar annual, monthly, daily and hourly presentations of the data were considered to discover what could be learned about each site and whether any preliminary indications were present in the indices which suggested energy conservation measures.

Energy (and cost) consumption data were normalized for variations in the size of conditioned space and for varying weather conditions. Occupancy factors were also considered to see if additional insights about each site could be gained. Historical trends in energy consumption were evaluated with sliding indices which were normalized for square footage and weather. Finally, interior comfort and lighting levels were measured to assess whether or not differences in consumption could be attributed to differences in the comfort and illumination levels.

3.2. What Types of Energy Conservation Measures Appear?

One of the objectives of studying energy usage in commercial businesses was to explore what types of energy conservation measures could be determined in advance from an analysis of a building's metered data. Our intent is that such a pre-screening could guide the auditor during the site visit -- thus improving the consistency and quality of the energy audit. During the course of this study we performed daily site visits to each store, recorded energy consumption and interior conditions, and then took a close look at the metered data to see if problematic conditions we discovered were indeed leaving telltale signatures in the energy consumption data. Here are a few examples of what was discovered.

3.2.1. Weather-Related Electricity Use

In the analysis of data from the Jersey Mall we applied the Princeton Scorekeeping Method (PRISM) to the stores we studied. PRISM is a useful tool in analyzing energy use in small commercial buildings. Our application of PRISM involved analyzing each store with PRISM CO (cooling plus base level), PRISM HO (heating plus base level), and PRISM HC (heating and cooling plus base level) to determine if weather-related electricity use could be statistically determined. PRISM CO, HO, and HC indeed provided us with a way to categorize energy consumption into five basic classes of customers, namely: 1) Heating plus base level (a reliable PRISM HO fit), 2) Cooling plus base level, and 3) Heating and cooling plus base level. We then extended that concept to the next logical step and sought the fourth and fifth level, which are: 4) an absence of heating and cooling -- flat consumption, and (5) an absence of heating and cooling -- erratic consumption. Knowing this classification for each store, in advance of an audit, can provide improved insight into what potential energy conservation measures need further investigation during the site visit.

3.2.2. Comparative Electricity Use

PRISM HO, CO and HC analysis of energy use at the Jersey Mall expressed in W/ft^2 (by dividing the energy use by conditioned floor area) allows for a comparison of the electricity used by the seven businesses we studied at the Jersey Mall. Figure 53 illustrates PRISM heating, cooling and base-level fractions expressed as W/ft^2 for the seven businesses.

To no surprise, the drive-up bank has the largest energy consumption per square foot on conditioned floor area. This is primarily due to its small size, "stand-alone" configuration, use of electricity for heating, cooling, and base-level purposes and 24 hour-per-day space conditioning. The exercise center and stationery stores did not reveal heating-season or cooling-season related loads, hence the base-level only representation. In the case of the exercise center a complex interaction between large process loads (i.e., saunas, spas, etc.) overwhelm energy consumption for air conditioning and heating which are below expected levels because of a lack of proper ventilation. At the stationery store, electricity use related to cooling is not recorded by the utility meter assigned to the store.

In regards to dominant energy uses, in the video store and travel center computers, appliances and large receptacle are the largest loads, while at the furniture store lighting loads dominate. In the general merchandise store energy use for base-level purposes (i.e., lighting, elevators, fans, and receptacles) dominates. Clearly, PRISM, originally developed for use in residential applications, proved to be a useful prescreening tool for the study at the Jersey Mall.

3.2.3. Energy Use During Unoccupied Periods

We discovered that energy use during unoccupied periods can be detected when one compares calculated base-level energy use to actual energy use. In three of the seven buildings such energy use was significant and accounted for 19% of the electricity use at the general merchandise store (lights, cash registers and an elevator malfunction), 37% of the electricity use at the drive-up bank (space heating, cooling and DHW operating continuously), and 50% of the electricity use at the travel center (microcomputers and HVAC operating continuously).

Surprisingly, the comparison of calculated base-level energy use to actual energy use also reveals an unexpected energy conservation candidate. Namely, when the monthly index is negative (calculated base-level use exceeds actual energy use) there is a good possibility that electric demand levels are being set too high by simultaneous operation of several appliances or electricity-consuming systems.

The calculation of annual Electric Load Factors (ELF) for the seven stores at the mall (varying from 19% to 48%) and Occupancy Load Factors (OLF; varying from 24% to 42%) also provides a useful indicator. For these stores it appears that a comparison of annual ELF to OLF reveals which stores may be consuming excess electricity during unoccupied hours. Specifically, the general merchandise store (an ELF to OLF ratio of 1.14), the travel center (1.16), and the drive-up bank (1.08) -- all had equipment operating during unoccupied periods. The remaining stores had ratios of less than 1.0 and did not have significant unoccupied-period electricity use.

3.2.4. Excessive Electric Demand

In four of the seven stores we find that excessive electric demand, determined by scaling the electric demand to conditioned floor space, can possibly indicate oversized air-conditioning equipment, oversized heating equipment, or too much base-level or appliances. Clearly, additional research needs to be performed on electric demand data as demand appears to be a useful index that most energy decision makers do not understand. Also, with the increased emphasis on reducing peak cooling-season electric demand, our results suggest that simple calculations could be performed by utility companies to pre-screen potential customers that could easily reduce peak electric demand by modifying or upgrading air-conditioning equipment with appropriately sized equipment (at prices considerably below the $200+/kW the utilities currently pay for peak electricity production [EPRI 1986]).

3.2.5. Characteristics About Economizer Operation

Quite surprisingly, in all of the three stores that contained equipment that could have utilized outside air for cooling during periods when conditions were appropriate, the economizers were inoperative. For the most part, we noticed a consistent "signature" for this condition (i.e., electric demand rising to (or staying at) higher, cooling-season levels without a corresponding rise in electricity usage). In these stores this indicated that economizers were not functioning. In the general merchandise store we did not observe the expected signature in the spring because the store was cooled with ground water which was pumped directly through the cooling coils in the AHUs. In the case of the exercise center, where the economizers were not functioning and the signature did not appear, large process-like loads overwhelmed any weather sensitivity, and thus the mismatch in electric demand and electricity usage during early (or late) cooling seasons did not appear.

3.2.6. Recent Changes in Operation of Equipment

In several of the businesses at the mall, significant changes occurred to either the occupancy, equipment or building envelope. Sliding PRISM allowed for a means of assessing these recent changes. For example, at the stationery store, over time, the owner did not replace the lamps in 38% of the fluorescent fixtures in the store. Sliding PRISM CO clearly indicated this.

At the general merchandise store, sliding PRISM CO indicated a nearly flat 22-month energy consumption with a 17% increase in base-level, and a 66% decrease in cooling energy usage. These trends provided valuable insights since the building had recently expanded the second floor (and hence added additional lighting load) and was suffering from a continual worsening of restricted flow in the chilled water system (caused by severe fouling of the cooling coils).

At the travel center, energy use for cooling nearly doubled from 1987 to 1988 which was easily determined. Conversations with the owner revealed that new computer equipment had been installed and that the owner replaced a water-cooled, 5-ton air conditioner with an air-cooled, 5-ton air conditioner which we suspect is less efficient.

Finally, at the exercise center, the gradual decrease in energy consumption appears to be signaling improperly maintained equipment and severely restricted ventilation.

3.2.7. Interior Environmental Conditions

An analysis of energy use in small commercial businesses must be accompanied by some measure of interior environmental conditions (i.e., comfort, lighting and ultimately IAQ). Some examples: at the general merchandise store, measurements showed that the the second floor sweltered during the summer -- an indication that additional cooling was required; at the stationery store, indoor temperature measurements revealed that cooling was indeed occurring even though the electricity use for the air- conditioning unit was not recorded by the utility meter assigned to the store; and indoor temperature and humidity measurements at the exercise center helped to reveal needed improvements to the ventilation systems. In all the stores, measurements of illumination are important in determining lighting quality and assessing the energy use required by the lighting systems.

3.2.8. Possible Errors in Utility Billing

Utility billing information, the heart of our analysis, is provided by a utility company (for the most part) from periodic readings obtained by utility company personnel. During the process of analyzing the utility billing information at the Jersey Mall we noticed several types of anomalies occurring in the utility bills. Since we are aware of new microprocessor-based utility meters that could eliminate such problems, through automated reading, we also understand that the current generation of kilowatt-hour meters will not be phased out in the near future. We identified three probable utility billing errors that occurred during the analysis at the Jersey Mall. Improving current methods for detecting anomalous utility billing information is clearly in the best interests of utility companies and utility customers.

3.3. Who Can Benefit From the Improved Energy Audit?

We have shown that one can obtain useful information about a building from an analysis of historical energy consumption data combined with a few simple indices (i.e., conditioned area, operating hours, etc.). This information is of little value unless it is used by those making energy- related decisions, including:

3.3.1. The Building Energy Analyst

An important beneficiary of energy-related information is the building energy analyst or energy auditor. For example, two CACS-type audits performed on the general merchandise store did not address the major concern of the occupants, which was the summertime comfort problem. If the auditor had followed a procedure similar to the one we propose, he/she could have gone into the store with preliminary knowledge that the space cooling system needed attention and that it may be a strong candidate for improvement (Haberl and Komor 1989). The auditor would have also been alerted to the need to investigate unoccupied-period energy use.

3.3.2. The Building Service Contractor

The building service contractor is yet another potential beneficiary of information extracted from metered data. At the Jersey Mall, several contractors are actively involved in various aspects of the building. Observations from the Jersey Mall indicate that they do not have any data on energy use, and that their only sources of information are complaints by the occupants when systems failed and information obtained during on-site inspections of equipment.

3.3.3. The Utility Supplier

Utility suppliers can also benefit from additional information extracted from a customer's utility records. Utility suppliers are going to great lengths to reduce summertime demand. Yet, a close look at the demand data savings possible from simple operation and maintenance items at the Jersey Mall indicate that 32 kW could be saved for about $56/kW -- far below the cost of supplying peak summertime electricity. The indices we explored in this study seem to be capable of identifying such savings using (for the most part) monthly utility billing data and selected additional information about each business -- without necessarily requiring a site visit to acquire the data.

Finally, in gathering the data for the Jersey Mall case study we noticed numerous billing anomalies that managed to pass through existing screening methods. Such anomalies cause problems for all parties involved and could have been detected with additional measures we employed to reduce the data for this analysis.

3.3.4. Local, State & Federal Agencies

Energy use in buildings is of interest to public agencies such as local, state, and federal planning agencies. Unfortunately, data on energy use are not collected in a consistent format, and are not easily accessible to policy makers and public sector analysts. Olsen et al. (1988) reviewed data sources on energy use in the small commercial sector and showed that even audit data are not accessible to public agencies or policy analysts who depend on it.

3.3.5. The Utility Customer

As retrofit decisions are usually made by the building occupant or owner, improved energy information provided to the customer after the audit must be in a form that is useful and understandable to occupants or owners if it is to have any effect on energy use. Field tests of a new information package have been performed with building occupants to better understand their reactions to metered data (Komor et al. 1989). Here we summarize the conservation actions we found at the mall.

The General Merchandise Store. The primary improvement to be made at the general merchandise store is to improve comfort conditions during the cooling season. Increased internal heat generation (due to added lighting on the second floor), severely fouled chilled water piping, blocked return air vents, inoperable economizers and a lack of thermostatic controls are the primary comfort related items which need to be addressed in this store.

Rapid payback items include turning-off or turning-down lighting and equipment during unoccupied hours, namely to reduce by 5 kW nighttime lighting and install a new time-out switch on the elevator. These items are summarized in Table 7. The reduction of nighttime lighting and replacement of the elevator would save about $12,000 per year, costing less than $750 to implement.

The Stationery Store The stationery store is a low-energy commercial business -- primarily because the electricity needed for air conditioning is not recorded by the utility meter assigned to the store. An analysis of the metered data from the store reveals that the store is consistently operated and most likely has few, if any, low cost energy conservation measures.

The Furniture Store The primary energy-saving measure which could be implemented at the furniture store is the rewiring of the air conditioner to prevent both 7.5-ton units from operating simultaneously. This $450 option would save $420 in electric demand during the first cooling season. A rewiring of the economizer would also help reduce energy costs and allow for filtered air to replace current un-filtered air entering the store through doors propped open during the spring and fall.

The Exercise Center The exercise center suffers most from a lack of proper ventilation and poor lighting levels. Unfortunately, solving both of these problems will raise energy consumption, thereby raising the utility bills. However, installation of a demand-limiting device could save an estimated $960 per year at a cost of about $1000 for installation which may help to offset the higher utility bills.

The Drive-Up Bank The drive-up bank suffers most from a malfunctioning utility meter, costing upwards of $300 per year in false electric demand readings. Insulation and a reduction in the use of space-conditioning equipment during unoccupied periods could save the bank $175 per year. Further electric demand savings of $240 per year could be obtained by rewiring the domestic water heater and electric heat pump to prevent simultaneous use.

The Travel Center The travel center consumes 50% of its electricity when the store is unoccupied. Turning-off computers and turning-off or turning- down space conditioning systems could save at least $320 per year, but would require additional time each day to allow for computers to reboot when turned on in the morning, and to properly shut-down the system in the evening. Should the air conditioner need replacing again in the future, the travel center should carefully re-size the unit (a 3-ton unit versus a 5- ton unit) to avoid the extra demand charge generated by the larger unit.

The Video Store The video store could save about $100 in electric demand per year by installing a switch that would prevent both electric resistance heaters from operating simultaneously. In the case of the video store, had the new tenants been made aware of the problems they were inheriting with the installed equipment, changes could have been made during their initial remodeling efforts.

The Jersey Mall At the Jersey Mall, in general, several recommendations can be made. First, during the course of our investigation we noticed the original 1950s design of the Jersey Mall called for about 0.5 to 1 CFM per square foot of ventilation which was cooled with well water circulated through cooling coils and then exhausted through large vents in the roof. This system, when installed, required large pressure relief hoods to allow air to escape from the building. Many of these hoods still exist today and have not been properly sealed. In total, for the Jersey Mall, there were about 220 square feet of ventilation hoods. Currently, about 190 square feet of these hoods remain and should be insulated and sealed-off to prevent infiltration since the newer air-conditioning systems in use do not require such large ventilation rates.

Second, although we found the current records adequate in all respects, information about HVAC systems at the Jersey Mall could benefit from improved cataloging of equipment, improved communication among contractors who have worked on systems, and transfer of operating instructions when a store changes hands. In some instances, we found several contractors working on the HVAC systems in one store, each hesitant to share information with other contractors for fear of losing business. Clearly, the current (and future) owners suffer in situations such as this and we found this to be a contributing factor to energy inefficiency.

3.4. Thoughts About the Future

Future research should focus on refining these methods, validating the important indices and establishing public domain documents that can serve as a foundation for the rebuilding of the commercial energy audit process. Our research supports the idea that energy audits should allow the energy analyst to interactively diagnose a building's problems by making use of an analysis of the metered data rather than the prescriptive, rule-of- thumb, fill-in-the-blank approach that prevails today.

3.4.1. A Commercial Building Energy Analysis Procedure

Useful information can be obtained from historical utility billing records and from a simple survey which may provide helpful insight as to whether or not a building is consuming energy efficiently. We propose a multi-level methodology (motivated by the work described in the ASHRAE [1987c] survey; and by the audit procedure described in Harrje and Dutt [1988]) to be used interactively during an analysis of an existing building's energy use. The multilevel methodology is summarized in Figure 54 and contains the following tasks:

Level 1: No Customer Contact A "Level-1" analysis uses monthly utility billing records, daily average temperatures and the building's SIC code (usually available from utility records) to prepare a relatively simple one page summary of consumption history for the customer. Use of PRISM, along with other energy usage and demand analyze, are suggested for this level of the analysis. This level could be used to determine the presence of heating or cooling equipment and provide the customer with an analysis of consumption history.

<u>Level 2: Phone Call</u> At Level-2, a phone call to the customer is used to collect additional information. The decision to proceed from Level 1 to Level 2 can be made by the customer -- for example, the one-page summary could be sent to the customer with a simple form saying, "If you would like more information, check here..." Level-2 data would encompass square footage, hours-of-operation, some information on energy-using equipment, and occupant concerns related to energy use. (In our experience, building managers and owners know very little about their HVAC systems, so comments on such systems must be used with caution.) Level-2 could have detected several of the problems we encountered at the Jersey Mall, for example: oversized equipment, excess energy used during unoccupied periods, recent changes in energy usage, and a comparative energy consumption index.

<u>Level 3: Site Visits</u> The Level-3 analysis involves the guided site visit. The analyst visits the site, with data and initial conclusions from the previous levels in hand. We envision two site visits. The first is a quick one-hour walk-through with limited instrumentation, at minimum a camera, light meter, thermometer and relative humidity sensor. The second visit, if required, would then include additional measurements, lasting perhaps 8 hours or longer and concentrating on measurements of connected loads, equipment testing, and verification of operation schedules and setpoint temperatures (such as the procedure outlined by Harrje and Dutt [1988] for multi-family buildings).

<u>Level 4: Follow-up</u> At Level-4, when the decision is made to implement the recommendations, careful follow-up monitoring is initiated and the effects of the retrofit are measured. Not only are the improvements evaluated, but careful attention is paid to evaluating operational, maintenance or environmental changes (e.g., comfort levels and lighting levels). Reporting to a standardized data base can also occur.

We found the above methods to be useful in the stores considered during the case study. We feel that our efforts have begun to unravel the complexities that have plagued commercial building energy audit procedures and we hope that they will be useful to others faced with similar tasks.

3.4.2. Additional Thoughts

Here are some additional thoughts about future research objectives for the improving the commercial building energy audit:

1. Prescreening tests for a customer's utility bill could easily be formulated that would allow utilities to serve their customers better by eliminating erroneous readings.

2. A "PRISM sieve" may be helpful for creating an electric-demand-based analysis. Specifically, balance-point temperature seems to be a reasonable dividing point for assessing cooling-related, heating-related and base- level electric demand.

3. A mixed hourly modeling procedure, such as we presented in this study, might serve as well as might other sophisticated hourly models (Press 1986). Specifically, scheduled loads should first be extracted from the data which would then allow for environmental conditions to be analyzed with a

residual analysis, like the one presented in this report.

4. Utility companies should further promote the correct sizing (or re- sizing through rebate and bounty programs) of air-conditioning systems in small commercial buildings. Such candidate stores could easily be prescreened with existing utility bill information, square footage of conditioned space, and installed air-conditioner size. If the results from the Jersey Mall are any indication, electric demand savings could have been achieved for an equivalent cost of about $50/kW (compared to $250 to $300/kW currently being spent for combustion turbine technology [EPRI 1986]).

5. Computerization of small commercial stores (i.e., microprocessor- controlled cash registers, photocopy machines, FAX machines, etc.) may be contributing significantly to increasing electricity requirements. Utility representatives should consult with computer manufacturers to determine how computerization can improve without unnecessary requirements for electricity (i.e., 24-hour-per-day operation of the computers or continuous operation of the building's heating-cooling system during unoccupied periods to prevent computers from overheating).

6. Comparative analysis should be performed on inverse hourly modeling procedures to determine which models yield suitable results (Rabl 1988; Reddy 1989). For example, Singular-Valued Decomposition, Principle Component Analysis, Auto-Regressive Moving Average, frequency domain, and simplified models should be evaluated (e.g., computation time, meaningfulness of coefficients, complexity, etc.) in side-by-side tests to determine which models are most suitable for which purposes. Such models might yield vast improvements over current end-use load models used to predict electric loads on utility grids.

7. "Canned" energy audits must undergo benchmark testing and certification before being adopted and used by utility companies. Although many accurate "canned" energy audit programs exist, if the results from our spot check are any indication, recommendations from such programs can be misleading. Clearly, a need exists for an analytical basis for improving commercial building energy audits.

8. Historical changes in electricity usage (and peak electric demand levels) should be considered over two or more seasons. This implies that utility records should be extended to 22 to 24 months from the current practice of 12 to 14 months.

9. Interior comfort conditions (including thermostat operation) and lighting conditions must be evaluated in order to comparatively assess energy consumption from one building to the next. Daily minimum-maximum temperature readings and lighting measurements should be performed in order to assess the quality of the interior environment.

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Tables and Figures

Table 1: *Recommendations From the ASHRAE SP-56 Survey.* This table contains recommendations from ASHRAE SP-56. Three levels of effort are recommended for the commercial building energy audit, as follows:

Level 1:	An analysis of past utility information; low level of detail; minimum expertise and cost.
Level 2:	Level 1 data as well as a simple walk-through and brief analysis of the building and its systems; moderate level of detail; moderate expertise and cost.
Level 3:	Levels 1 and 2 data plus a detailed engineering analysis of the building and its systems; high level of detail; substantial time, expertise and cost.

Table 2: *Information Available From a Typical Audit* This table provides a summary of the recommendations provided by two commercial energy audits performed on the general merchandise store. Both audits were performed by two different certified energy analysts using the same computerized commercial building energy analysis package. We present these findings to illustrate what a typical low-cost commercial customer energy audit provides, and to show how two audits on the same building can vary in their calculations of energy consumption and recommendations of energy-saving retrofits.

A. Energy End-Use Breakdown

End-Use	**Estimated Consumption (MBtu)**	
	AUDIT #1	**AUDIT #2**
Heating	1120	1084
Cooling	953	703
DHW	55	73
Lighting	1970	1606
Distribution	30	672
Process	59	88
	----------	----------
Total	4187	4226

B. Recommended Retrofits

End Use	**AUDIT #1 Recommendations Estimated Payback (yrs)**	**AUDIT #2 Recommendations Estimated Payback (yrs)**
Heating	Boiler Maintenance 0.6 Vent Damper 3.9	None
Cooling	None	None
DHW	Insulate Pipes 2.9 Insulate DHW Tank 3.0	None
Lighting	Screw-in fluorescent 2.6 High Eff. Fluorescent 2.6 Replace ballasts 13.7 Circular flourescent 0.3 Elliptical Incandescent 0.8	Screw-in fluorescent 0.9 High Eff. Flourescent 2.1 Replace ballasts 10.8
Distr.	Insulate pipes 6.8	None
Process	None	None
Envelope	Weatherstrip 9.1 Insulate walls 20.5 Insulate roof 22.1 Install thermal pane 35.3	None

Table 3: *Description of ELF and OLF calculations*

Electric Load Factor (ELF), also referred to as the diversity factor, and Occupancy Load Factor (OLF) are calculated as follows:

Electric Load Factor (ELF):

$$\text{ELF} = \frac{\text{kWh(for the period)}}{\text{kW(max in period)*hours in period}}$$

Occupancy Load Factor (OLF):

$$\text{OLF} = \frac{\text{occupied hours in period}}{\text{24 x days in the period}}$$

***Table 4:** General merchandise, stationery & furniture store info.* This table contains information about the general merchandise, stationery and furniture stores.

ITEM:			
GENERAL:	**GENERAL MERCHANDISE**	**STATIONERY STORE**	**FURNITURE STORE**
SIC Code:	5311	5943	5712
Size (ft^2):	60,000	2990	2700
Building Age (yrs):	36	36	36
Type:	Bit. roof, Masonry walls	Bit. roof, Masonry walls	Bit. roof, Masonry walls
Windows:			
(% of floor area):	0.7%	16.8%	6.6%
Window Type:	single pane	single pane	single pane
No. Floors	2 floors	1 floor (note #1)	1 floor (1)
OCCUPANCY:			
M-F hrs:	10:00 - 9:00	9:30 - 5:30	10:00 - 5:30
SAT hrs:	10:00 - 7:00	9:30 - 5:30	10:00 - 5:30
SUN hrs:	12:00 - 5:00	Closed	Closed
Employees:	40-50	3-4	2-3
O.L.F. (%, Ann.)	41.8%	28.8%	26.4%
ENERGY:			
Tot. Ele. ($\$/ft^2$-yr):	$1.35	$0.65	$1.77
E. Use ($\$/ft^2$-yr)	$0.92	$0.39	$0.90
E. Dem ($\$/ft^2$-yr)	$.0.42	$0.39	$0.96
E. Dem (% tot-$)	31.4%	40.0%	49.0%
Ann. kWh (W/ft^2)	1.75	0.78	1.46
Base-level (W/ft^2)	1.39	0.78	1.13
Cooling (W/ft^2)	0.35	0.0	0.33
Heating (W/ft^2)	0.0	0.0	0.0
Ann. kW (W/ft^2)	3.1-4.3	2.47-2.87	4.3-11.3
E.L.F. (Avg, Mon.,%)	47.7%	27.5%	23.0%
Ele. (%, unocc.)	19.3%	2.0%	4.9%
PRISM RESULTS:			
Period:	10/86-12/87	10/86-12/87	10/86-12/87
Model:	CO	CO	CO
Ref. Temp (SE) (F):	54.0(3.9)	85.9(0.3)	64.0(2.9)
Base-Level (CV) (kWh/day):	1931(4.4%)	55.72(4.0%)	92.25(3.0%)
CV(NAC) (kWh/yr)	886,200(1.9%)	19,000(6.4%)	43600(1.9%)
Cool Slope (CV) (kWh/F-day):	60.5(10.2%)	286.7(-85.3%)	7.34(22.1%)
R squared	o.954	0.203	0.967
Cooling (%)	20.3%	-7.2%	22.7%
Base-level(%)	79.7%	100% (see note 2)	77.3%
FLAT PROFILE ANALYSIS:			
Period:	8/87-9/88	8/87-9/88	8/87-9/88
Mean (kWh/mo):	72769	1553	3368.5
Sdev (%):	15.0%	15.0%	33.2%

Table 4:* *(cont.) *General merchandise, stationery & furniture store info.* This table contains information about the general merchandise, stationery and furniture stores.

ITEM:			
	GENERAL MERCHANDISE	**STATIONERY STORE**	**FURNITURE STORE**
LIGHTING:			
Flourescent (kW):	115.1	6.5	9.3
Incandescent(kW):	21.6	3.0(1)	0.6(1)
Total (W/ft^2)	2.27	2.17	3.44
Ill. Levels (fc)	50-60	50-80	70-110
SYSTEMS:			
Heat Sys. Type:	Steam Boiler	Rooftop Furn.	Duct Furnace
Heat Sys. Fuel	Oil	Nat. Gas	Nat. Gas
Heat Cap. (Btu/hr):	3,200,000	250,000	180,000
Heat (Btu/ft^2):	53.3	83.5	66.6
Heat Sys. Ctrl:	Outside Reset	H/C Stat. w/o S.B.	H/C Stat. w/o S.B.
Heat Sys. Dist:	Ducts w/coils	Ducts, Dir. Return	Ducts, Plen. Return
# of Heat Sys:	1 (3)	1 (4)	1
Cool Sys. Type	Chiller (5)	Package A/C	Package (A/C)
Cool Sys. Fuel	Electricity	Electricity	Electricity
Cool Cap. (ton)	150	7-1/2	15
Cool (sqft/ton):	400	398	180
Cool Sys. Ctrl.	Manual	H/C w/o S.B	H/C w/o S.B
Cool Sys. Dist:	6 AHU, Plen.	AHU,Dir.	AHU,Dir.
Economizer	Yes	Yes	Yes
# of Cool Sys.	1-chill. 6-coils	1 compr. 1 coils	2 compr. 2 coils
Other Equipment:	75 Gal N.G. DHW; 24 cash regs.; 2-10 hp. Escal.; 1-50 hp. D. C. Elev. (in the basement); 1-25 hp. C. W. pump; 6-7 hp. AHUs; 1-phone switchboard; 1-aux. 5-ton A/C	2 cash regs. 1 copy machine	66 gal. Ele. DHW 1 cash register

NOTES:

(1) The stationery and furniture stores have unconditioned basements used for storage. The basements were not included in the conditioning analysis. However, the lights in the basements were included in the lighting analysis since frequent trips are made to retrieve merchandise during the day.

(2) We include the PRISM results for the stationery store only to show an example in which PRISM did not accurately estimate the cooling component, as indicated by the large CV of the cooling slope. Negative cooling slopes and a negative percent-cooling are physically unreasonable numbers.

(3) The general merchandise store has a heating system which uses low pressure steam controlled with an open-loop, outside-reset timer. 3 AHUs on each floor distribute cooling and heating. The AHUs turn on/off with a time-clock and are manually switched on/off by the manager during the day. A small salon on the second floor has a separate cooling system. Heating and Cooling thermostats for the main store appear are inoperative.

(4) The stationery store also has a unit heater in the basement with separate thermostatic control. Like the store's rooftop unit, this unit heater also does not register on the utility meter.

(5) The general merchandise store contains a 150-ton ground-water coupled chiller. The store was originally designed to be cooled with well- water only.

Table 5: *Description of the exercise center.* This table contains information about the exercise center.

EXERCISE CENTER

ITEM:		
GENERAL:		
SIC Code: --	--	
Size (ft^2):	8900	
Building Age (yrs):	36	
Type:	Bit. Roof	
Windows		
(% of floor area):	2.5%	
Window Type:	single pane	
No. Floors	2 (w/basement)	
OCCUPANCY:	**Fall/Winter/Spring**	**Summer**
M-Tu-W hrs:	6:00am - 10:00pm	6:00am - 10:00pm
Th-F hrs:	6:00am - 9:00pm	6:00am - 9:00pm
S-S hrs:	9:00am - 5:00pm	8:00am - 2:00pm
Employees:	6 - 9	
O.L.F.(%,Ann.)	60%(est.)	
ENERGY:		
Tot.Ele.(\$/ft^2-yr):	\$1.51	
E.Use(\$/ft^2-yr):	\$1.02	
E.Dem(\$/ft^2-yr):	\$0.48	
E. Dem.(% tot-\$):	32.0%	
Ann. kWh(W/ft^2):	1.94	
Base-level (W/ft^2):	1.94	
Cooling (W/ft^2):	0.0	
Heating (W/ft^2):	0.0	
Ann kW (W/ft^2):	4.11-4.81	
E.L.F.(Avg.Mon.,%):	41.2%(est.)	
Ele.(%,unocc.):	exceeds actual (see note 1)	
PRISM RESULTS:		
Period:	10/86 - 12/87	
Model:	CO (see note 2)	
Ref.Temp(SE) (F):	42.0(64.2)	
Base-Level(CV)		
(kWh/day):	423.0(6.1%)	
CV(NAC) (kWh/yr):	158714(2.3%)	
Cool Slope(CV)		
(kWh/F-day):	0.734(166%)	
R squared:	0.084	
Cooling(%):	---	
Base-level(%):	(see note 5)	
FLAT PROFILE ANALYSIS:		
Period:	10/78-9/88	
Mean (kWh/mo):	12373.8	
Sdev (%):	11.0%	
LIGHTING:		
Fluor (kW):	3.8	

Table 5:* *(cont.)* *Description of the exercise center. This table contains information about the exercise center.

EXERCISE CENTER

ITEM:	1st Floor	Basement Left	Basement Center	Basement Right
LIGHTING:				
Incand (kW):	2.5			
Total (W/ft^2):	0.72			
Ill.Levels(fc):	15-30 upstairs			
Ill.Levels(fc):	5-7 downstairs (3)			
SYSTEMS:				
Heat Sys. Type:	Duct Furn.	E.Resis.	E.Resis.	--
Heat Sys. Fuel:	Nat.Gas	Elec.	Elec	--
Heat Cap.(Btu/hr):	2x120000	60000(est)	60000(est)	--
Heat (Btu/ft^2):	84.4	30.0	30.0	--
Heat Sys. Ctrl:	H/C w/o S.B.	H/C w/o S.B.	--	--
Heat Sys. Dist:	2 AHU,Plen	1 AHU, dir.	--	--
# of Heat Sys:	2	1		
Cool Sys. Type:	Package A/C	Package A/C	Package A/C	Package A/C
Cool Sys. Fuel:	Elec.	Elec.	Elec.	Elec.
Cool Sys. Cap:	10 ton	5 ton	5 ton	2-1/2 ton
Cool (sqft/ton):	284.5	400	400	800
Cool Sys. Ctrl:	H/C w/o S.B.	H/C w/o S.B.	C/O w/o S.B.	C/O w/o S.B.
Cool Sys. Dist:	2 AHU,Plen,.	1 AHU, Dir.	1 AHU, Dir.	1 AHU, Duct.
Economizer:	Yes	Yes	Yes	No
# of Cool Sys:	1 com,1 coil	1 com,1 coil	1 com,1 coil	1 com,1 coil
Other Equip:				
	1 120kBtu N.G.DHW	2-exhaust fans		
	2-30 gal 6kW E.DHW	2-4.2kW saunas		
	1-15 gal ele.DHW (4)			

NOTES:

(1) The base-level kW times occupied-hours estimate for the electricity consumed during occupied periods (413 hours x 37.6 = 15,528 kWh) exceeds the actual electricity (1/88 = 11,970 kWh). At the exercise center, the presence of the electric water heaters and saunas consistently set the peak (37.6 kW) above the average daily operating level (i.e., 11,970 / 413 hours = 28.8 kW). A load-shedding system could save this store 8.7 kW/month.

(2) The PRISM results are included to illustrate that PRISM does not detect an increase in electricity use during the cooling season. The low R^2 and negative cooling indicate physically unrealistic results.

(3) The illumination levels do not consider higher lighting near the windows. Measurements were taken at least 15 feet in from the windows, using a hand held illumination meter 4 feet above the floor, except in the basement of the exercise center where they were taken at the floor level).

(4) The electricity ratings are from manufacturers' labels except as noted with (est). The estimated (est) reading was taken from similar equipment where the ratings were known from previous analysis.

(5) Base-level = 100% is implied from the 11% standard deviation on 22 months of electricity usage -- a flat consumption.

***Table 6:** Drive-up bank, travel center, video store information.* This table contains information about the drive-up bank, travel center and video stores.

ITEM:	DRIVE-UP BANK	TRAVEL CENTER	VIDEO STORE
GENERAL:			
SIC Code:	6000	4722	-
Size (ft^2):	322	720	550
Build.Age(yrs)	8	36	36
Type:	Bit.Roof, Mason.wall	Bit.Roof, Mason.Wall	Bit.Roof, Mason.Wall
Windows (% of floor area):	9.3%	15.0%	19.6%
Window Type:	Bullet Proof	Single Pane	Single Pane
No. Floors:	1	1	1
OCCUPANCY:			
M-F hrs:	9:00-4:00	9:00-5:30	10:00-10:00
SAT hrs:	9:00-12:00	10:00-4:00	10:00-10:00
SUN hrs:	Closed	Closed	12:00-6:00
Employees:	1	3 - 4	1 - 2
O.L.F.(%,Ann.):	24%(est)	29%(est)	29%(est)
ENERGY:			
Tot.Ele.($/ft^2-yr):	$5.73	$1.69	$2.24
E.Use($/ft^2-yr):	$3.22	$0.98	$1.15
E.Dem($/ft^2-yr):	$2.51	$0.71	$1.08
E. Dem.(% tot-$):	43.9%	42.2%	48.5%
Ann. kWh(W/ft^2):	5.92	1.76	2.04
Base-level (W/ft^2):	2.07	1.10	1.36
Cooling (W/ft^2):	0.78	0.29	0.24
Heating (W/ft^2):	3.06	0.36	0.44
Ann kW (W/ft^2):	9.6-38.8	3.1-10.4	7.8-14.7
E.L.F.(Avg.Mon.,%):	25.9%	33.9%	18.9%
Ele.(%,unocc.):	36.9%	50.4%	exceeds actual
PRISM RESULTS			
Period:	10/86-12/87	11/86-12/87	11/86-12/87
Model:	H/C	H/C	H/C
H.Ref.Temp(SE) (F):	64.3(14.3)	58.0(34.7)	54.6(8.8)
C.Ref.Temp(SE) (F):	66.0(13.0)	60.0(3.0)	76.0(3.0)
Base-Level(CV) (kWh/day):	12.03(15.9%)	18.62(12.9%)	16.38(2.8%)
CV(NAC) (kWh/yr):	12536(6.5%)	10865(6.6%)	8943(4.7%)
Heat Slope(CV)	1.36(0.3%)	0.65(1.2%)	0.69(0.3%)
Cool Slope(CV) (kWh/F-day):	1.52(6.8%)	0.95(0.9%)	5.01(4.6%)
R squared:	0.824	0.553	0.804
Cooling(%): 1	3.3%	16.9%	11.6%
Heating(%)	51.65%	20.5%	21.44%
Base-Level(%)	35.05%	62.6%	66.9%

Table 6 (cont.): *Drive-up bank, travel center, video store information.* This table contains information about the drive-up bank, travel center and video stores.

ITEM:	**DRIVE-UP BANK**	**TRAVEL CENTER**	**VIDEO STORE**
FLAT PROFILE ANALYSIS:			
Period:	10/87-9/88	10/87-9/88	8/87-7/88
Mean (kWh/mo):	1465.1 1	150.9	820.1
Sdev (%)	46.2%	42.3%	31.3%
LIGHTING:			
Fluor (kW):	0.960	0.4	0.52
Incand (kW):	1.0(outside)	0.6	0.60
Total (W/ft^2):	2.98	0.86	2.03
Ill.Levels(fc):	-	55-75	-
SYSTEMS:			
Heat Sys. Type:	Heat Pump	Heat Pump	2-Elec.Resis.
Heat Sys. Fuel:	Elec.	Elec.	Elec.
Heat Cap.(Btu/hr):	18000	60000	2-6.8Kbtu(est)
Heat (Btu/ft^2):	56.5	83.3	36.36
Heat Sys. Ctrl:	E/H/C w/o S.B.	H/C w/o S.B.	H/O therm.
Heat Sys. Dist:	1 AHU 1	AHU	wall units
# of Heat Sys:	1	1	2
Cool Sys. Type:	Package H/P	Package H/P	window A/C
Cool Sys. Fuel:	Elec.	Elec.	electric
Cool Sys. Cap.:	1.5 ton	5 ton 1	ton(est)
Cool (sqft/ton):	20	144	550
Cool Sys. Ctrl:	E/H/C w/o S.B.	H/C w/o S.B.	A/C panel
Cool Sys. Dist:	1 AHU	1 AHU	direct
Economizer:	no	no	no
# of Cool Sys:	1 compr.	1 compr.	1 compr.
Other Equip:	1-port.heater	4-PCs	1-computer
	1-toaster	2-printers	1-coffee pot
	1-refrig.	1-modem	1-E.water H/C
	4kW E.DHW	1-refrig.	
	2-add.mach.	1-copier	
	1-coffee pot	-coffee pot	

NOTES:

(1) The thermostatic control for the drive-up bank has the following settings: electric resistance heating, heat pump heating, off, and cooling. The thermostat does not have a night setback feature.

(2) The travel store has hot water supplied to a sink in the rear of the store from a DHW heater shared with other stores.

(3) The base-level kW times occupied-hours estimate in the calculation of the video store's electricity consumption during occupied periods (1470.6 kWh) exceeds the actual electricity for the month chosen (11/87: 576 kWh). In the case of the video store, the store had a electric water heater in the office, coffee pot, toaster, etc. Such devices could have consistently set the peak (4.3 kW) above the average daily operating level (1.7 kW). A switch on the two electric heaters could save this store about 3 kW/month in demand charges during the heating season -- a 22% savings in electricity costs.

***Table 7:** Summary of Energy Conservation Recommendations.* This table contains a summary of energy conservation recommendations for each store with estimates of energy savings and associated costs for implementing the measures. The items in this table are primarily operation and maintenance measures which can be implemented at low to no cost.

STORE	COST	SAVINGS	
		ELECTRIC DEMAND	**ELECTRICITY USAGE**
GENERAL MERCHANDISE: 1. Reduce nighttime lighting by rewiring those fixtures that do not need to be on 5 kW x (1-.418) x 8760 h = 25491 kWh x .10 $/kWh = $2549 kWh savings. Cost for this measure is estimated at 10 hrs labor at $50/hour....................	$500	-	$2549
2. Replace elevator timeout 15 kW x 12 mo x 10 $/kW = $1800 15 kW x(1-.418) x 8760 h = 76475 kWh x .10 $/kWh = $7647. Cost for this measure is estimated at one service call = $250.........................	$250	$1800	$7647
FURNITURE STORE: 1. Rewire air conditioner & thermostat 7 kW x 6 mo. x 10 $/kW = $420. The cost for this measure is 6 hrs. labor at $50 per hour......................	$450	$420	-
EXERCISE CENTER: 1. Install demand limiter on 5 devices 8 kW x 12 mo. x 10 $/kW = $960. The cost for this measure is based on a verbal bid from the HVAC service contractor for the store............	$1000	$960	-
DRIVE-UP BANK: 1. Insulate & reduce unoccupied use of space heating/cooling $(.369-.20) \times 3.22$ \$/ft^2 x 322 ft^2 = \$175. The cost for this measure is based on \$100 material, and 8 hours labor at \$50 per hour........	$500	-	$175
2. Rewire water heater/heat pump 2 kW x 12 mo. x $10 = $240. The cost is based on 1 hour of labor and $50 material........................	$100	$240	-
3. Malfunctioning utility meter......... (not included in total)	$0	($300+)	

Table 7 (cont.): *Summary of Energy Conservation Recommendations.* This table contains a summary of energy conservation recommendations for each store with estimates of energy savings and associated costs for implementing the measures. The items in this table are primarily operation and maintenance measures which can be implemented at low to no cost.

STORE	**COST**	**SAVINGS**	
		ELECTRIC DEMAND	**ELECTRICITY USAGE**
VIDEO STORE: 1. Rewire electric resistance heaters 2 kW x 5 mo. x 10 $/kW = $100. The cost for this is based on $50 material and one hour labor at $50 per hour.......	$100 $100	-	
TRAVEL CENTER: 1. Turn-off computers at night and reduce unoccupied use of equipment (.504-.05) x 720 ft^2 x .98 $/$ft^2$ = $320...............	$0	-	$320
TOTAL...............................	$2900	$3520	$10691

Figure 1: *Diagram of the Jersey Mall.* This figure shows the Jersey Mall in plan view. The mall contains 220,000 square feet of conditioned space and has 52 tenant businesses. Electricity, natural gas and fuel oil are the primary fuels consumed by the mall. The location of the general merchandise, stationery, video and furniture stores, exercise and travel centers and drive-up bank are shown.

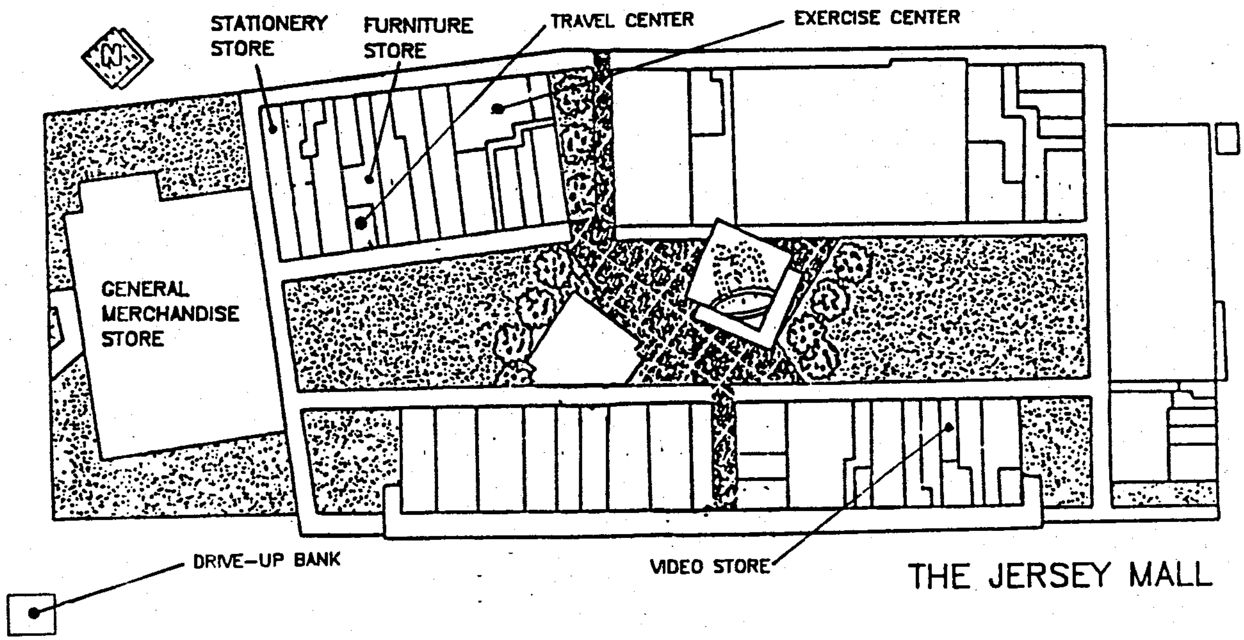


Figure 2: *Minimum-Maximum & Average Monthly Outdoor Temperatures.* This figure illustrates the monthly weather information based on data from the National Weather Service. The values shown are for the closest weather station to the Jersey Mall (Newark, New Jersey). The monthly average, minimum and maximum daily average temperature values correspond to the utility billing period for the mall (i.e., the utility meters are read about the 10th of each month).

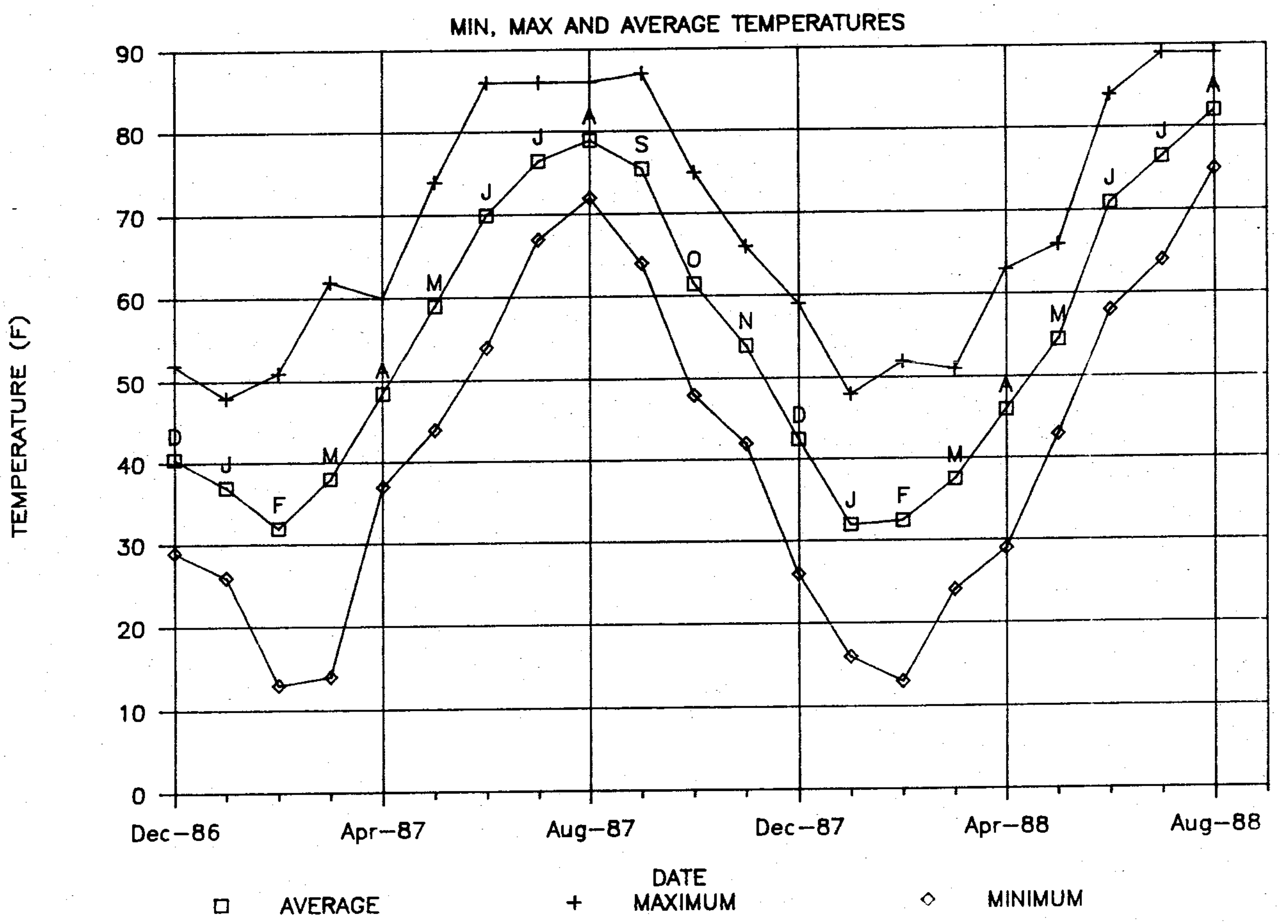


Figure 3: *Weather Normalized Annual Electric Use (General Merchandise).* This figure shows weather normalized annual power levels for the general merchandise store. The NAC, base-level and cooling curves represent the Sliding PRISM CO analysis expressed in units of W/ft². Sliding PRISM CO is the PRISM CO model, applied in successive 12 month increments, in this case to 22 months of utility billing data. The dashed lines are standard errors.

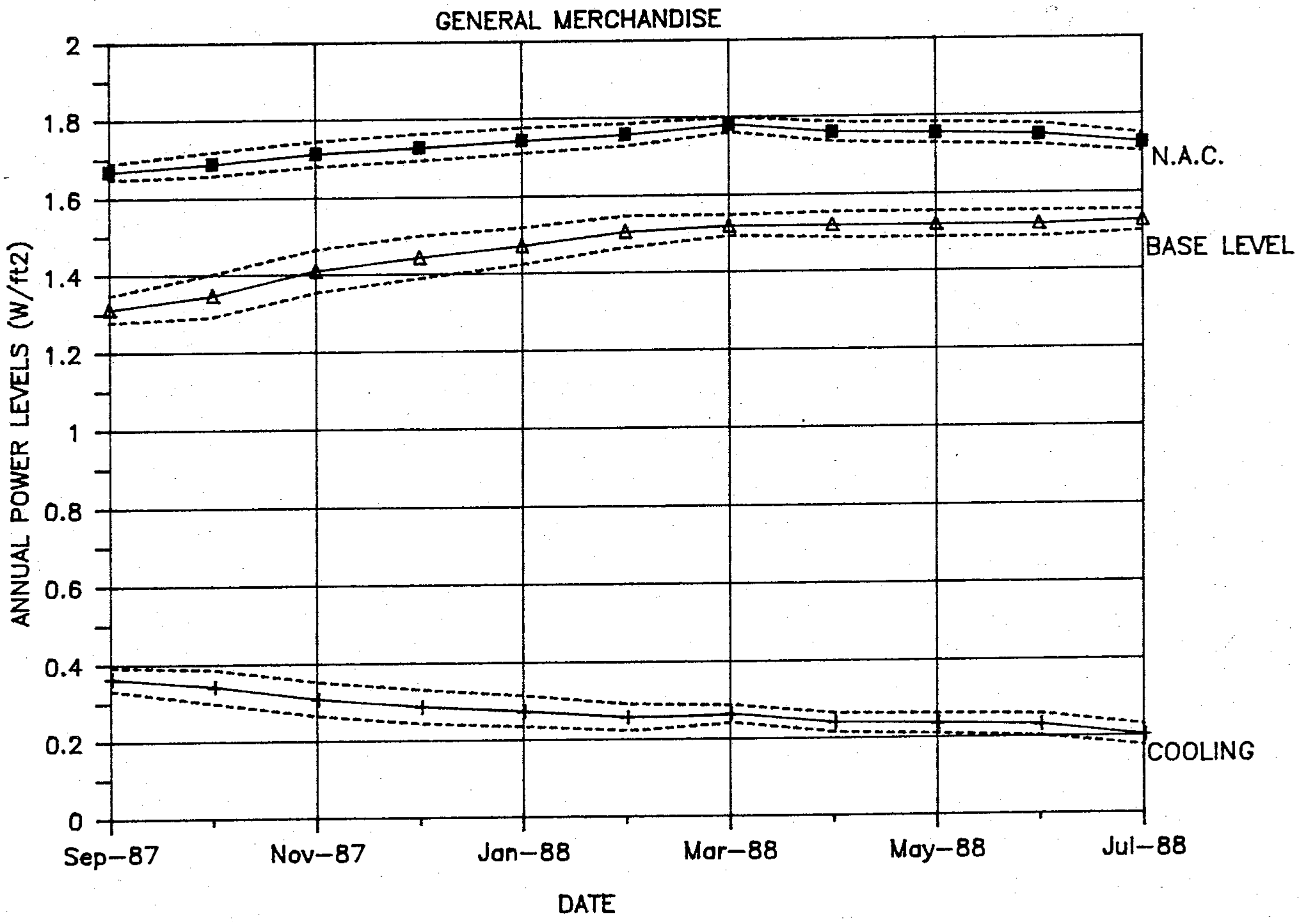


Figure 4: *Monthly Electricity Use (General Merchandise).* These figures show monthly power levels for the general merchandise store. Power levels (W/ft^2) are shown for both electricity usage (kWh) and peak monthly electric demand (kW).

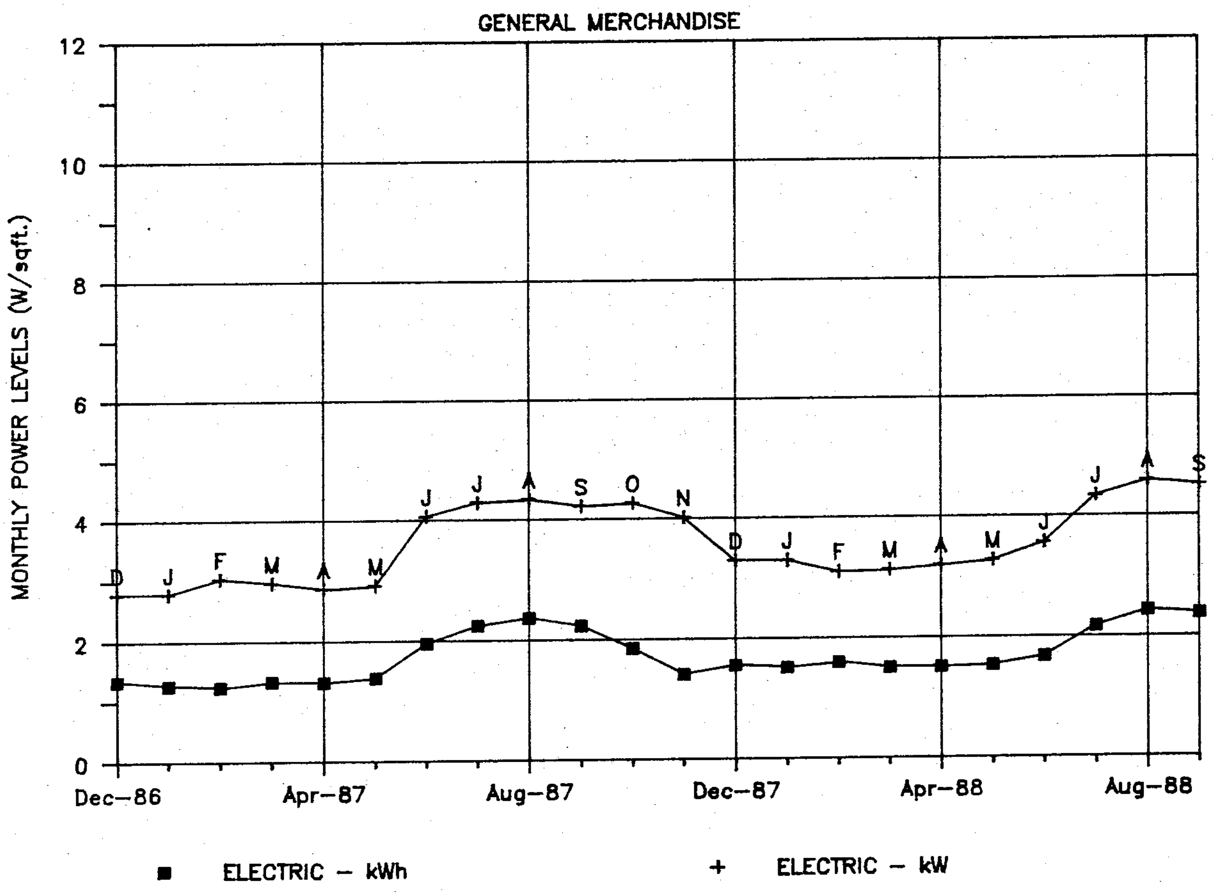


Figure 5: *Monthly ELF and OLF (General Merchandise).* This figure contains monthly load factors for the general merchandise store. Monthly Electric Load Factors (ELF) and Occupancy Load Factors (OLF) are as shown. Equations used to calculate ELF and OLF are given in Table 3.

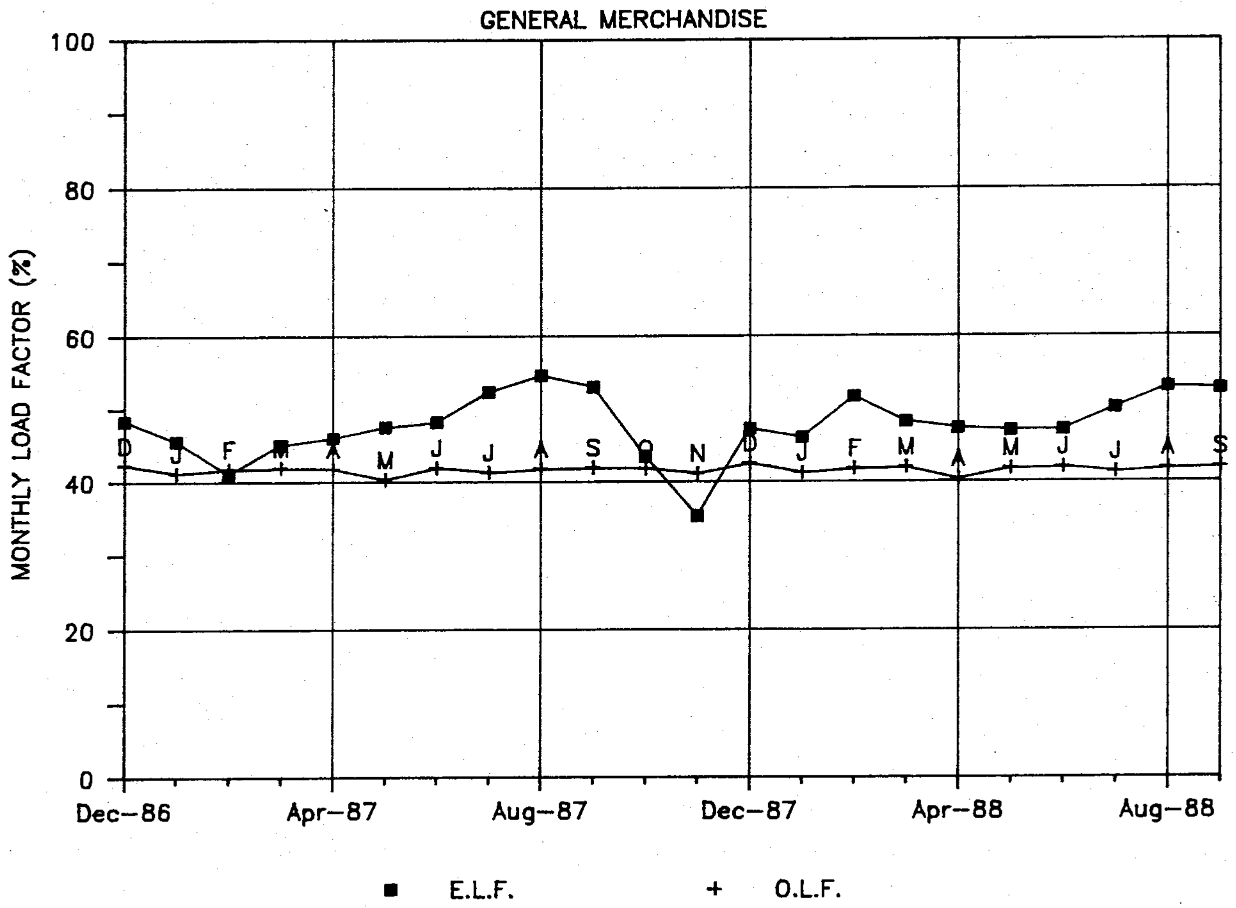


Figure 6: *Daily Electricity Use (General Merchandise).* This figure shows daily electricity usage (W/ft^2) for the general merchandise store. Data include actual, base-level model and residuals. The daily base-level model represents the summation of the hourly base-level model shown in Figure 11. The residual represents the actual minus the base-level model.

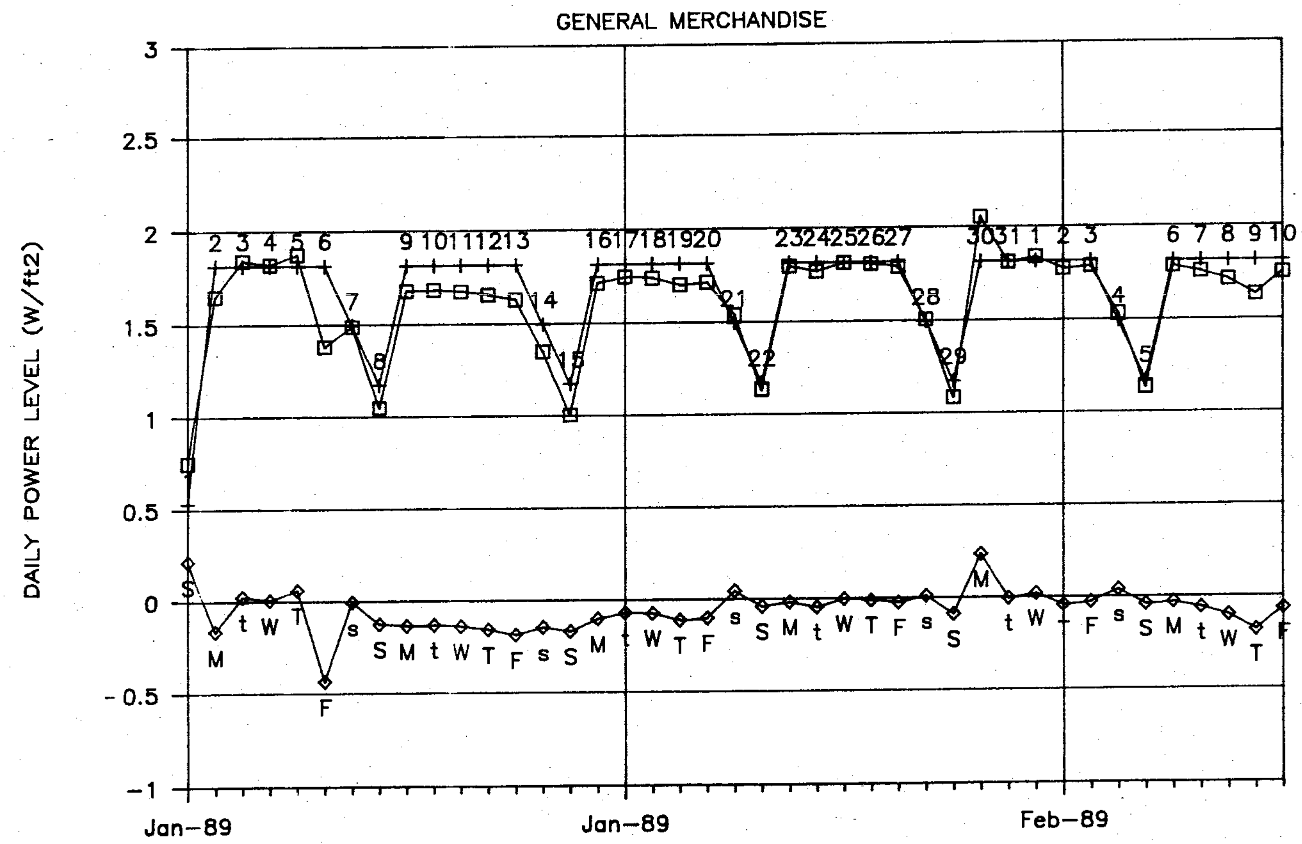


Figure 7: *Daily Minimum-Maximum Zone Temperatures (General Merchandise).* This figure shows daily minimum and maximum zone temperatures for the general merchandise store. The zone temperatures are displayed against average daily ambient temperature. Data are for the period March 1988 through February 1989.

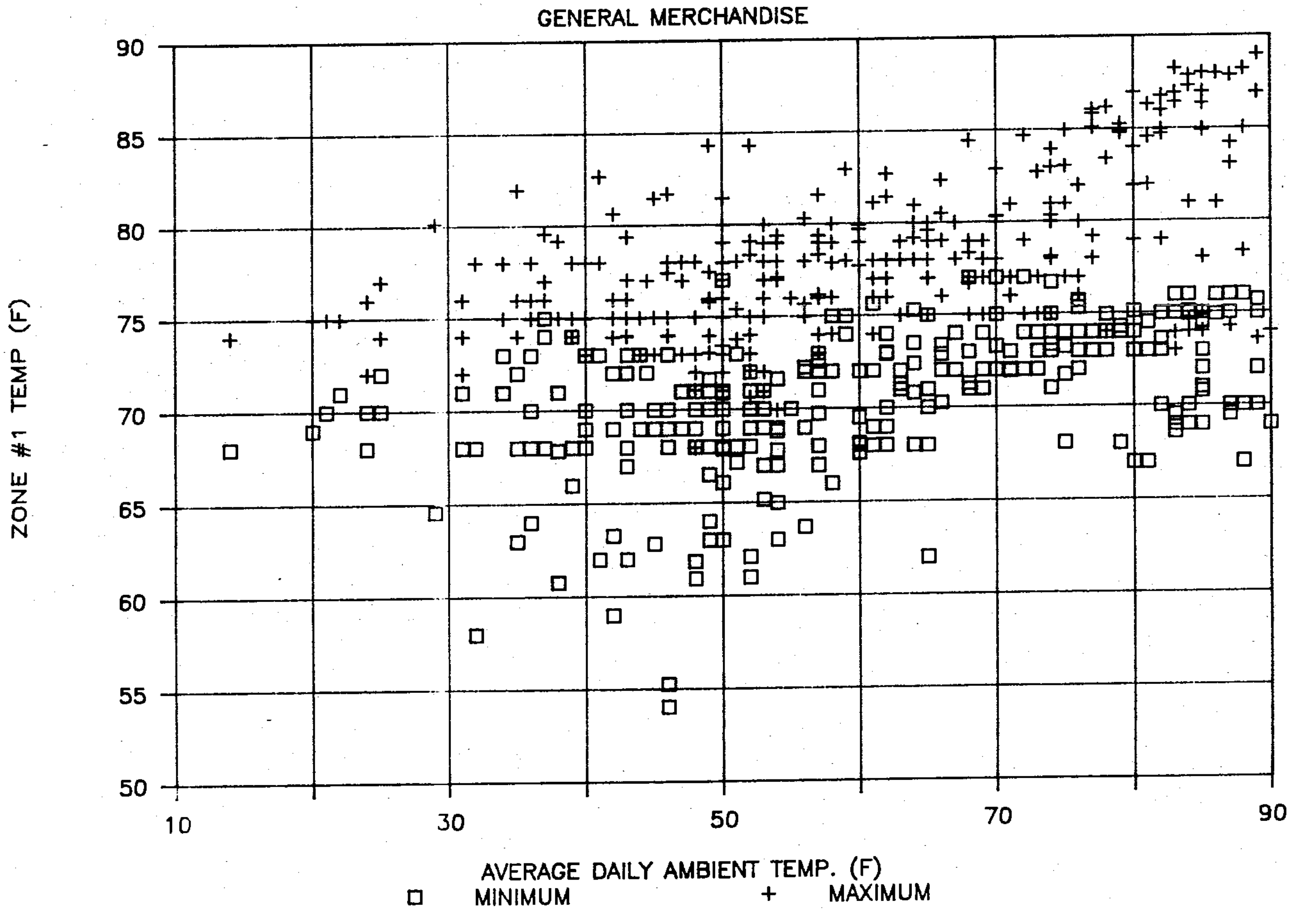


Figure 8: *Hourly Electrical Use and Zone Temperatures (General Merchandise).* This figure shows average hourly power levels (W/ft^2) in Figure (a), and hourly zone temperatures for the general merchandise store in Figure (b). Data are for the period January 1, 1989 through February 10, 1989.

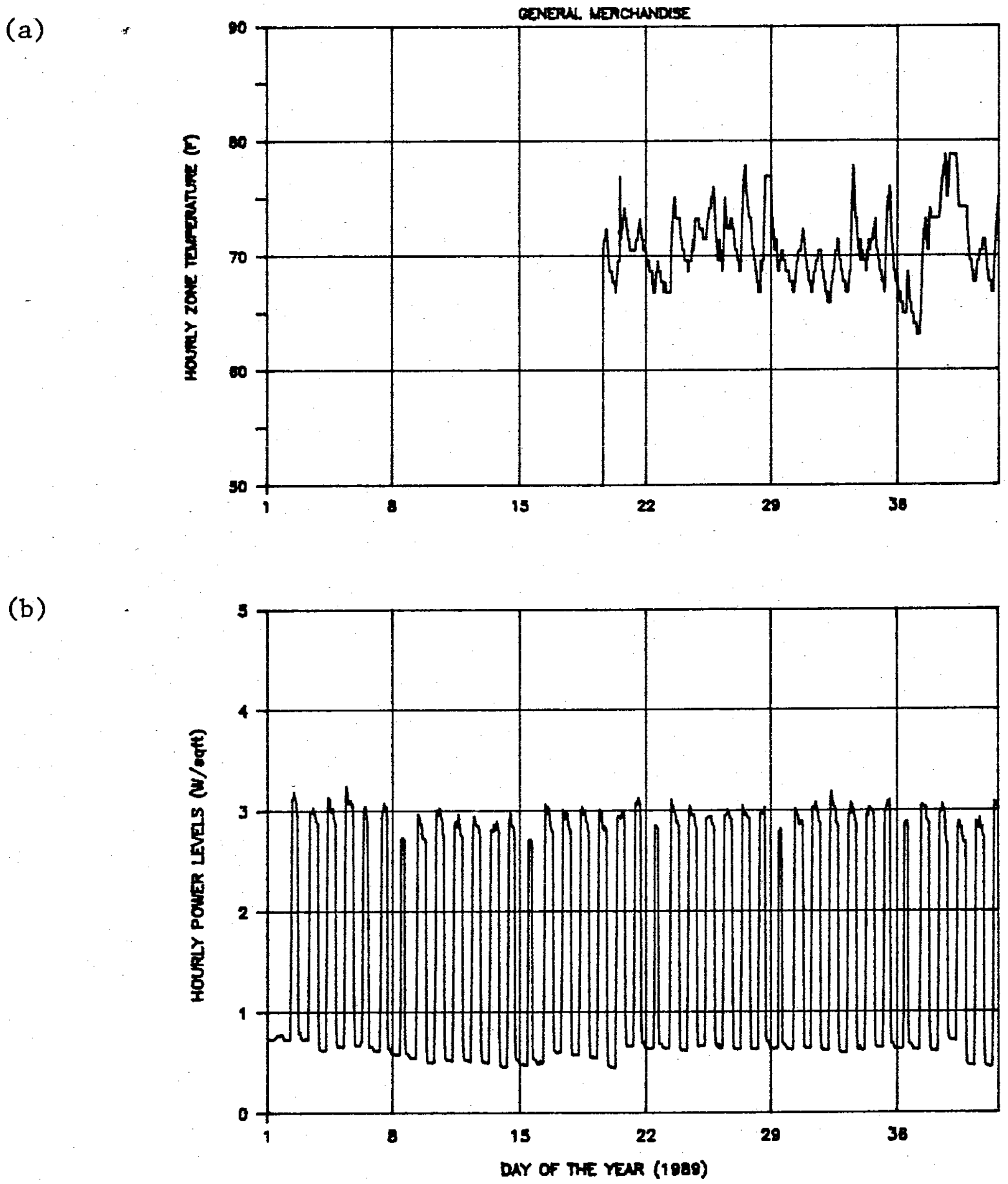


Figure 9: *Hourly Electricity Use (General Merchandise).* This figure shows the hourly electricity usage for the general merchandise store. The data shown represent the period from March 14, 1988 to March 13, 1989. The day-of-the-year and hour-of-the-day form the x-y plane. Hourly electricity (kWh/h) usage is represented as the height of the surface above the x-y plane. Figure (a) displays the contours with the day-of-the-year axis facing the viewer. Figure (b) displays the contours with the hour-of-the-day axis facing the viewer. Zero values represent missing data.

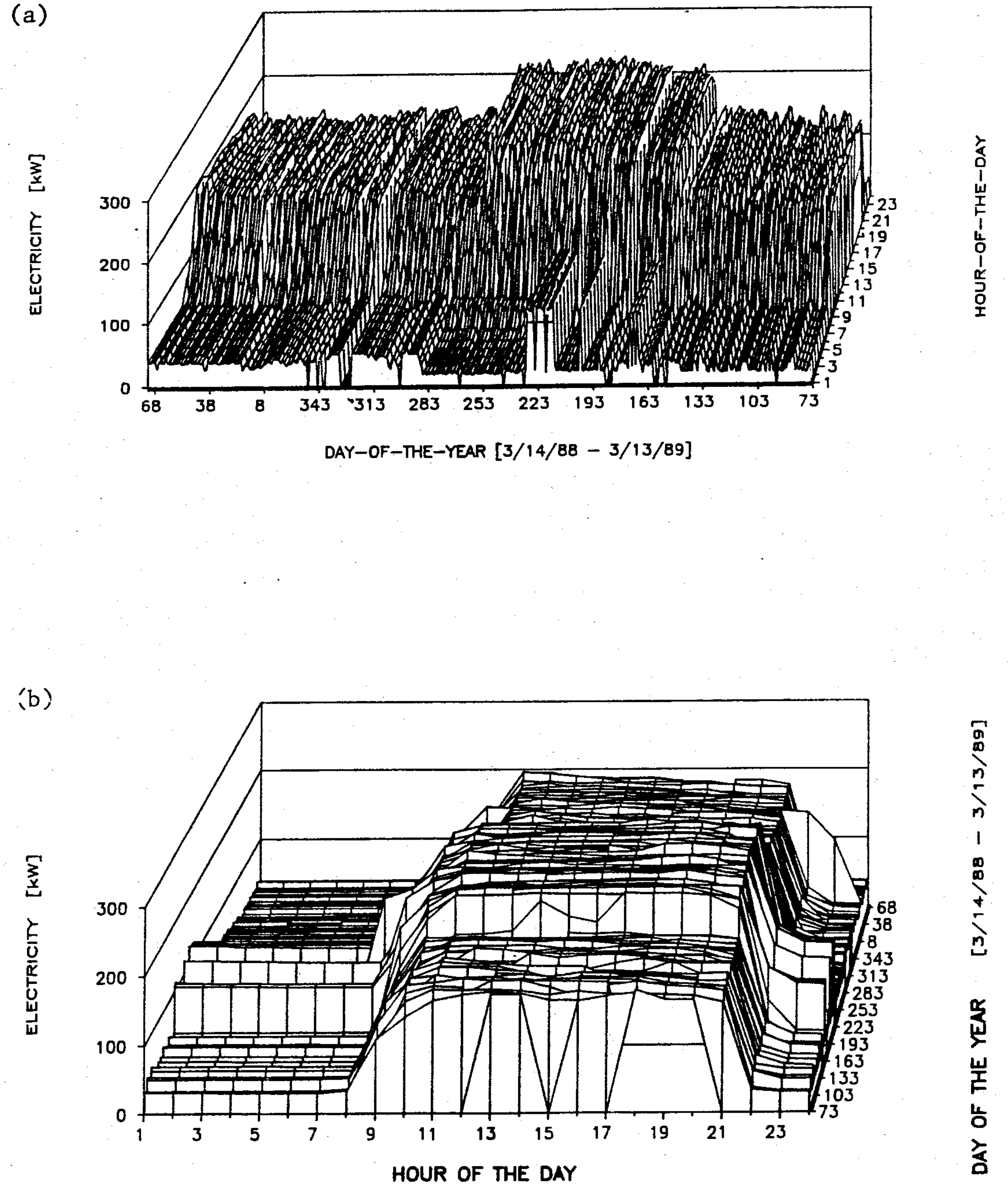


Figure 10:* *Archetypal Electric Load Shape Profile Identification. This figure shows archetypal electrical shapes as described by Reiter (1986). Shapes represent electricity use from unoccupied base-level (fans, receptacles, emergency lights, etc.), occupied base-level (fans, lights and receptacles), base-level plus heating, base-level plus cooling and base- level plus cooling with precooling.

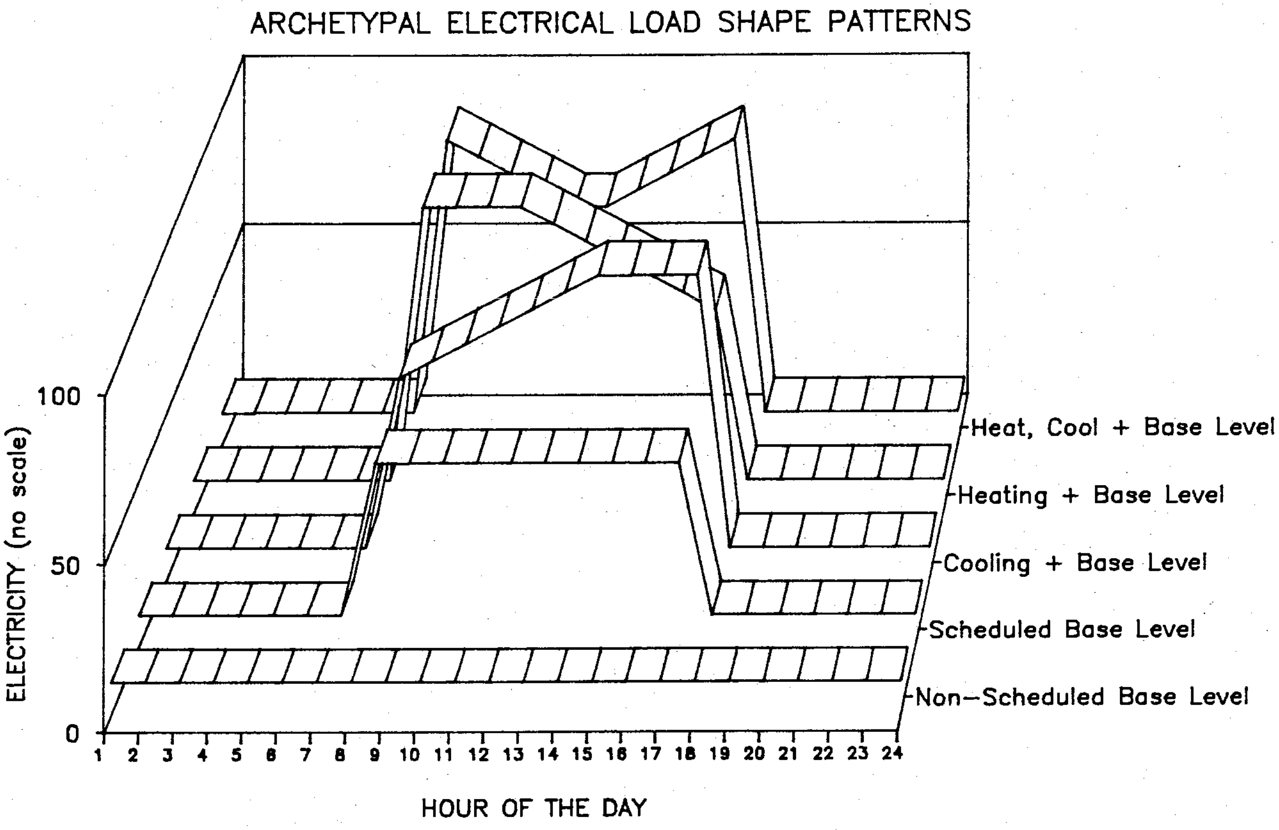


Figure 11: *Comparative Hourly Electrical Profiles (General Merchandise).* This figure shows hourly electricity usage profiles for the general merchandise store. Hourly profiles for the actual electricity use (a), base-level model (b), positive residual (c), and absolute value of the negative residual (d) are shown. In each plot the day-of-the-year and hour- of-the-day form the x-y plane, respectively. Hourly electricity usage (kWh/h) is represented as the height of the surface above the plane.

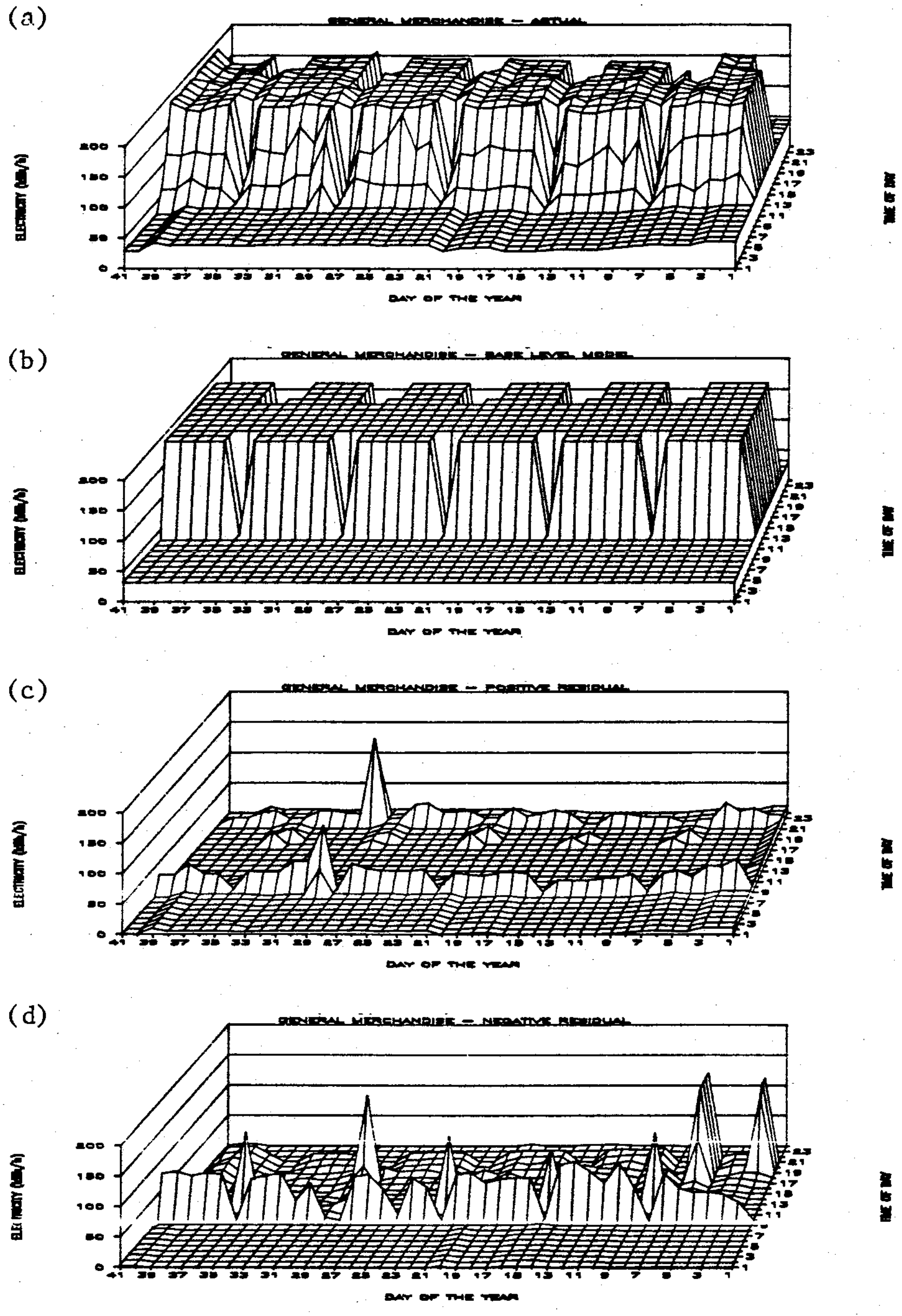


Figure 12: *Weather Normalized Annual Electrical Use (Stationery Store).* This figure shows weather normalized annual power levels for the stationery store. NAC and cooling curves are omitted because the PRISM CO analysis indicated no significant weather-related energy usage during the cooling season. The base-level curve for the stationery store represents the average of 12 months applied in successive 12 month increments. The dashed lines are one-half standard deviation from the average.

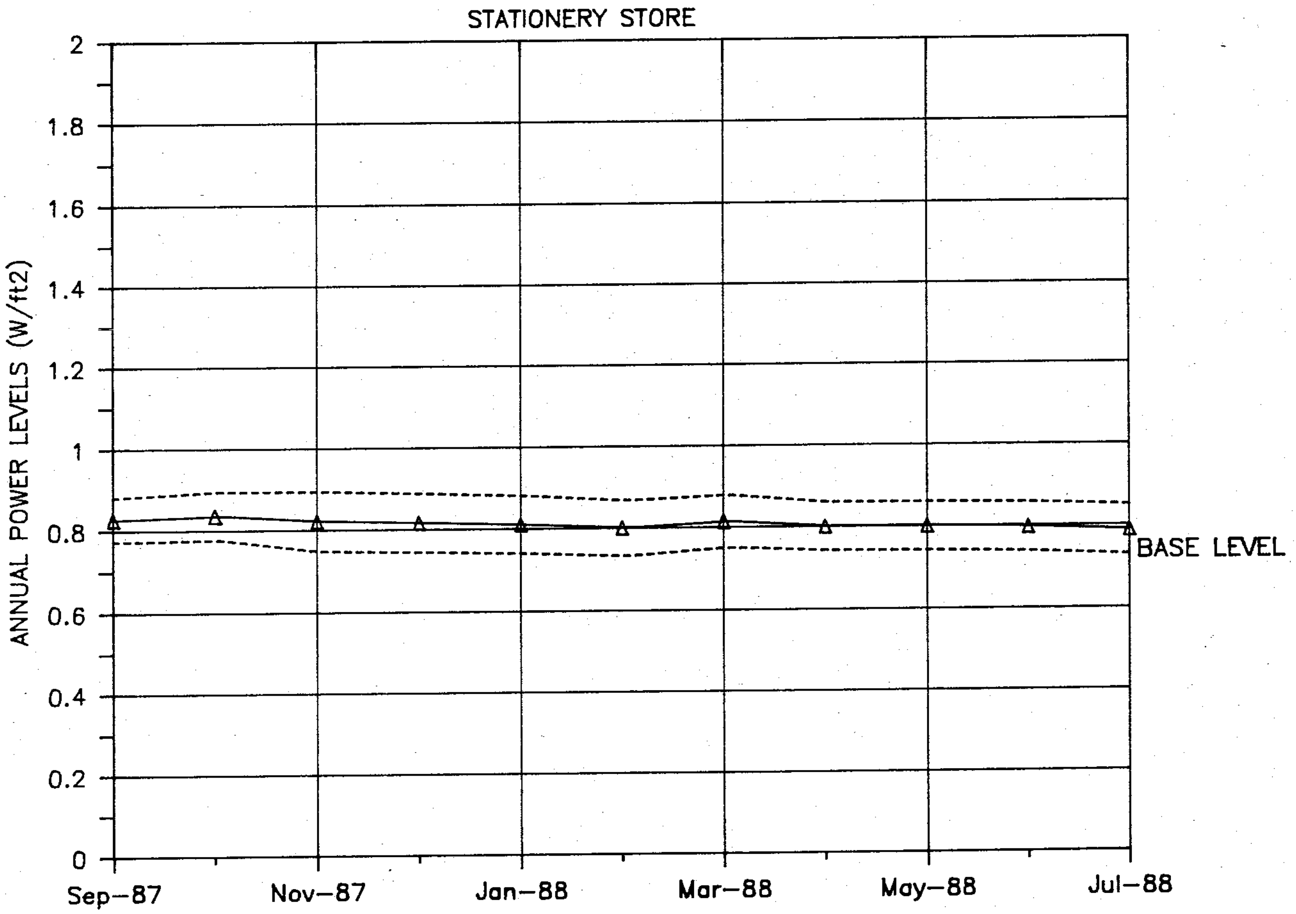


Figure 13: *Monthly Electricity Use (Stationery Store).* This figure shows monthly electricity power levels for the stationery store. Power levels (W/ft^2) are shown for both electricity usage (kWh) and peak monthly electric demand (kW).

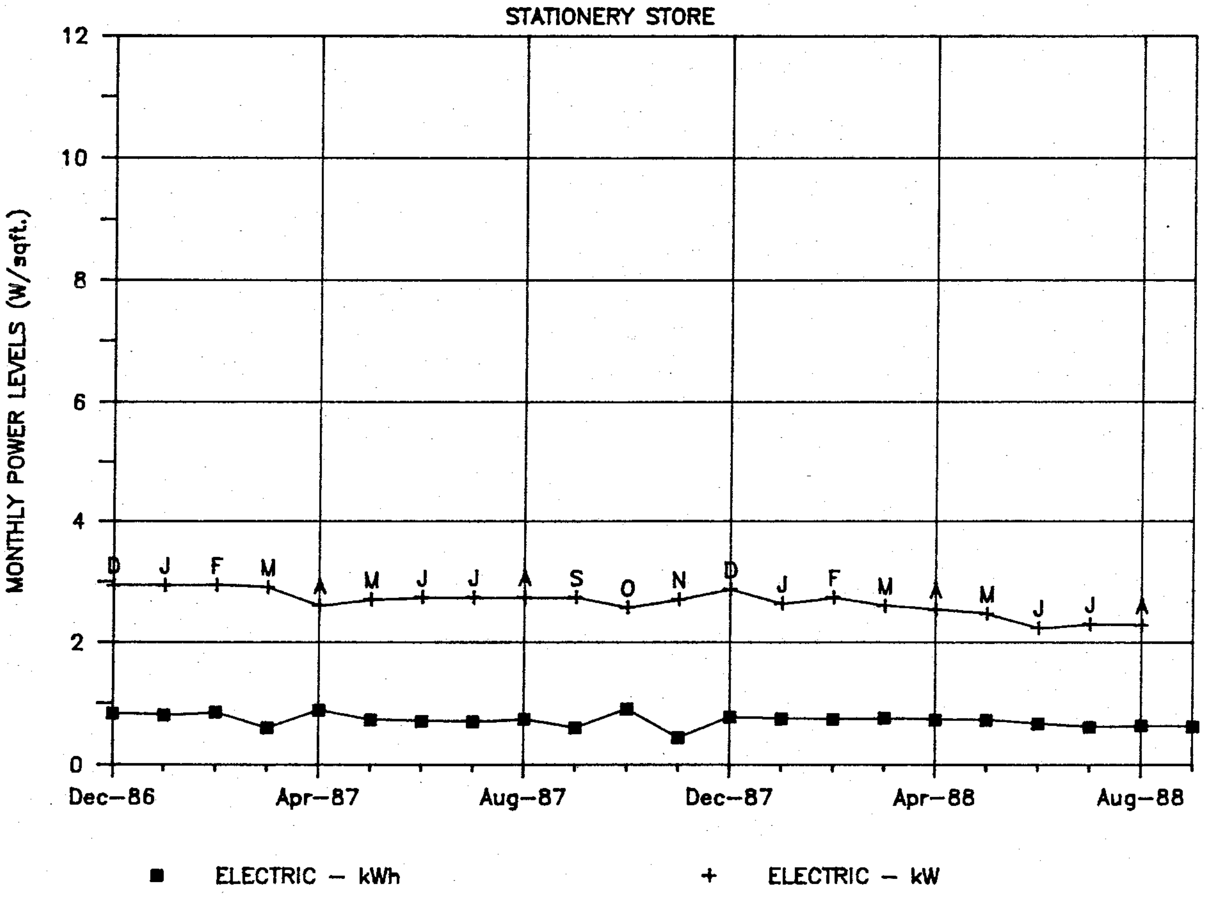


***Figure 14:** Monthly ELF and OLF (Stationery Store).* This figure contains monthly load factors for the stationery store. Monthly Electric Load Factors (ELF) and Occupancy Load Factors (OLF) are shown.

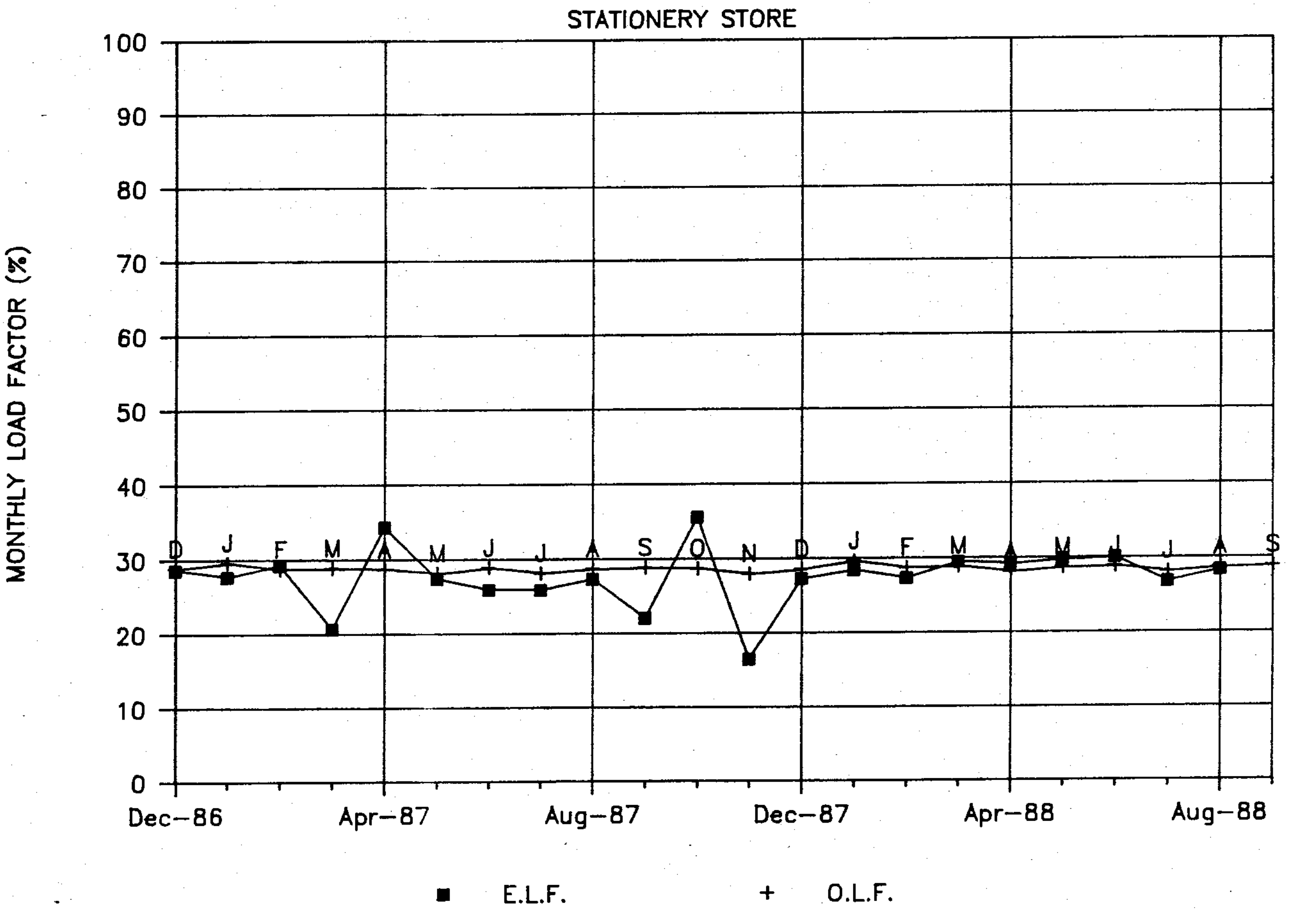


Figure 15: *Daily Electricity Use (Stationery Store).* This figure shows daily electricity usage (W/ft^2) for the stationery store. Data include actual, base-level model and residuals for the period January 1, 1989 to February 10, 1989.

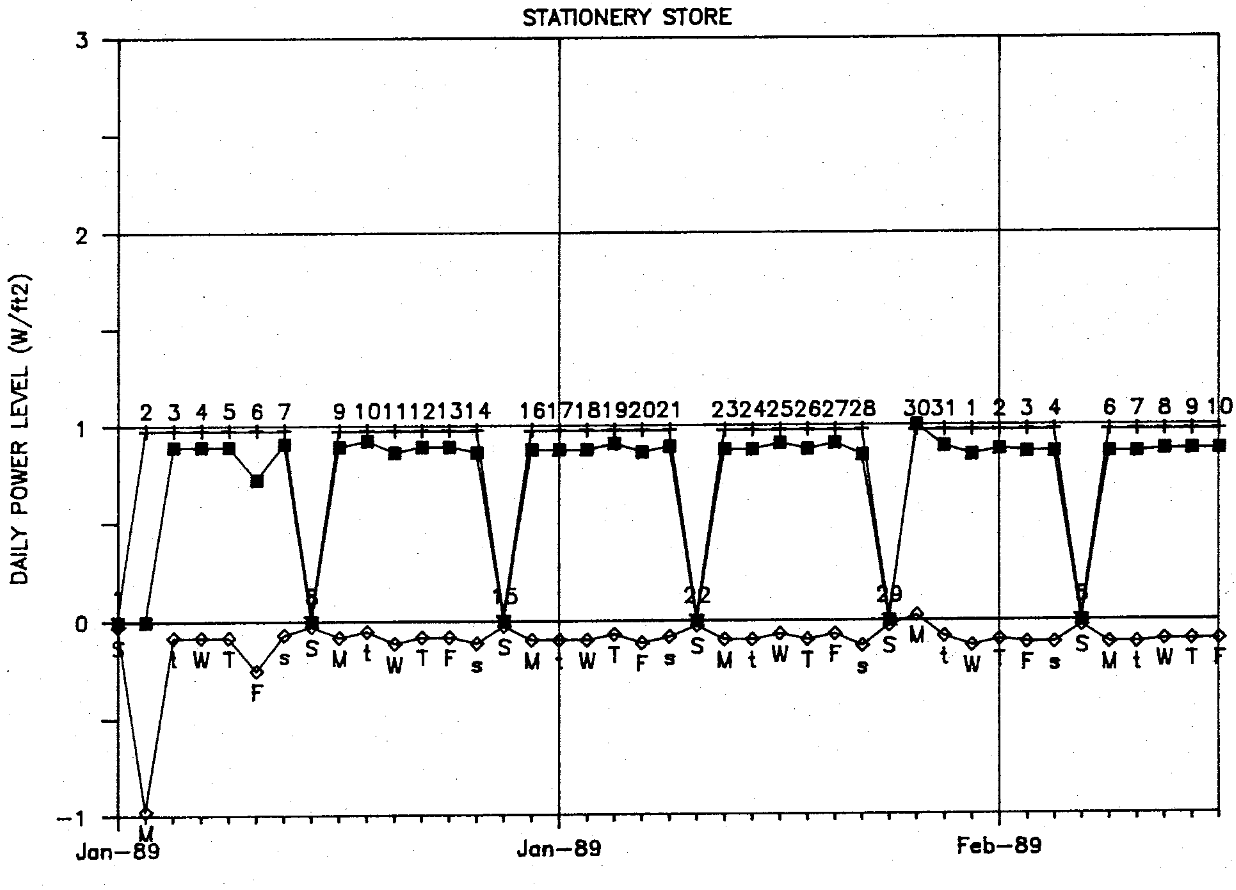


Figure 16: *Daily Minimum-Maximum Zone Temperatures (Stationery Store).* This figure shows minimum and maximum zone temperatures for the stationery store. The zone temperatures are displayed against average daily ambient temperature for the period September 1988 through February 1989.

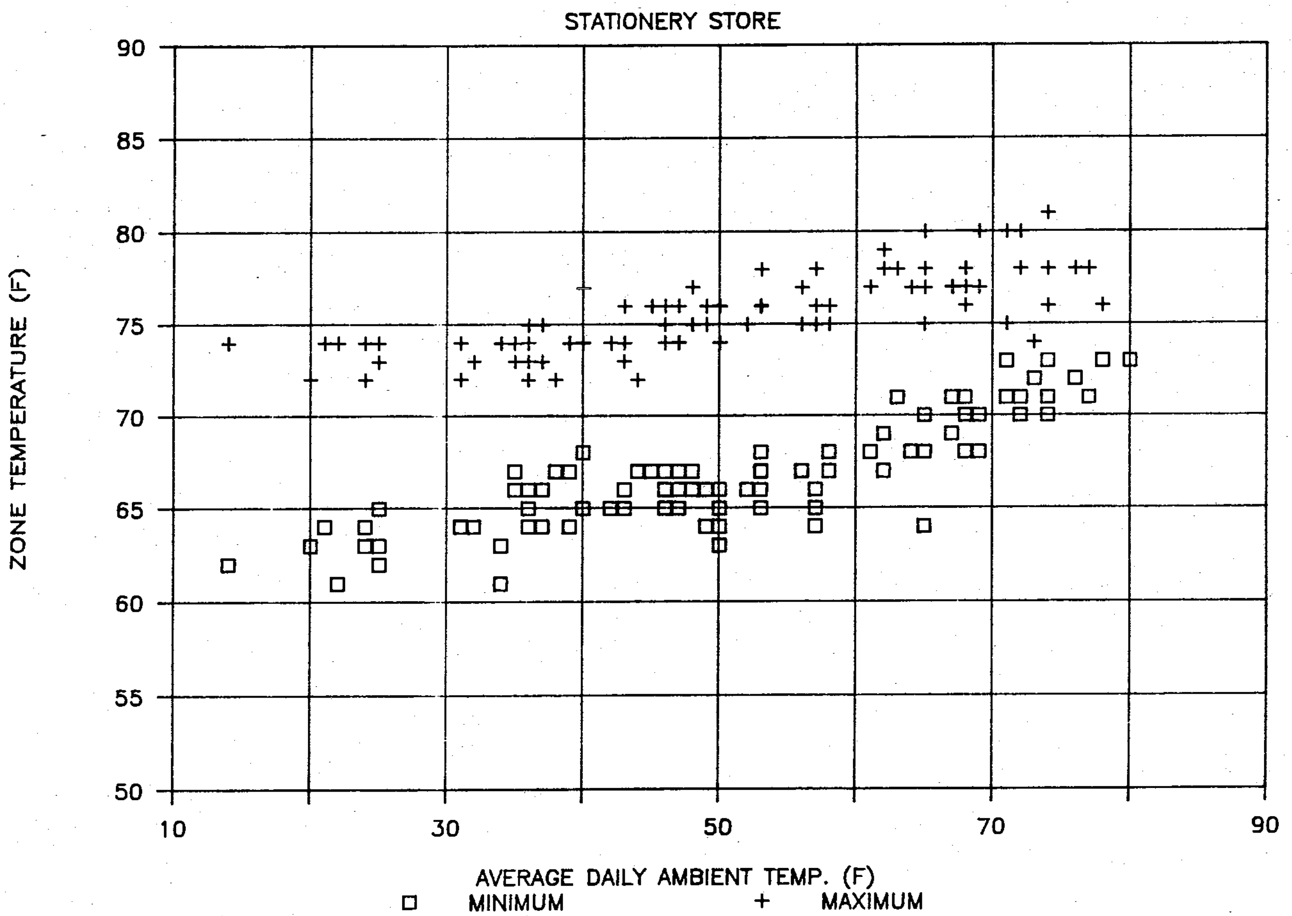


Figure 17: *Hourly Electrical Use and Zone Temperatures (Stationery Store).* This figure shows average hourly power levels (W/ft^2) in Figure (a), and hourly zone temperatures in Figure (b) for the stationery store.

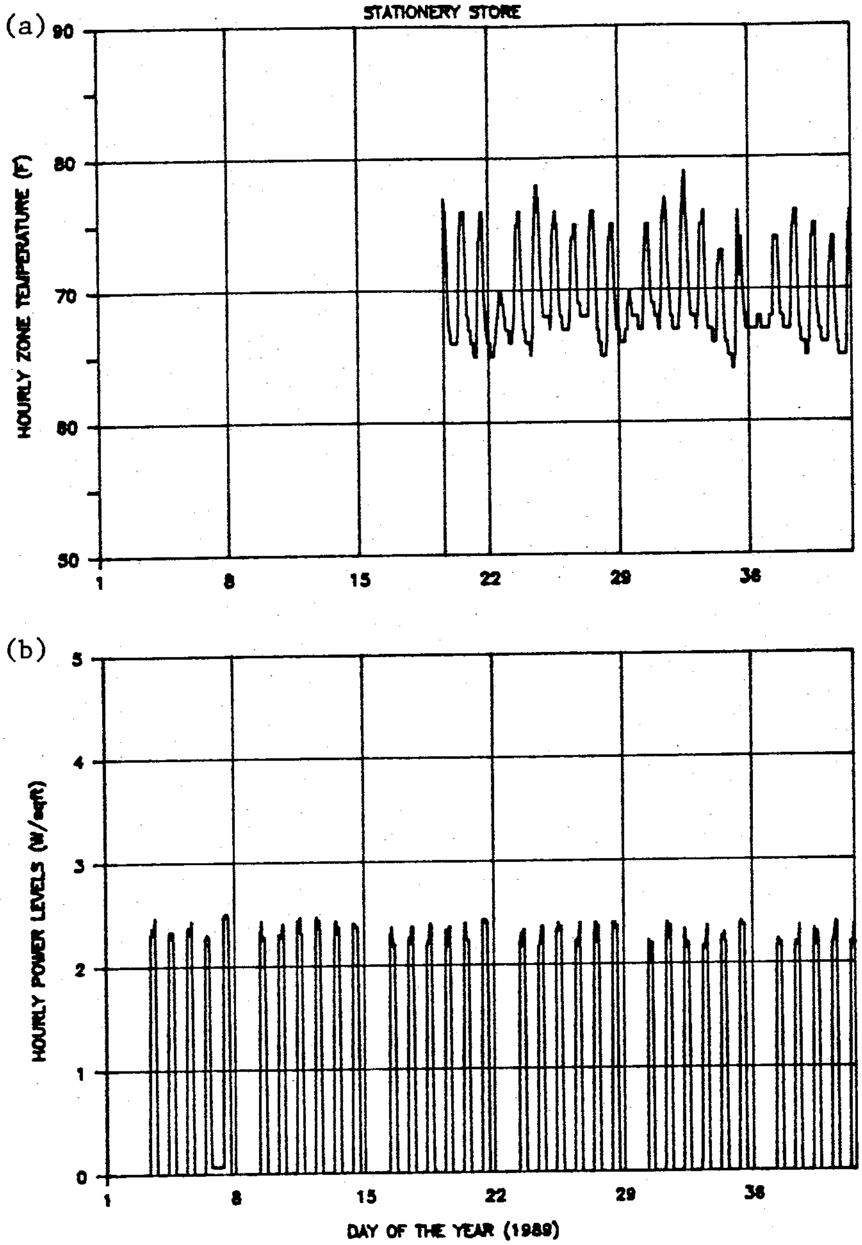
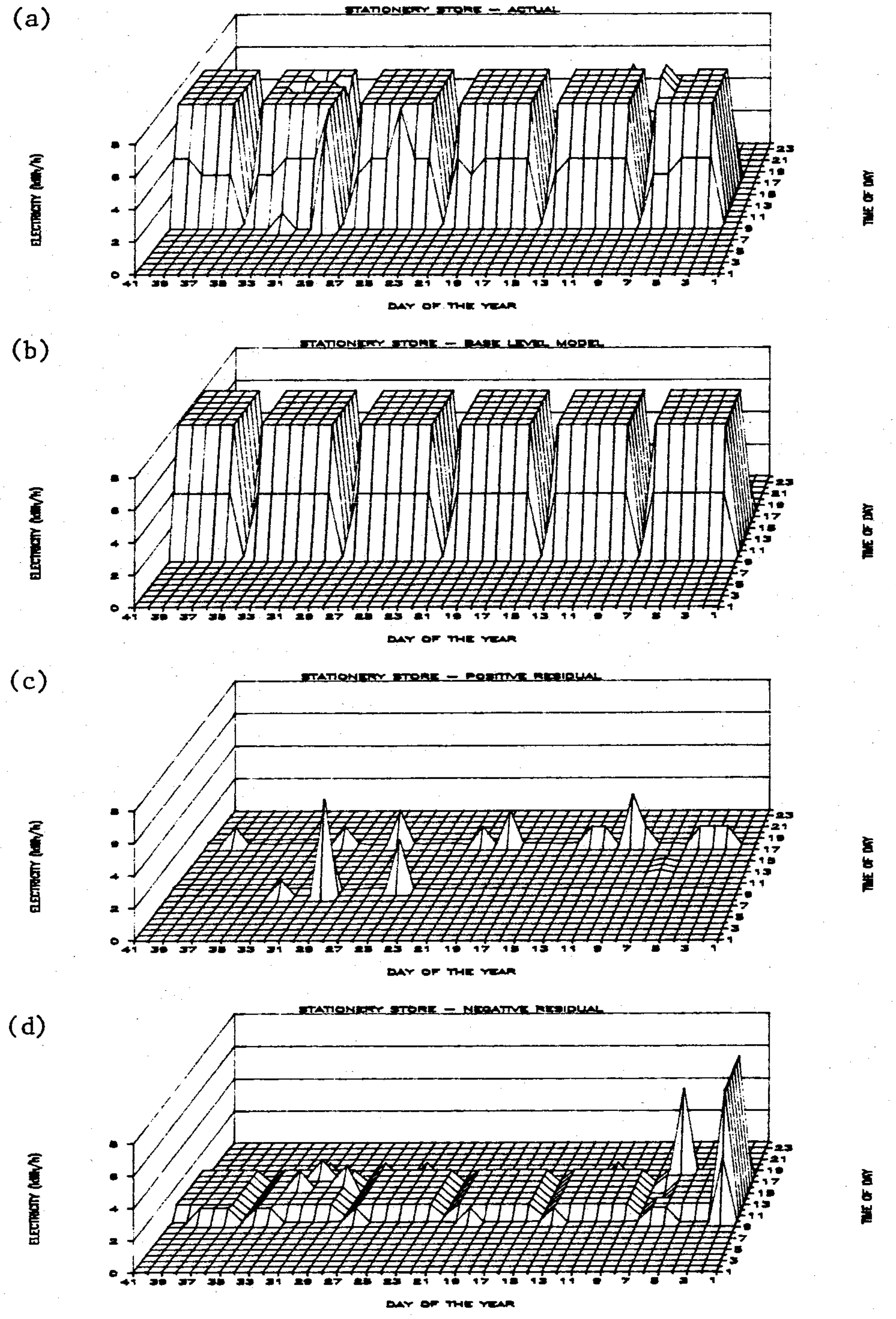


Figure 18: *Comparative Hourly Electric Profiles (Stationery Store).* This figure shows average hourly electricity usage profiles for the stationery store. Hourly profiles for the actual electricity use (a), base- level model (b), positive residual (c), and absolute value of the negative residual (d) are shown. In each plot the day-of-the-year and hour-of-the- day form the x-y plane, respectively. Hourly electricity usage (kWh/h) is represented as the height of the surface above the plane.



STATIONERY STORE — ACTUAL

STATIONERY STORE — BASE LEVEL MODEL

STATIONERY STORE — POSITIVE RESIDUAL

STATIONERY STORE — NEGATIVE RESIDUAL

Figure 19: *Weather Normalized Annual Electrical Use (Furniture Store).* This figure shows weather normalized annual electricity power levels for the furniture store. For the furniture store the NAC, base-level and cooling curves represent the Sliding PRISM CO analysis expressed in units of W/ft^2. The dashed lines are standard errors.

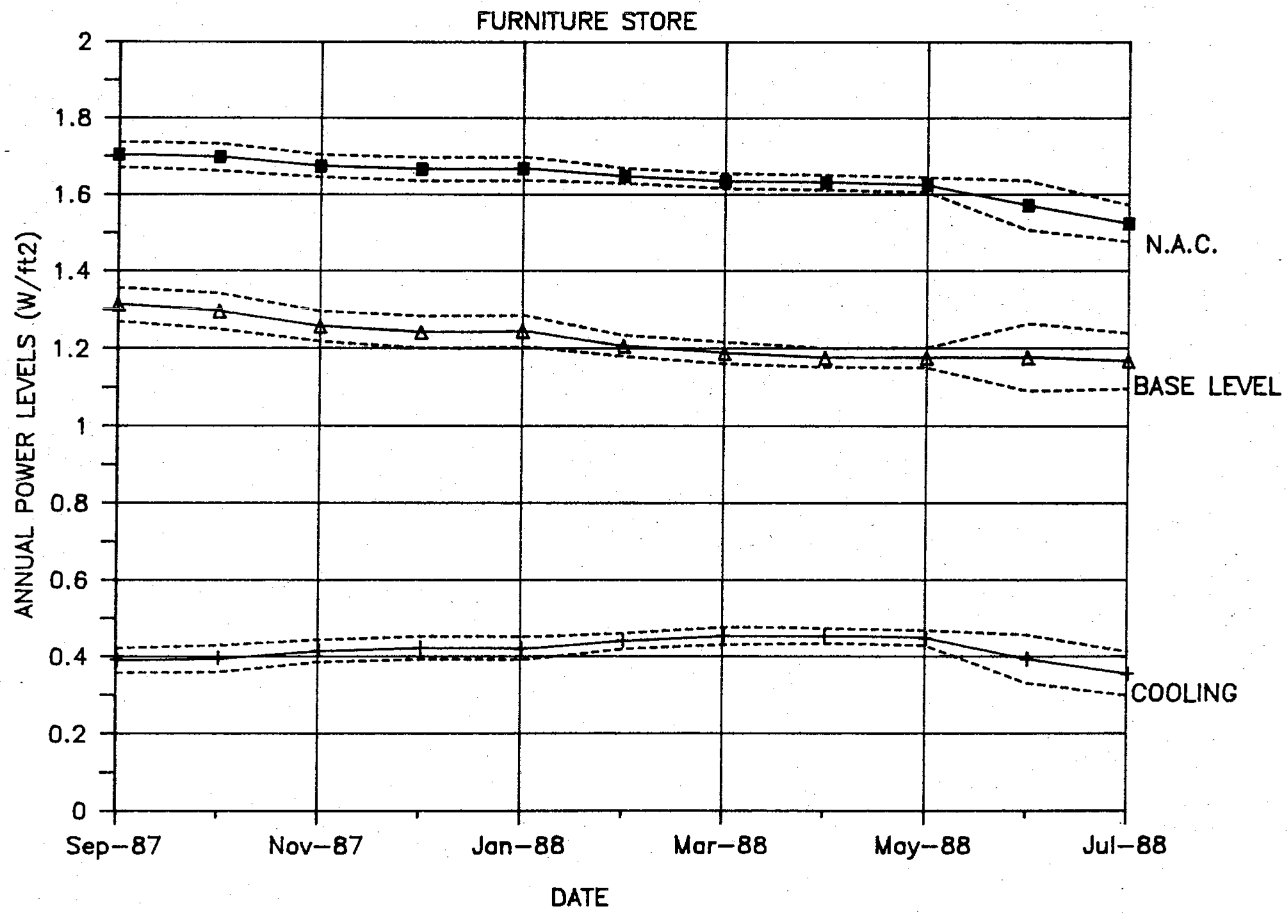


***Figure 20:** Monthly Electricity Use (Furniture Store).* This figure shows monthly average electricity power levels for the furniture store. Power levels (W/ft^2) are shown for both electricity usage (kWh) and peak monthly electric demand (kW). The electric demand reading for July 1987 is estimated.

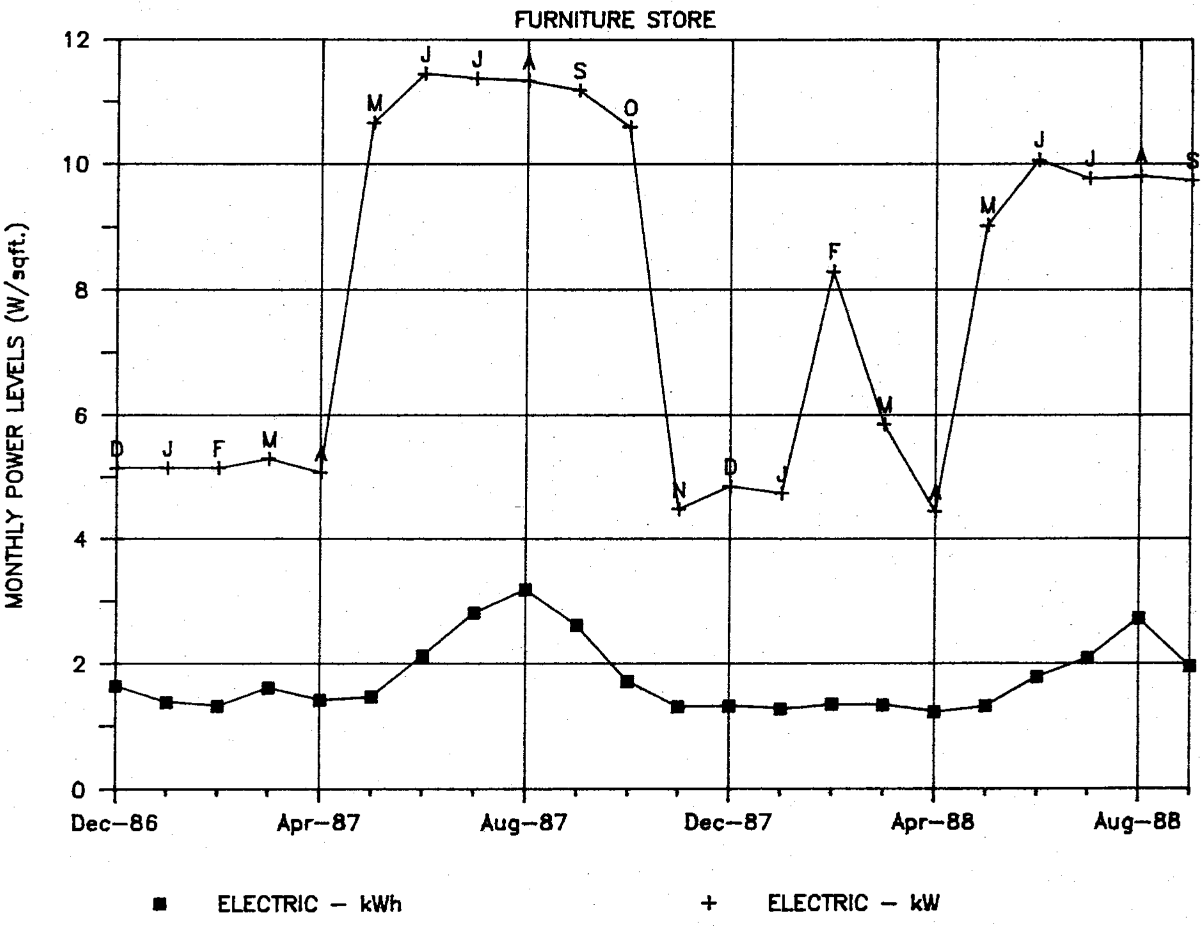


Figure 21: *Monthly ELF and OLF (Furniture Store).* This figure contains monthly load factors for the furniture store. Monthly Electric Load Factors (ELF) and Occupancy Load Factors (OLF) are shown.

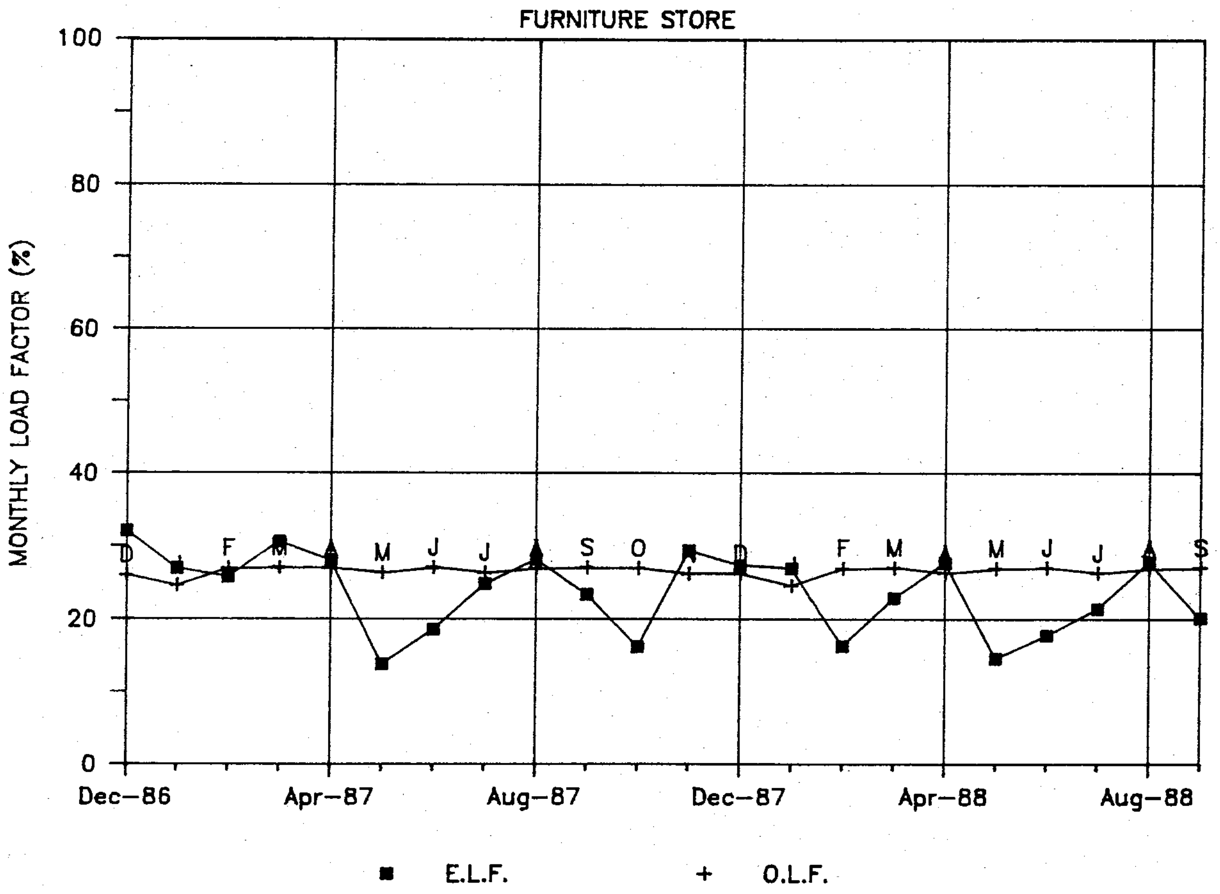


Figure 22: Daily Electricity Use (Furniture Store). This figure shows daily average electricity usage (W/ft^2) for the furniture store. Data include actual, base-level model and residuals.

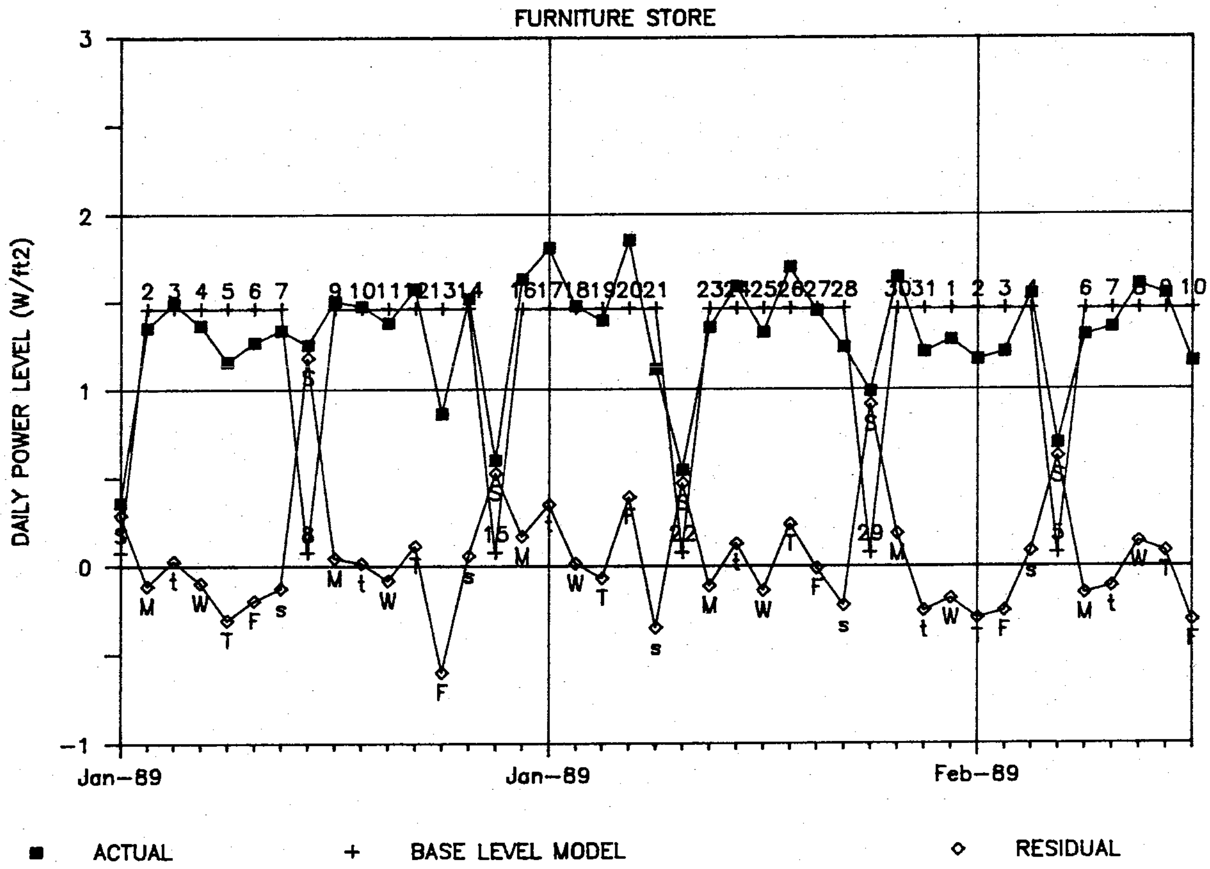


Figure 23: *Daily Minimum-Maximum Zone Temperatures (Furniture Store).* This figure shows minimum and maximum zone temperatures for the furniture store. The zone temperatures are displayed against average daily ambient temperature for the period September 1988 through February 1989.

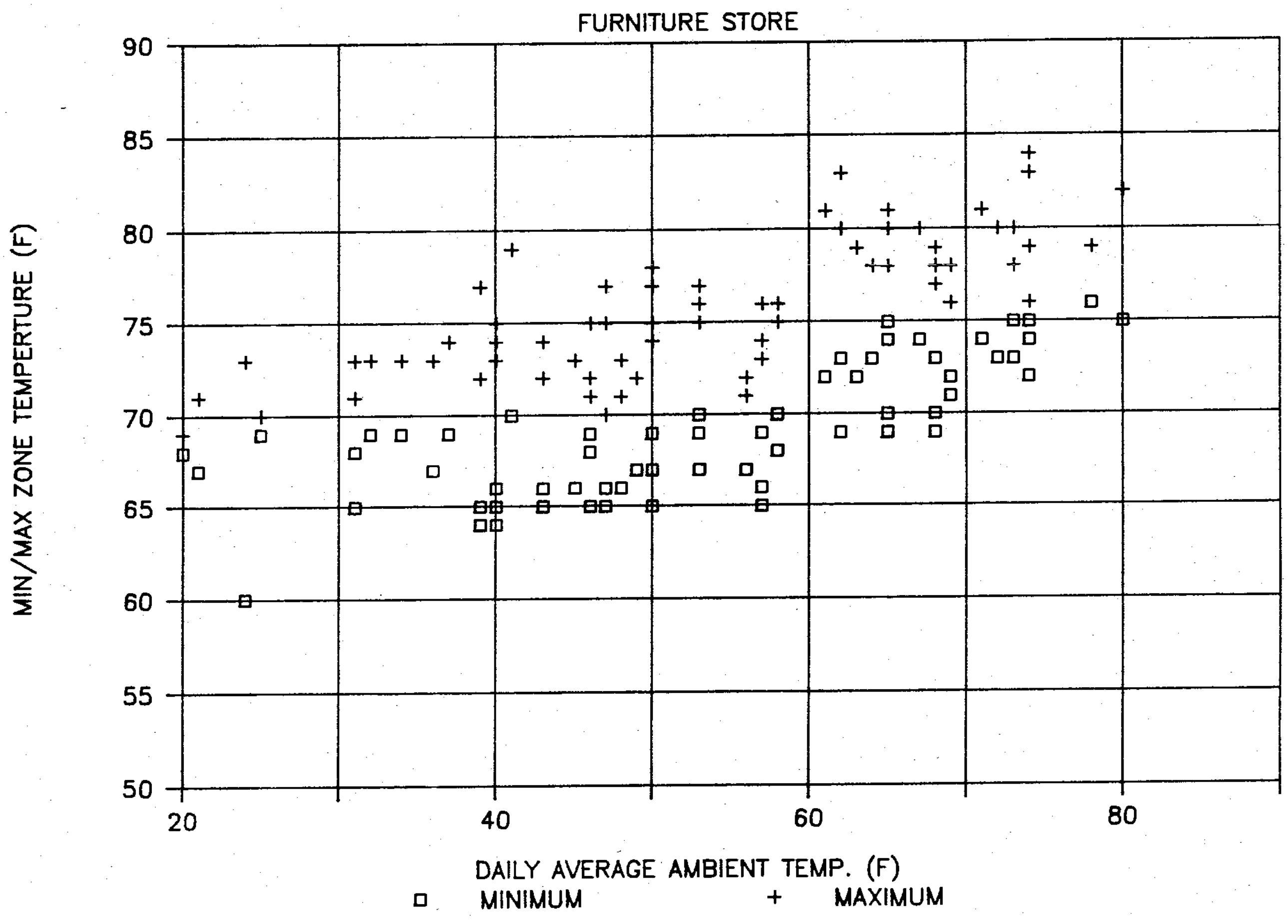
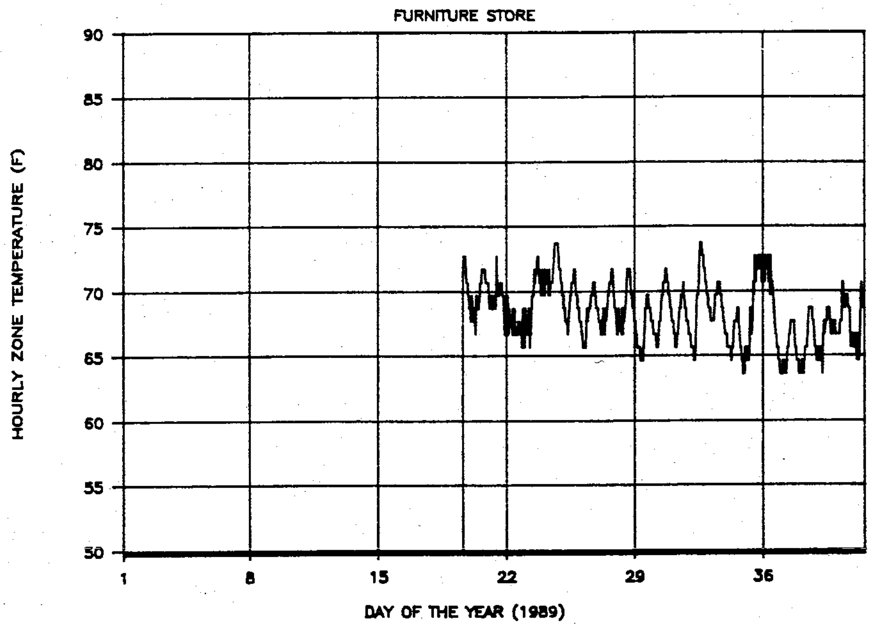


Figure 24: *Hourly Elec. Use and Zone Temperatures (Furniture Store).* This figure shows average hourly electricity power levels (W/ft^2) in Figure (a), and hourly zone temperatures in Figure (b) for the furniture store.

(a)



(b)

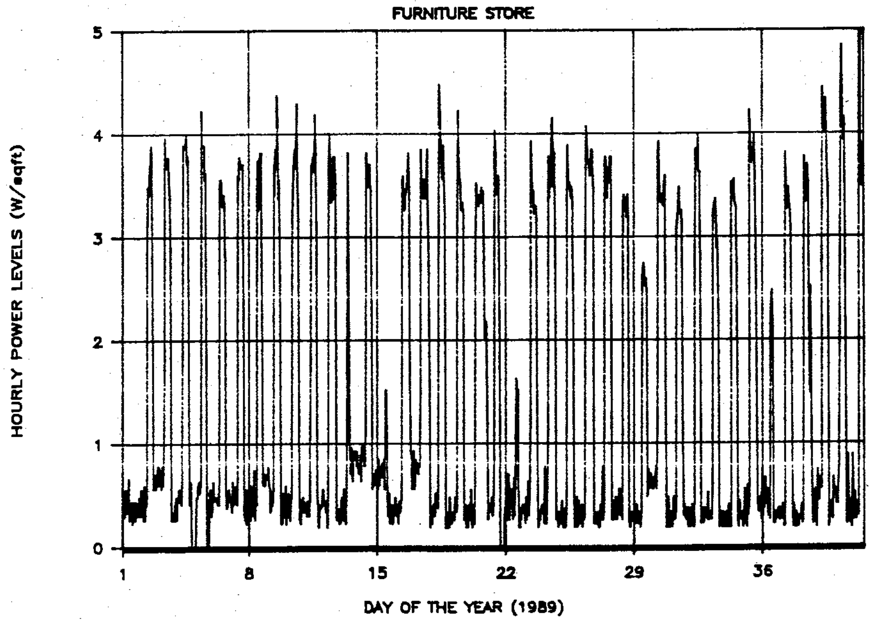


Figure 25: *Comparative Hourly Electric Profiles (Furniture Store).* This figure shows hourly electricity usage profiles for the furniture store. Hourly profiles for the actual electricity use (a), base-level model (b), positive residual (c), and absolute value of the negative residual (d) are shown. In each plot the day-of-the-year and hour-of-the-day form the x- y plane, respectively. Hourly electricity usage (kWh/h) is represented as the height of the surface above the plane.

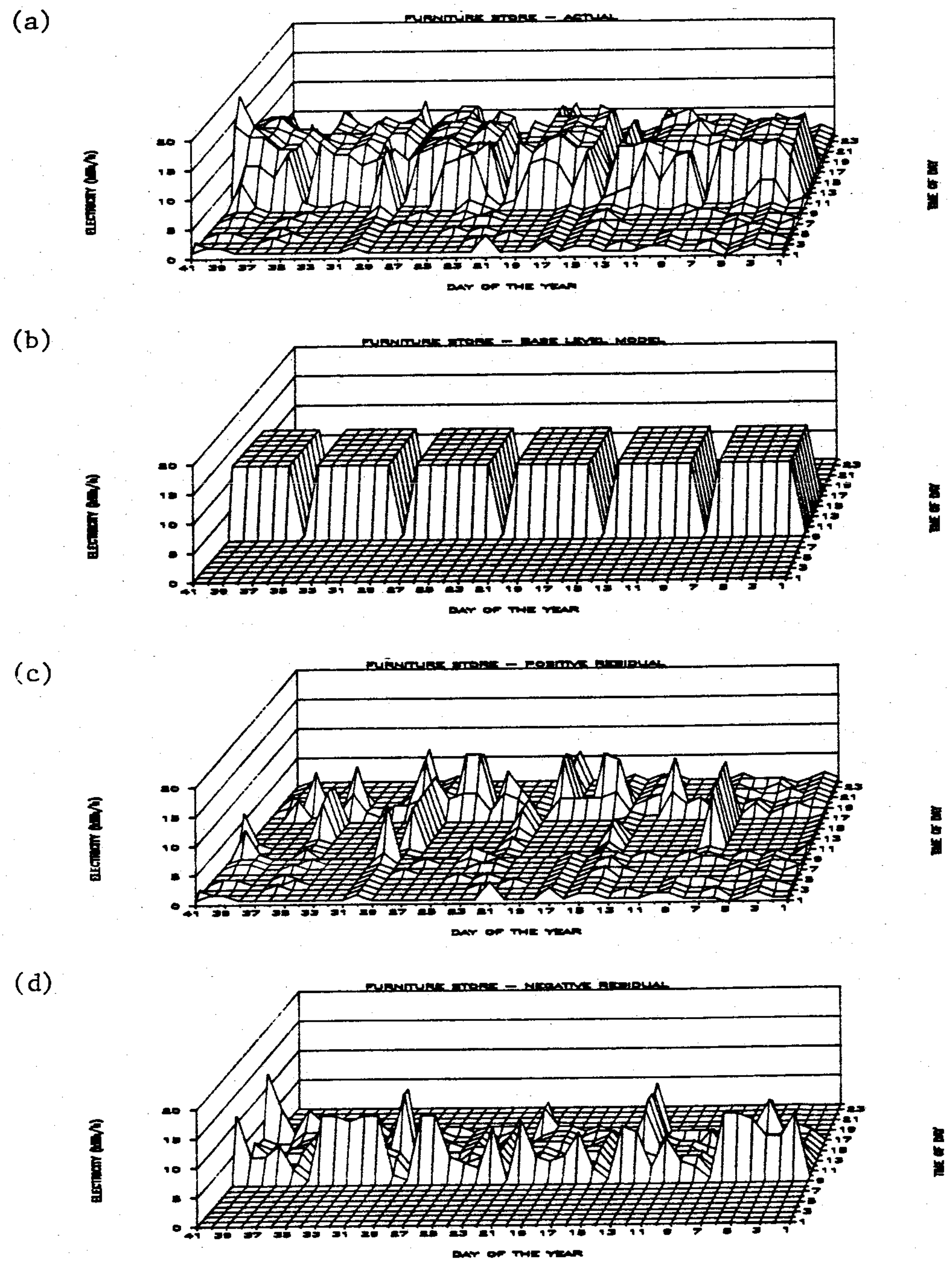


Figure 26: *Monthly Electricity Use (Exercise Center).* This figure shows average monthly electricity power levels for the exercise center. Power levels (W/ft^2) are shown for both electricity usage (kWh) and peak monthly electric demand (kW). The deviation during the months of December 1986 and January 1987 is thought to be a probable kWh billing error.

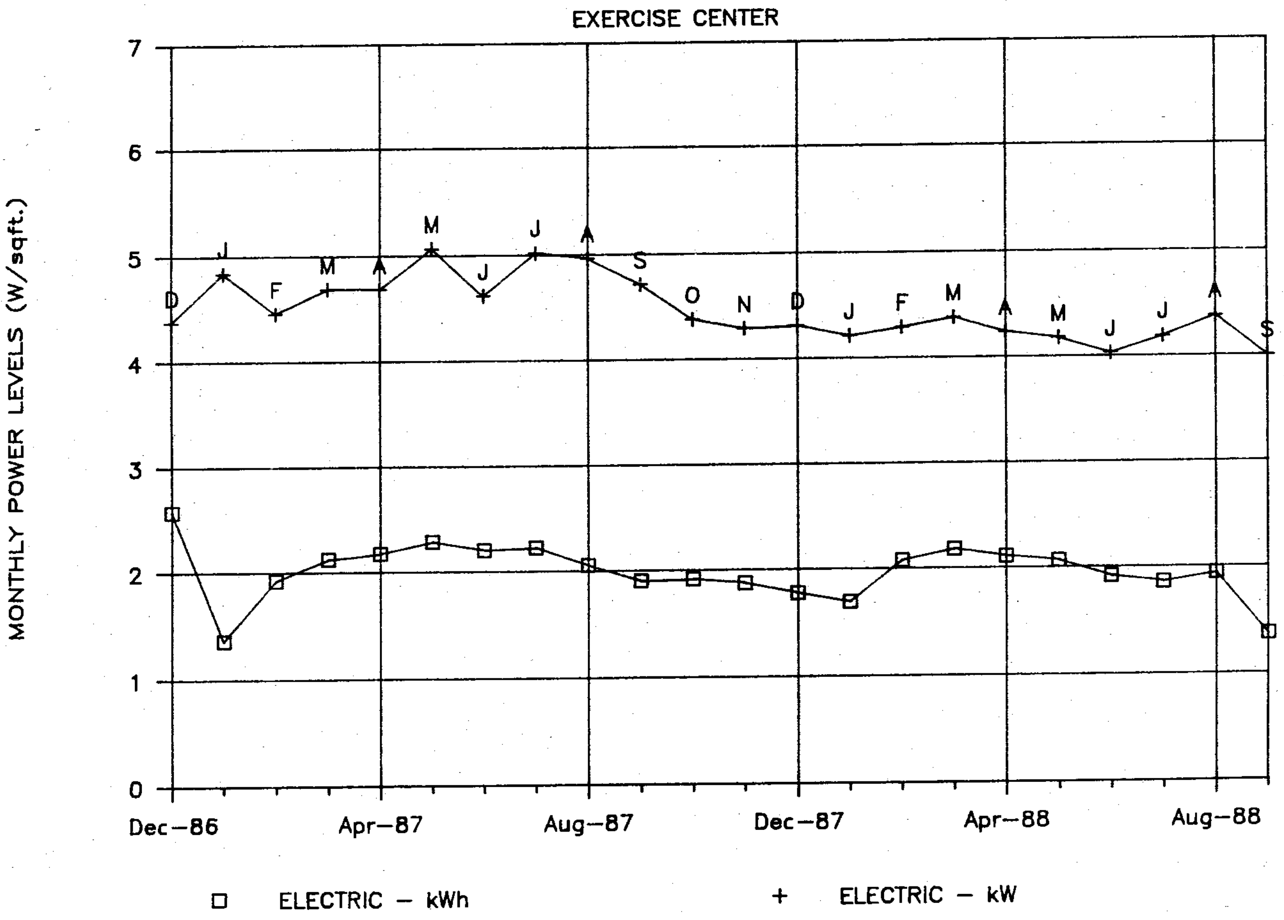


Figure 27: *Monthly Electric Use versus Ambient Temperature (Exercise Center).* This figure shows monthly power levels versus average monthly ambient temperature for the exercise center. Power levels (W/ft^2) are shown for both electricity usage (kWh) and peak monthly electric demand (kW). Data labels for electric demand are for month and year of use (e.g., A88 is August 1988, the symbol J is used for June and January [January is always colder], and M for March).

NOTE: For intervals spanning more than a day, degree-days are well known to be a much better indicator of energy consumption than are average outdoor temperatures (averaged over all days in the interval). Since computation of degree-days requires an assumed reference temperature (such as that estimated in the PRISM model), and since cooling and heating related degree-days are both relevant in this study, average temperatures are shown here as a surrogate for degree-day information.

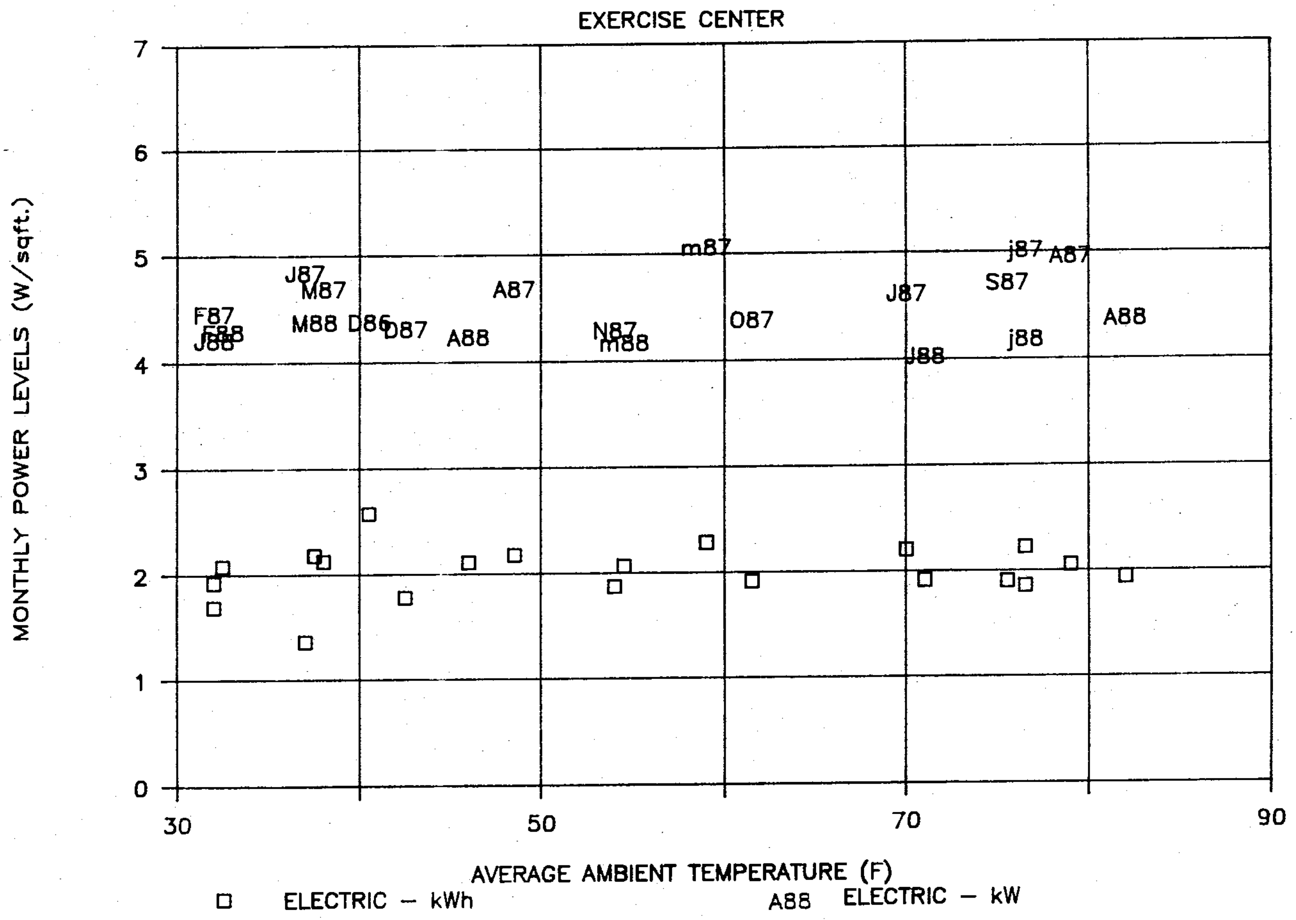


Figure 28: *Monthly ELF and OLF (Exercise Center).* This figure contains monthly load factors for the exercise center. Monthly Electric Load Factors (ELF) and Occupancy Load Factors (OLF) are shown.

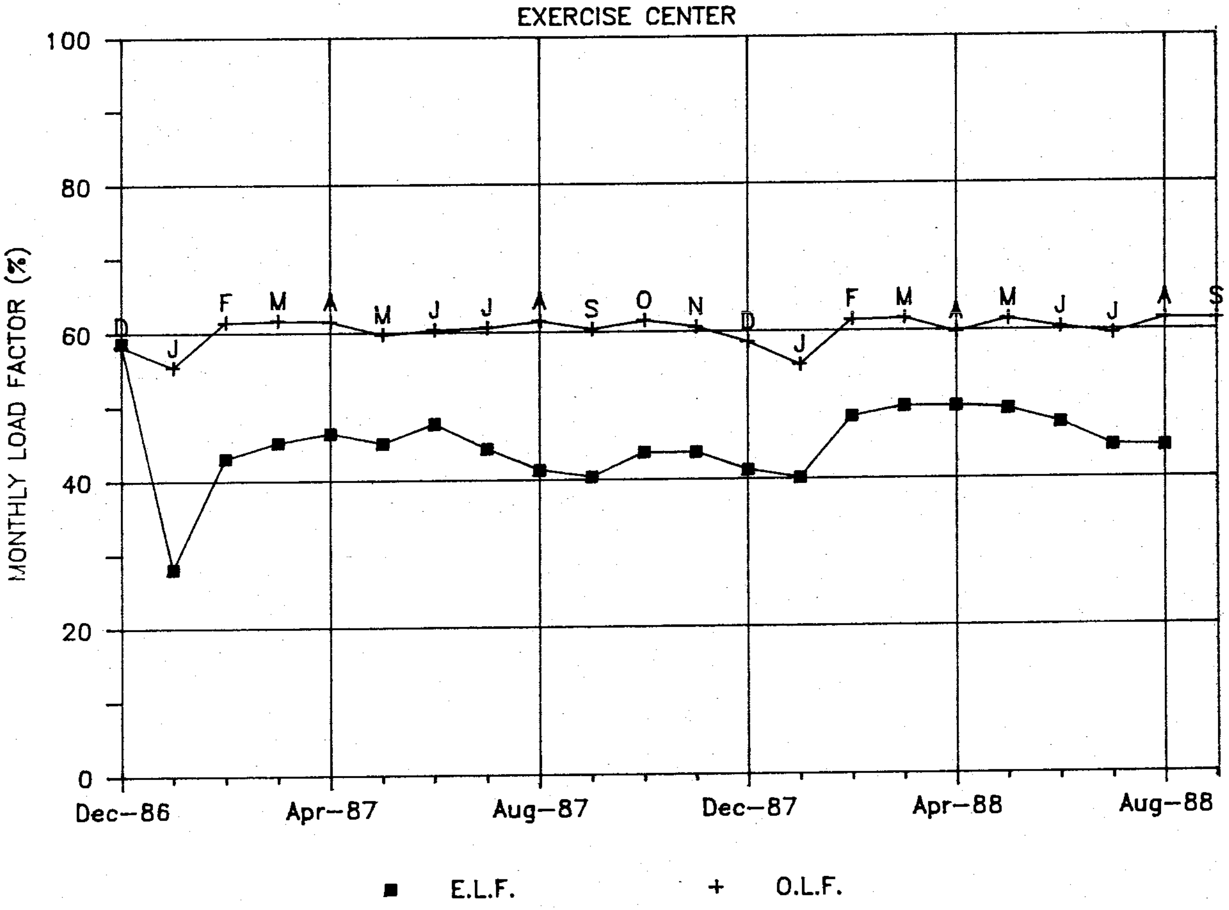


Figure 29: *Daily Natural Gas Usage versus Ambient Temperature (Exercise Center)* . This figure shows daily natural gas usage (CCF per day) versus daily average ambient temperature for the exercise center for the period September 1988 through March 1989. Natural gas data are from daily logbook readings.

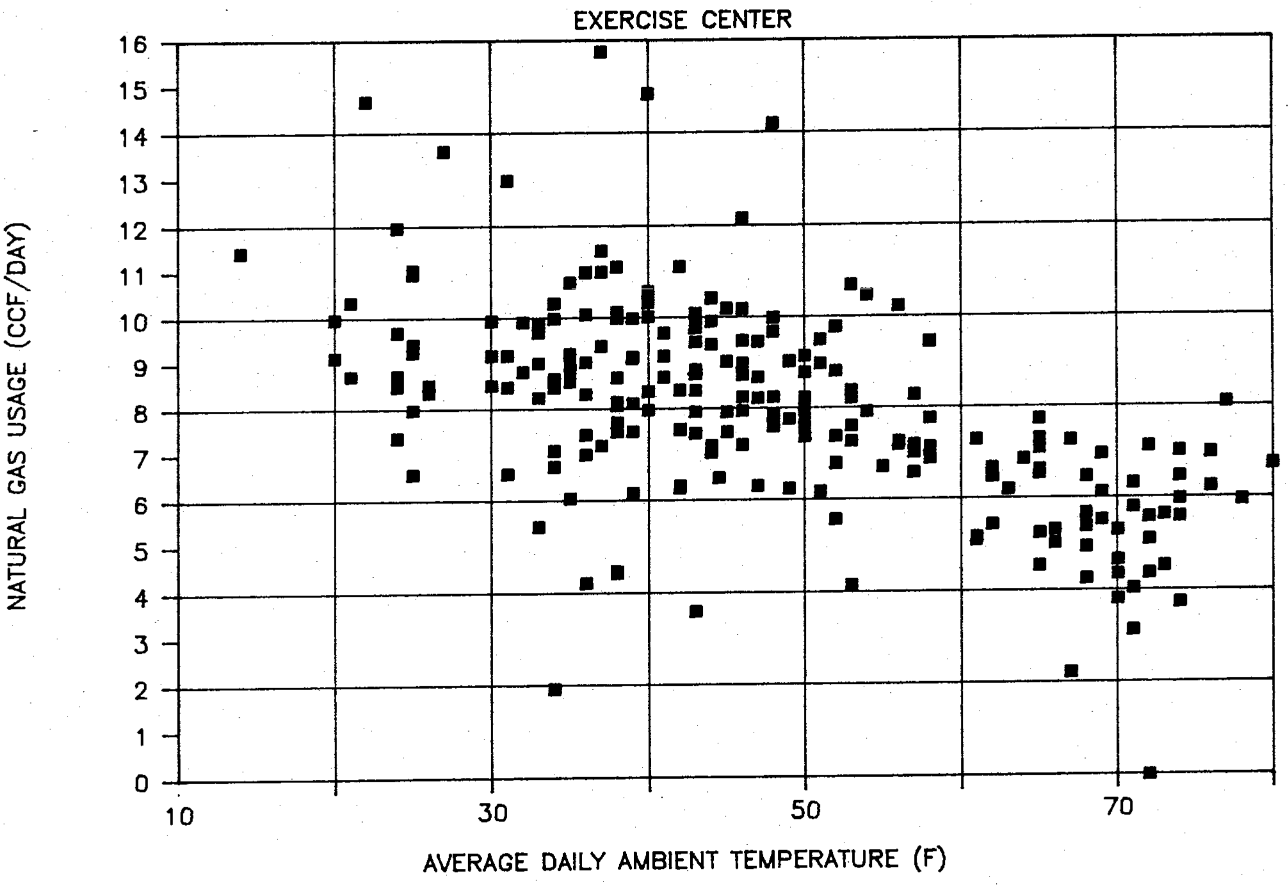


Figure 30: *Daily Natural Gas Usage versus Water Usage (Exercise Center).* This figure shows daily natural gas usage (CCF per day) versus daily water usage (gal/day) for the exercise center for the period September 1988 through March 1989. Data are from daily logbook readings.

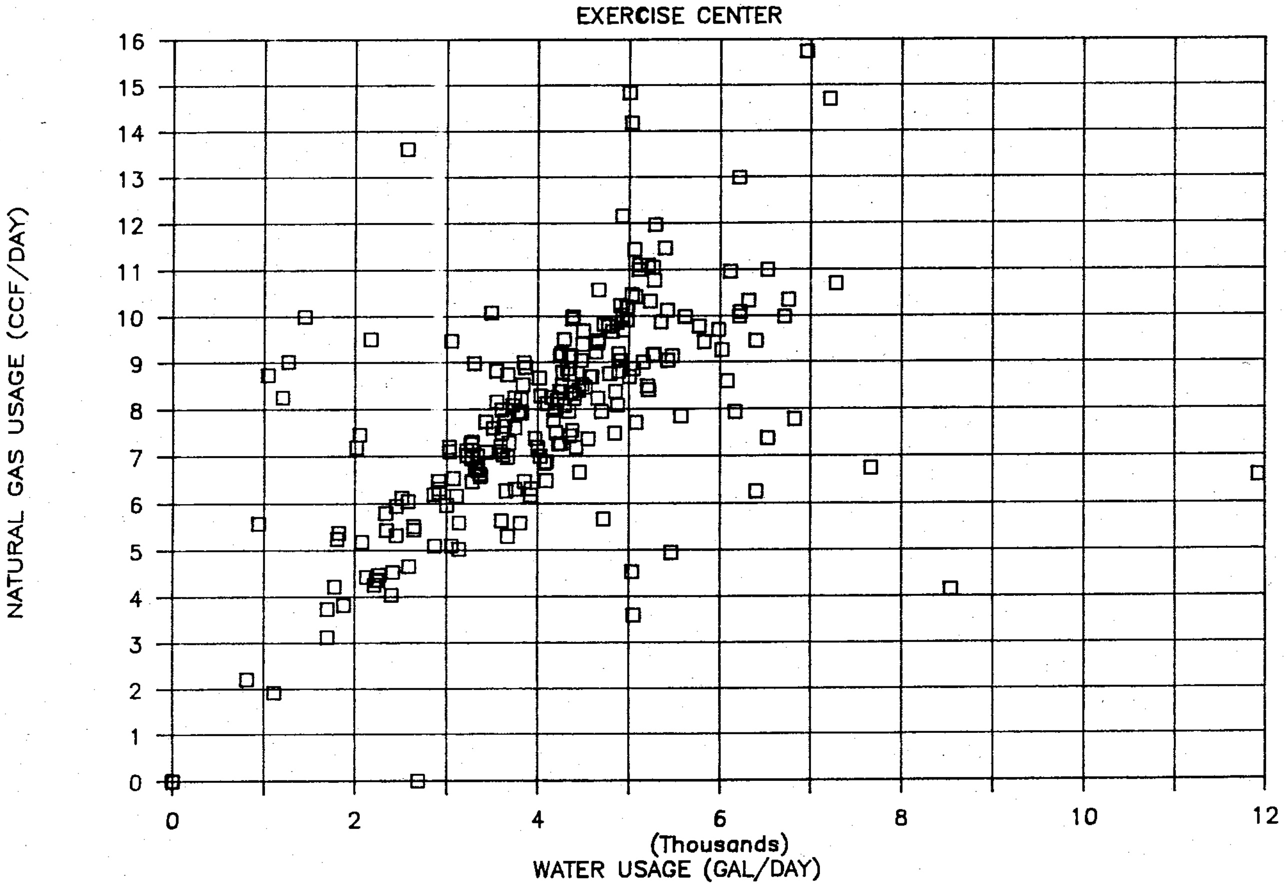


***Figure 31:** Daily Minimum-Maximum Temperature for the Upper Zone(Exercise Center).* This figure shows daily minimum and maximum zone temperatures for the exercise center. The upper zone temperatures are displayed against average daily ambient temperature. Data are for the period September 1988 through February 1989.

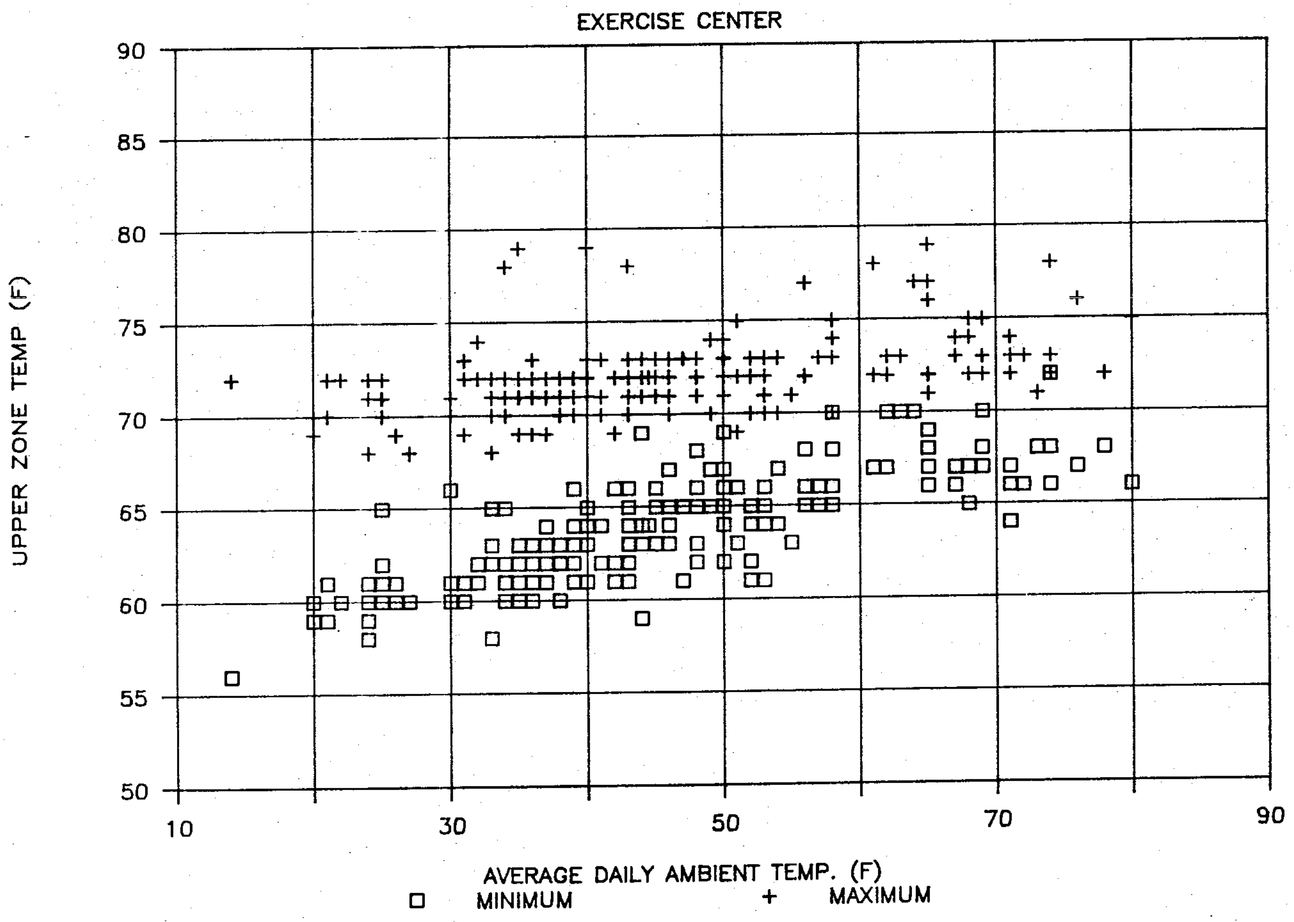


Figure 32: *Daily Minimum-Maximum Temperature for Lower L. Zone(Exercise Center).* This figure shows daily minimum and maximum zone temperatures for the exercise center. The lower left zone temperatures are displayed against average daily ambient temperature. Data are for the period September 1988 through February 1989.

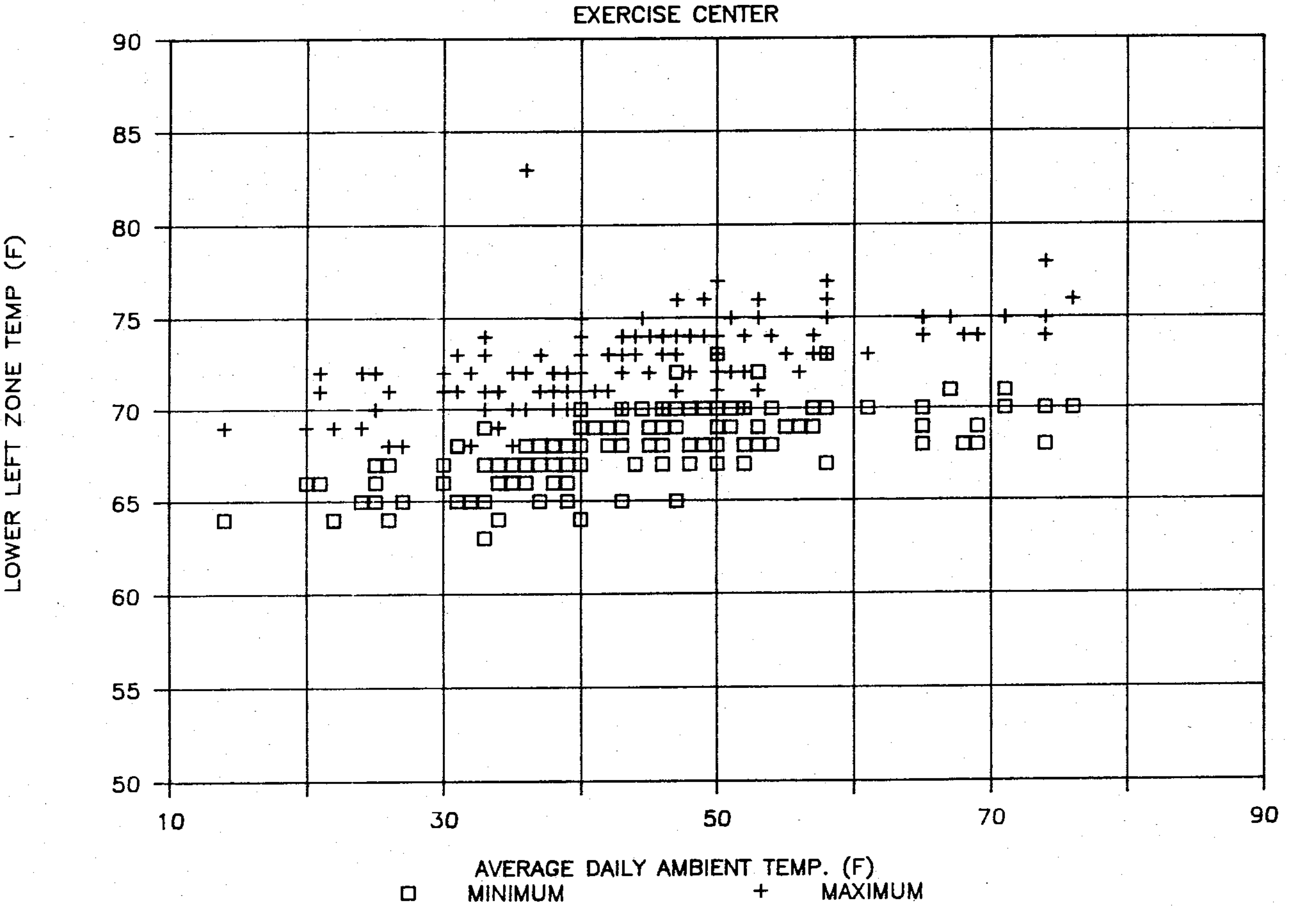


Figure 33: *Daily Minimum-Maximum Temperature for Lower R. Zone (Exercise Center).* This figure shows daily minimum and maximum zone temperatures for the exercise center. The lower right zone temperatures are displayed against average daily ambient temperature. Data are for the period September 1988 through February 1989.

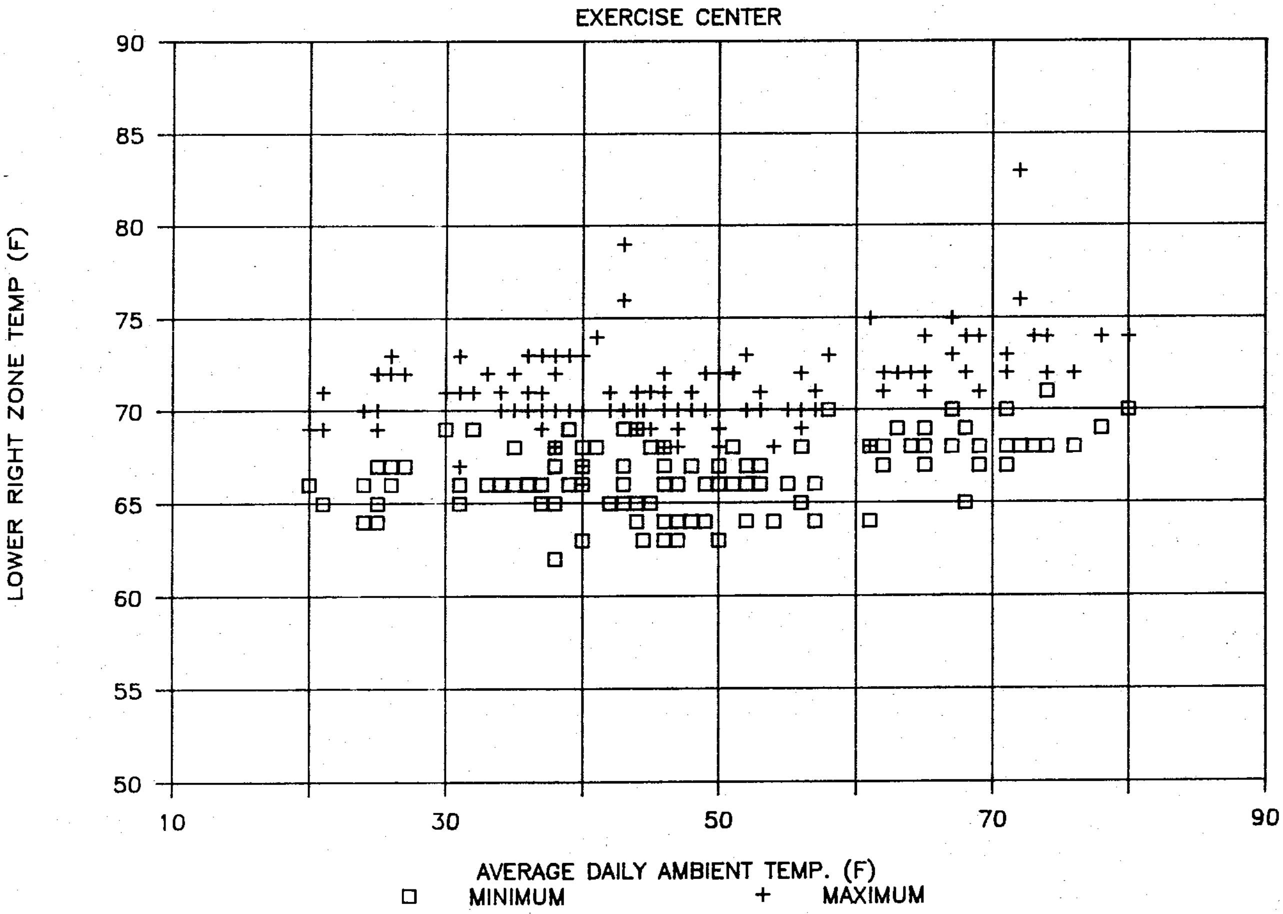


Figure 34: *Hourly Upper Zone Temperatures (Exercise Center).* This figure shows the average hourly zone temperature for the upper zone at the exercise center for the period February 10, 1989 (day 41) through March 10, 1989 (day 69).

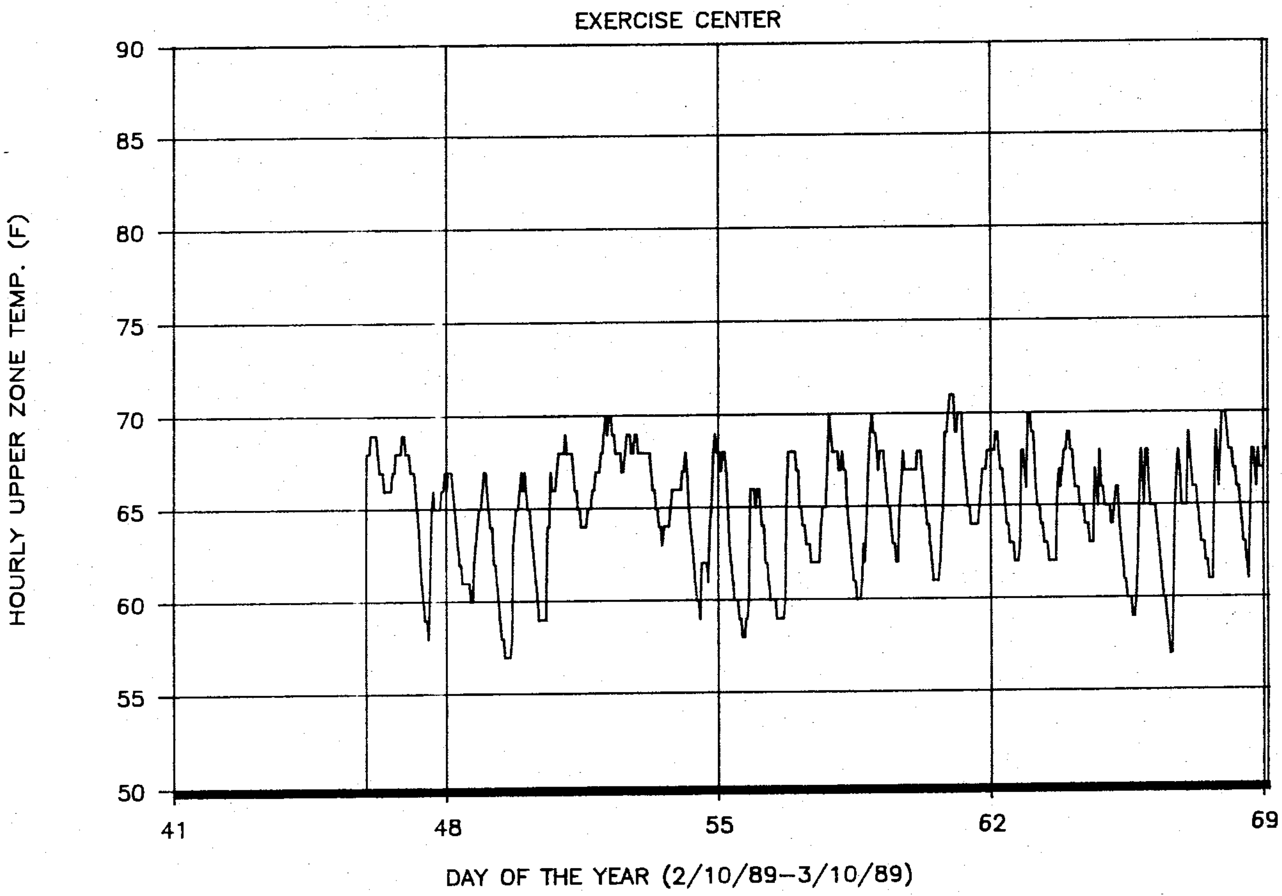


***Figure 35:** Daily Relative Humidity Measurements (All Stores).* This figure shows daily relative humidity measurements for the general merchandise (GM), stationery (ST), and furniture stores (FU), and the exercise (EX^= upper zone of the exercise center, EXv= lower zone) and travel centers (TR). The interior relative humidity is displayed against average daily ambient temperature. All values in this figure were obtained using a portable hand-held humidity measuring instrument.

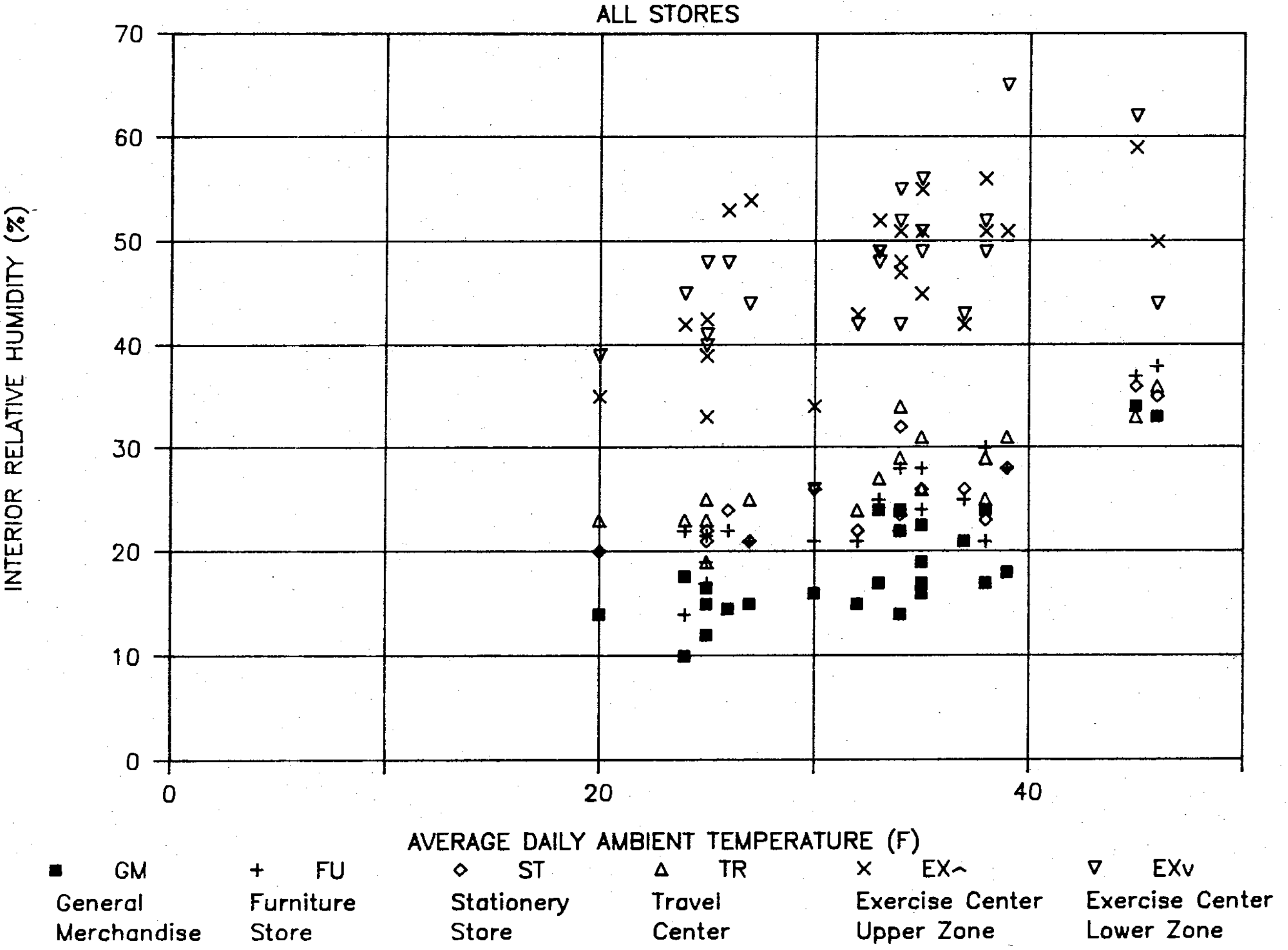


Figure 36: *Hourly Electricity Use (Exercise Center).* This figure shows average hourly electricity power levels (W/ft^2) for the exercise center for the period January 1, 1989 through February 10, 1989.

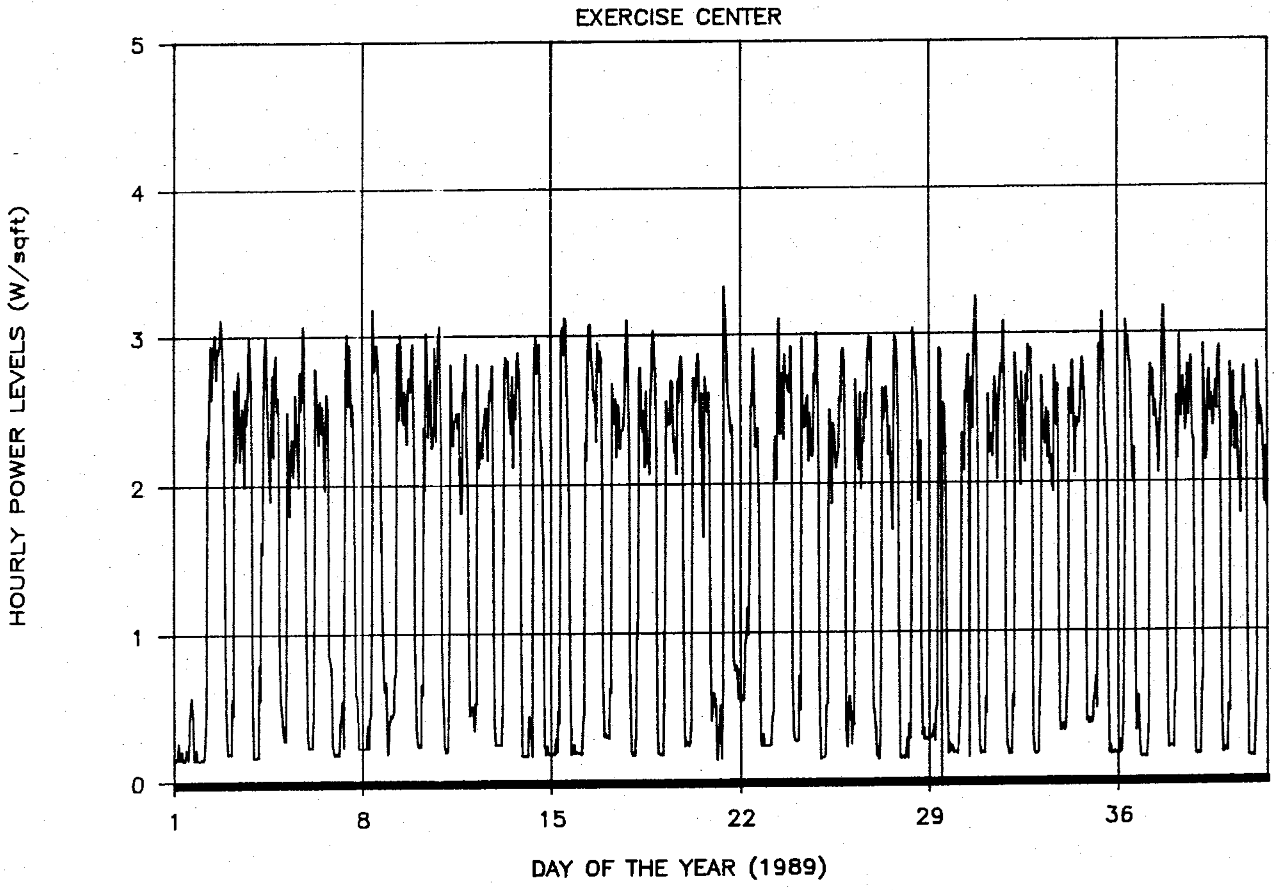


Figure 37: *Comparative Hourly Electric Profiles (Exercise Center).* This figure shows hourly electricity usage profiles for the exercise center. Hourly profiles for the actual electricity use (a), base-level model (b), positive residual (c), and absolute value of the negative residual (d) are shown. In each plot the day-of-the-year and hour-of-the- day form the x-y plane, respectively. Hourly electricity usage (kWh/h) is represented as the height of the surface above the plane.

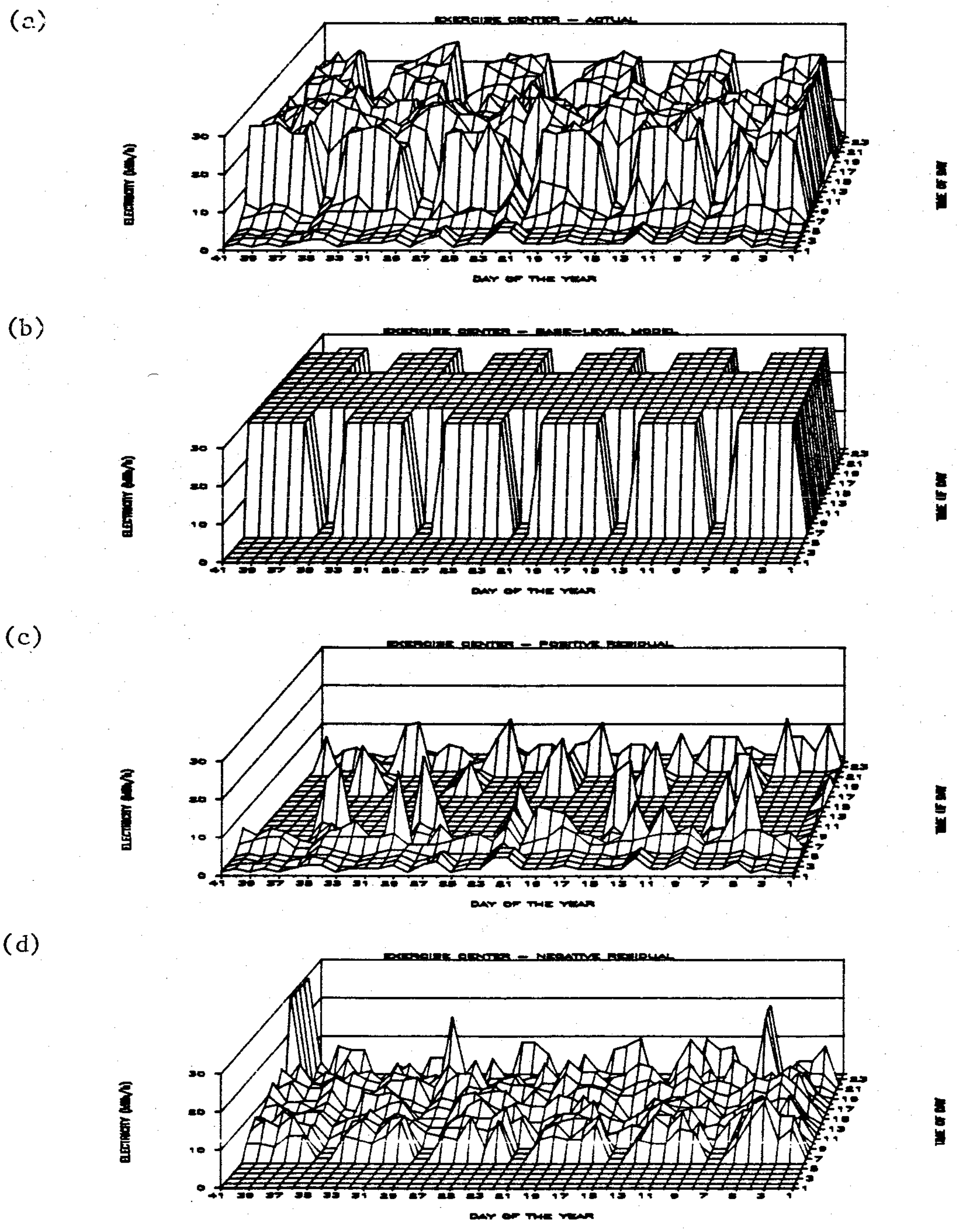


Figure 38: *Monthly Electricity Use (Drive-up)* This figure shows average monthly electricity power levels for the drive-up bank. Power levels (W/ft^2) are shown for both electricity usage (kWh) and peak monthly electric demand (kW). Two electric demand power levels are shown: those which include probable erroneous readings (Elec - kW) and those where the probable erroneous readings have been removed (kW - w/o error).

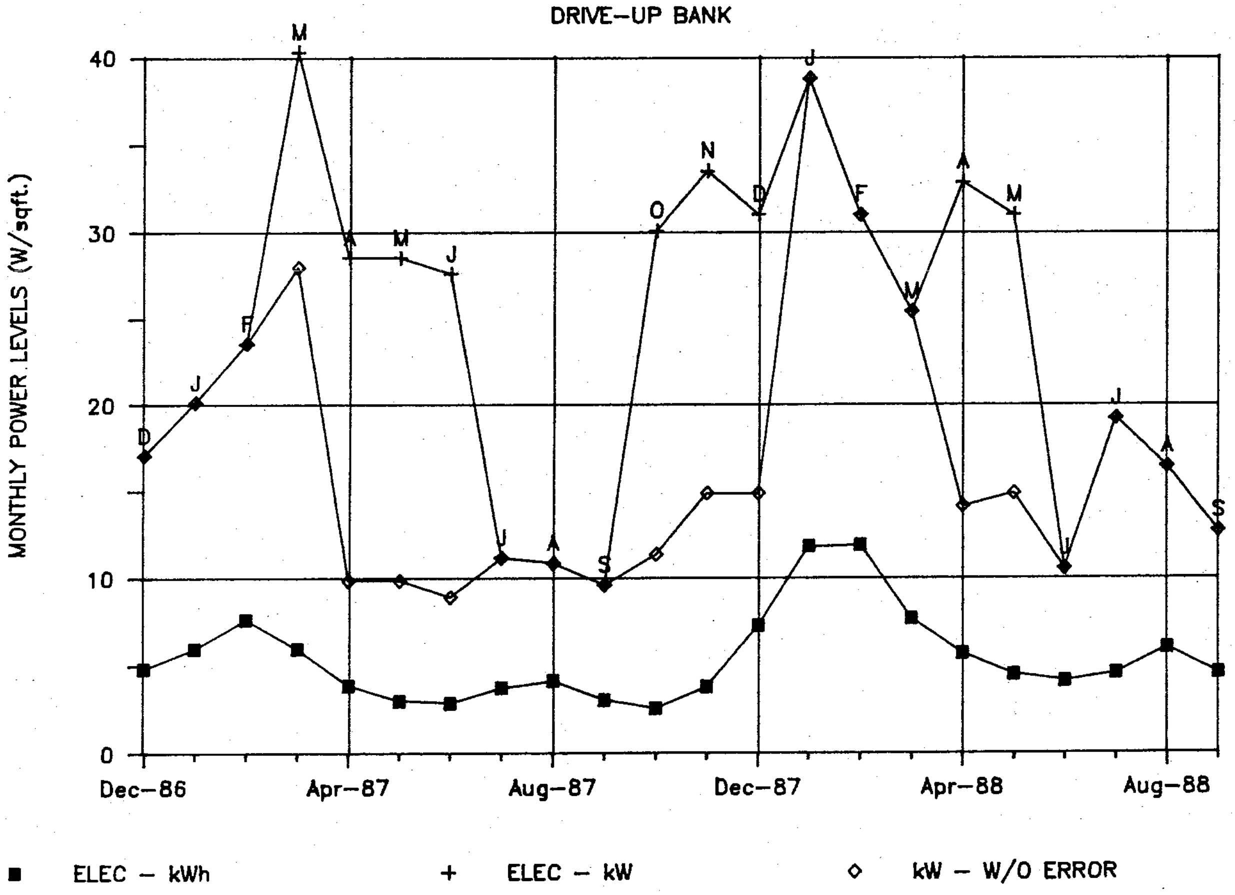


Figure 39: *Monthly Electricity Use versus Ambient Temperature (Drive-up).* This figure shows average monthly electricity power levels versus average monthly ambient temperature for the drive-up bank. Power levels (W/ft^2) are shown for both electricity usage (kWh) and peak monthly electric demand (kW).

NOTE: For intervals spanning more than a day, degree-days are well known to be a much better indicator of energy consumption than are average outdoor temperatures (averaged over all days in the interval). Since computation of degree-days requires an assumed reference temperature (such as that estimated in the PRISM model), and since cooling and heating related degree-days are both relevant in this study, average temperatures are shown here as a surrogate for degree-day information.

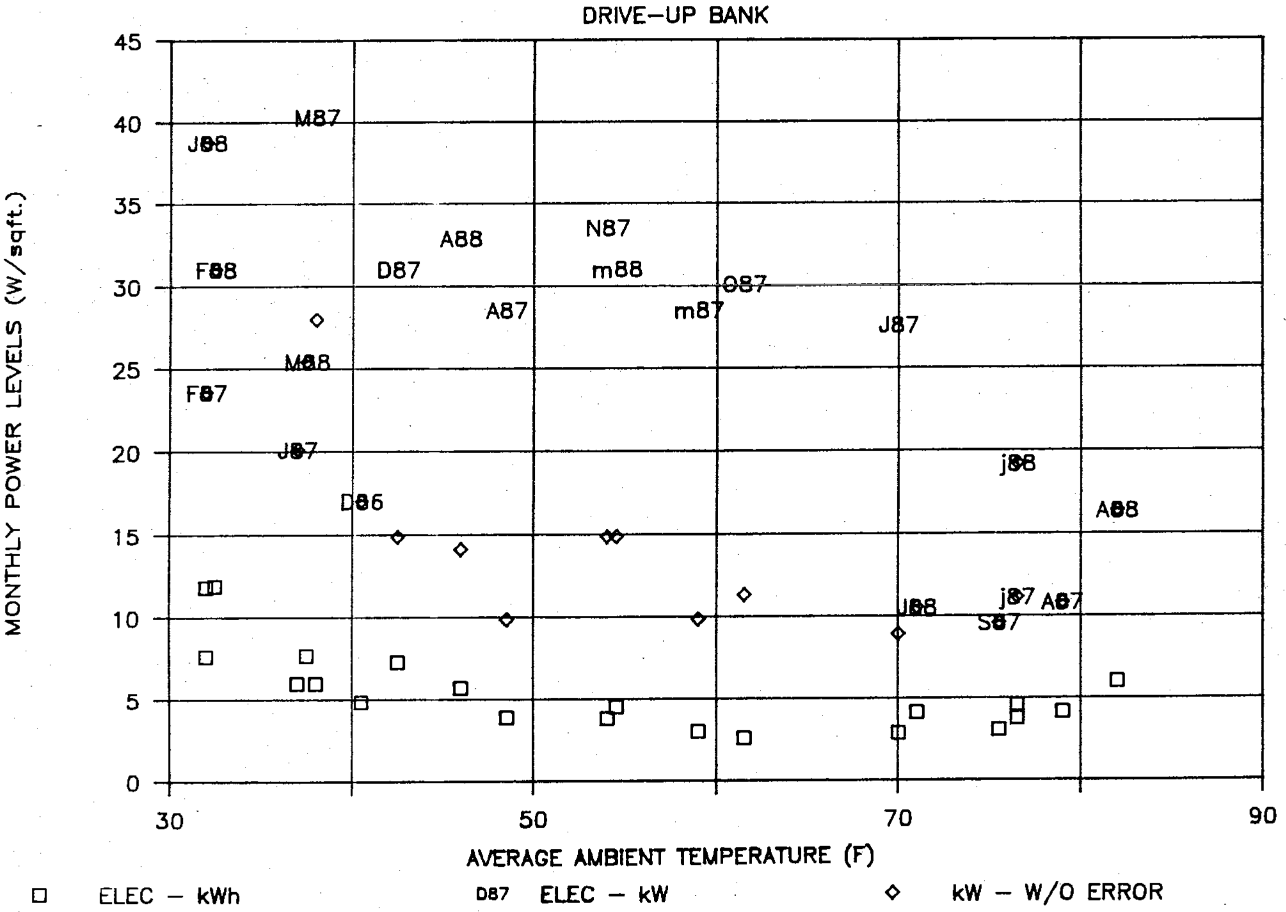


***Figure 40:** Daily Electricity Use and Ambient Temperature (Drive-up).* This figure shows daily average electricity usage (W/ft^2) for the drive-up bank and average daily ambient temperature for the period January 1, 1989 through February 10, 1989. Data are from daily logbook readings.

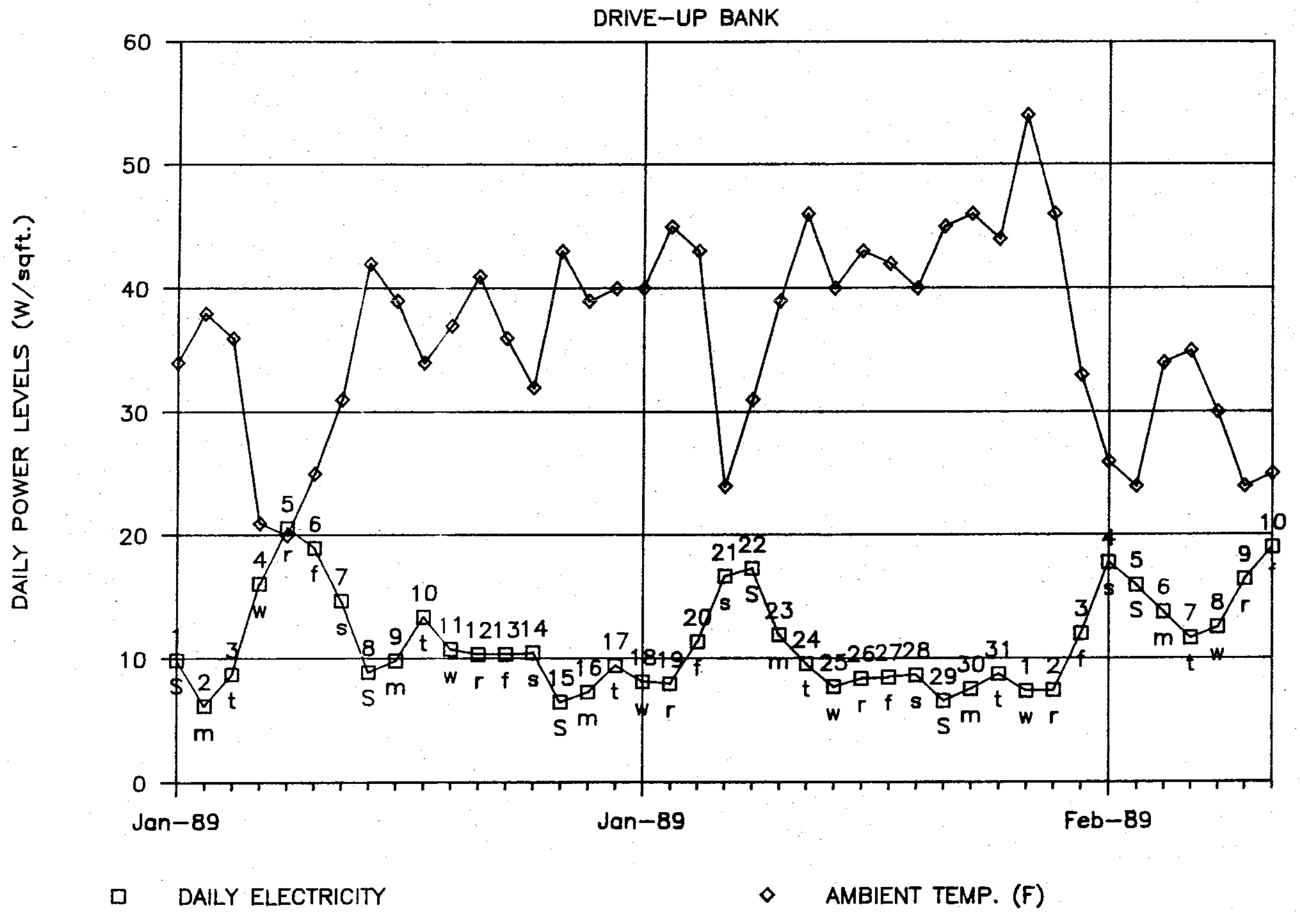


Figure 41: *Daily Electricity Use versus Ambient Temperature (Drive-up).* This figure shows daily average electricity power levels for the drive-up bank displayed against the average daily ambient temperature. Data are from daily logbook readings for the period September 1988 through March 1989. The letters used for the data labels represent the day-of-the-week (i.e.,s = Sunday, etc.).

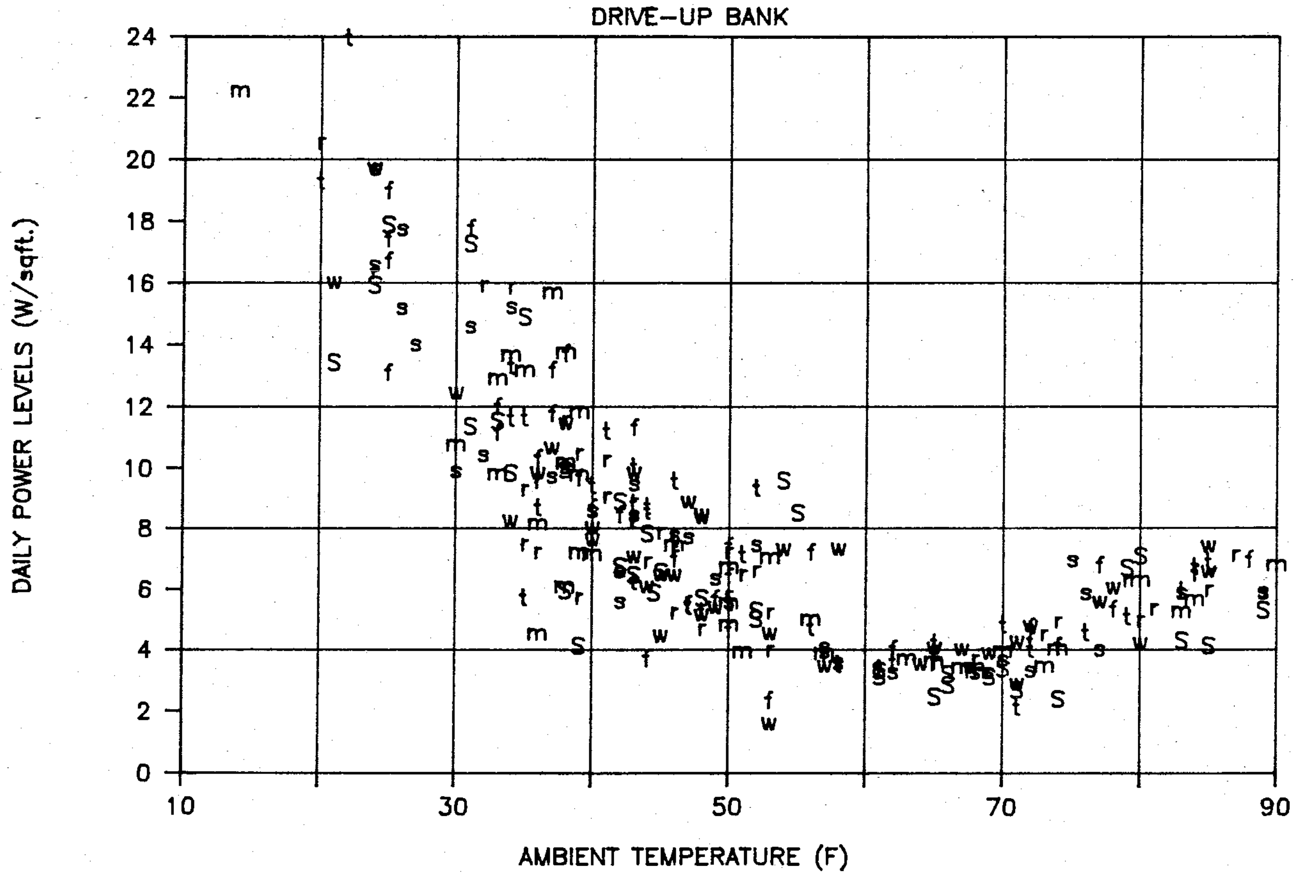


Figure 42: *Monthly Electricity Use (Travel Center).* This figure shows average monthly electricity power levels for the travel center. Power levels (W/ft^2) are shown for both electricity usage (kWh) and peak electric monthly demand (kW).

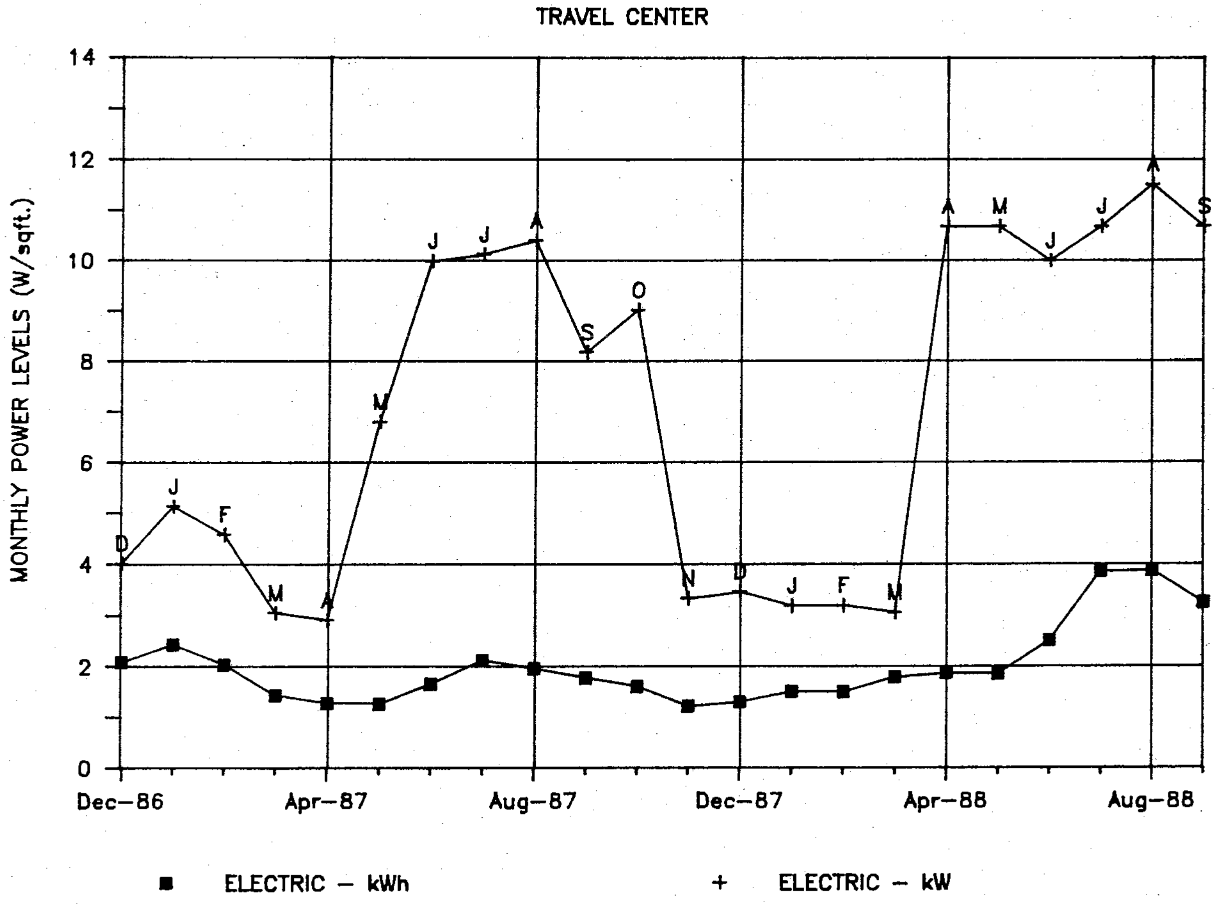


Figure 43: *Monthly Electricity Use versus Ambient Temperature (Travel Center)* . This figure shows average monthly electricity power levels versus average monthly ambient temperature for the travel center. Power levels (W/ft^2) are shown for both electricity usage (kWh) and peak monthly electric demand (kW).

NOTE: For intervals spanning more than a day, degree-days are well known to be a much better indicator of energy consumption than are average outdoor temperatures (averaged over all days in the interval). Since computation of degree-days requires an assumed reference temperature (such as that estimated in the PRISM model), and since cooling and heating related degree-days are both relevant in this study, average temperatures are shown here as a surrogate for degree-day information.

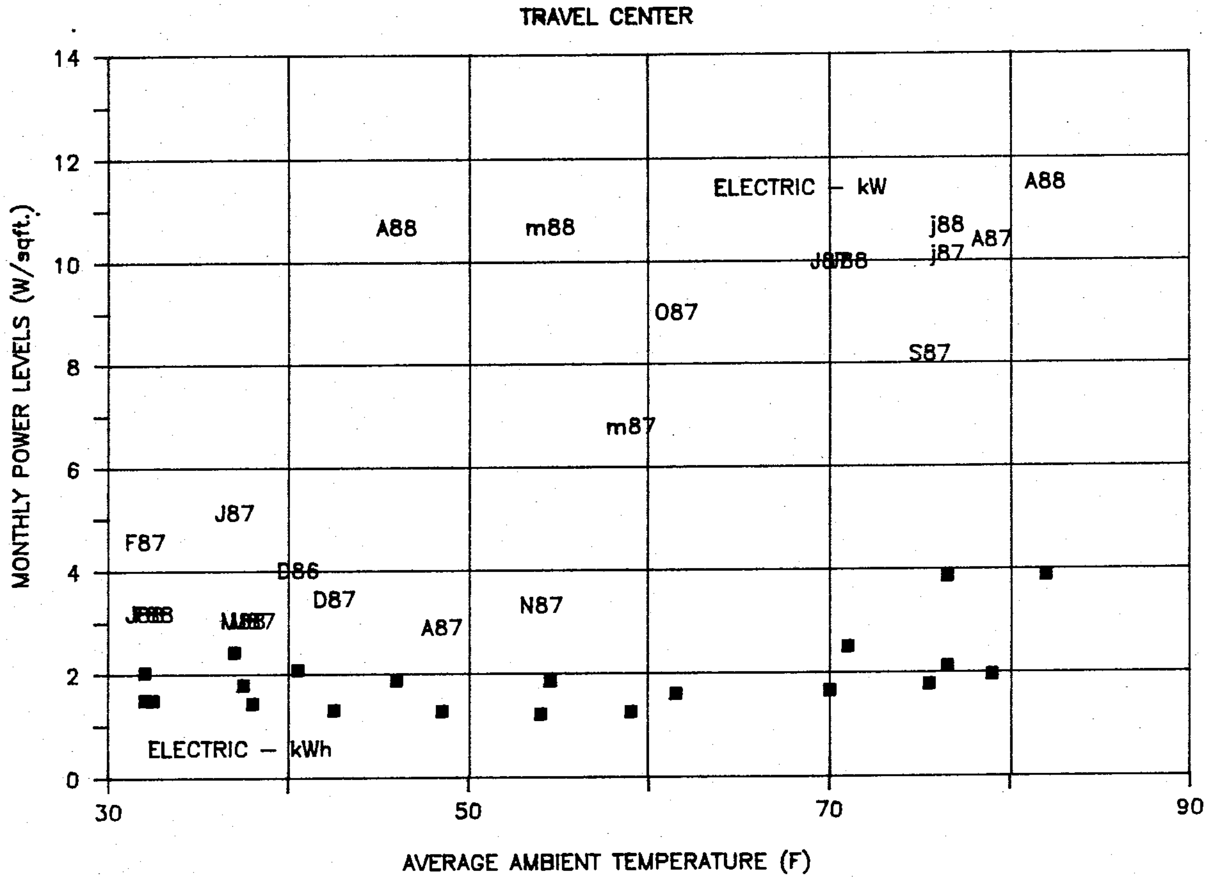


***Figure 44:** Daily Electricity Use (Travel Center).* This figure shows average daily electricity usage (W/ft^2) for the travel center for the period January 1, 1989 through February 10, 1989. Data are from daily logbook readings.

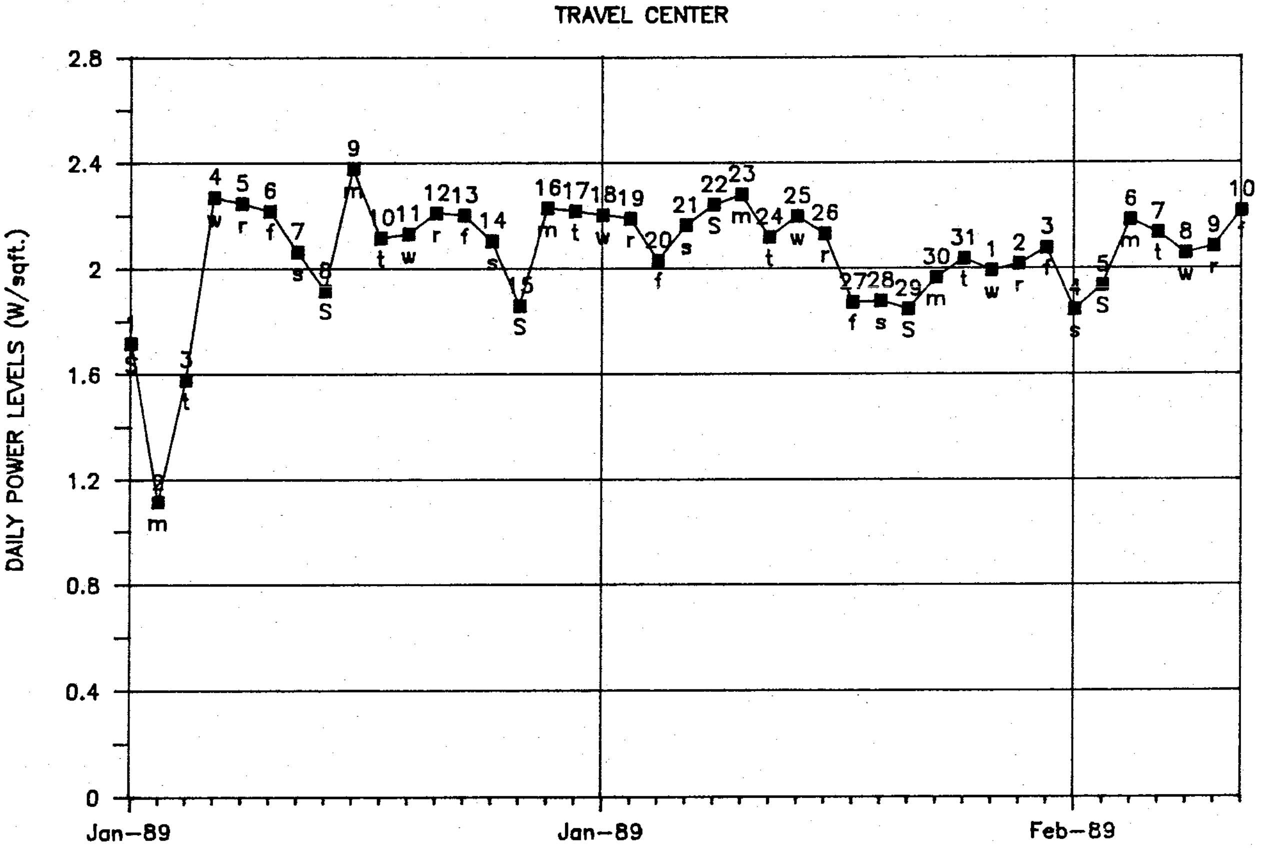


Figure 45: *Daily Electricity Use versus Ambient Temperature (Travel Center).* This figure shows daily power levels for the travel center displayed against the average daily ambient temperature. Data are from daily logbook readings for the period September 1988 through March 1989.

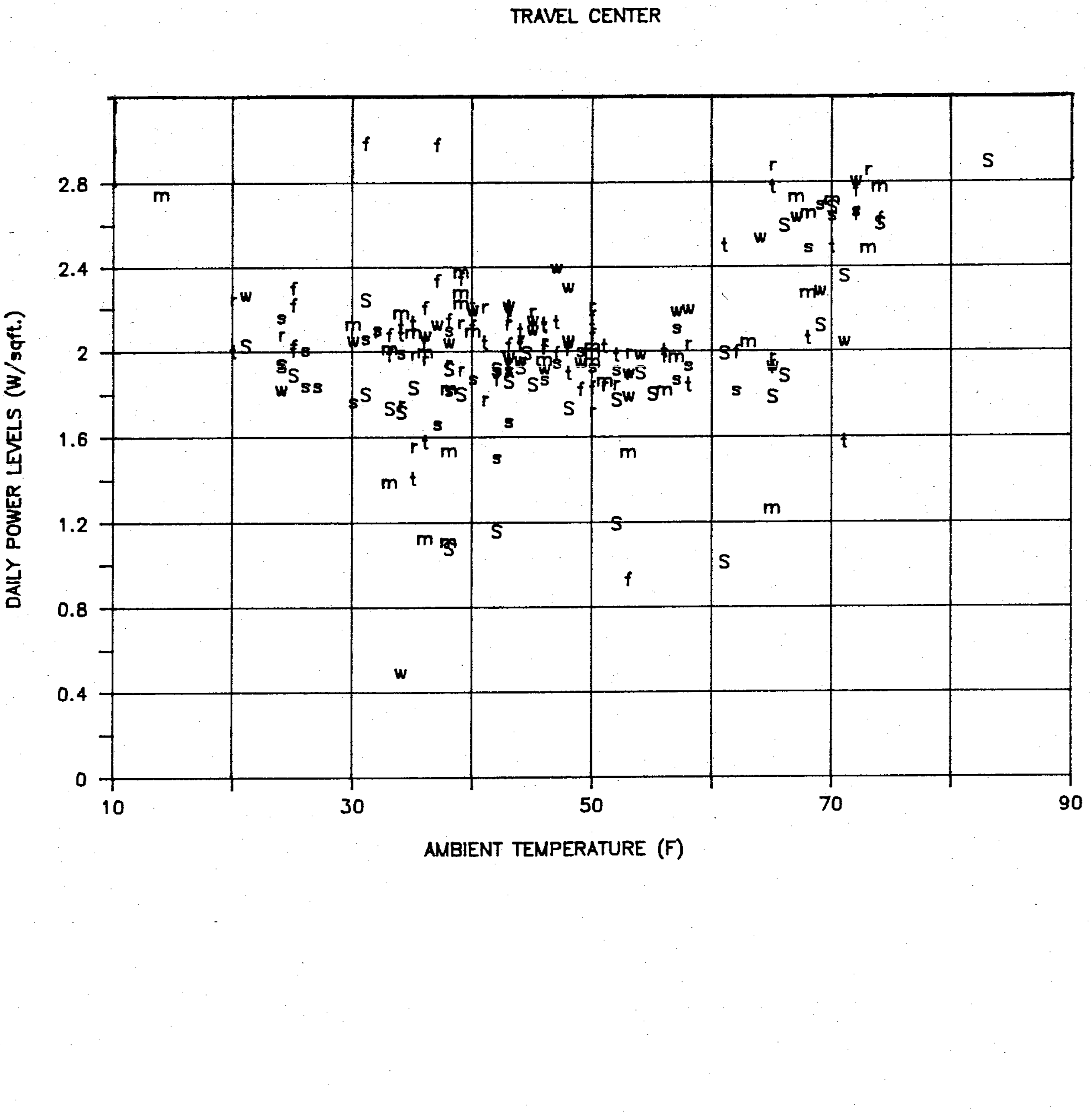


***Figure 46:** Daily Minimum-Maximum Temperature (Travel Center).* This figure shows minimum and maximum zone temperatures for the travel center. The zone temperatures are displayed against average daily ambient temperature. Data are for the period September 1988 through March 1989.

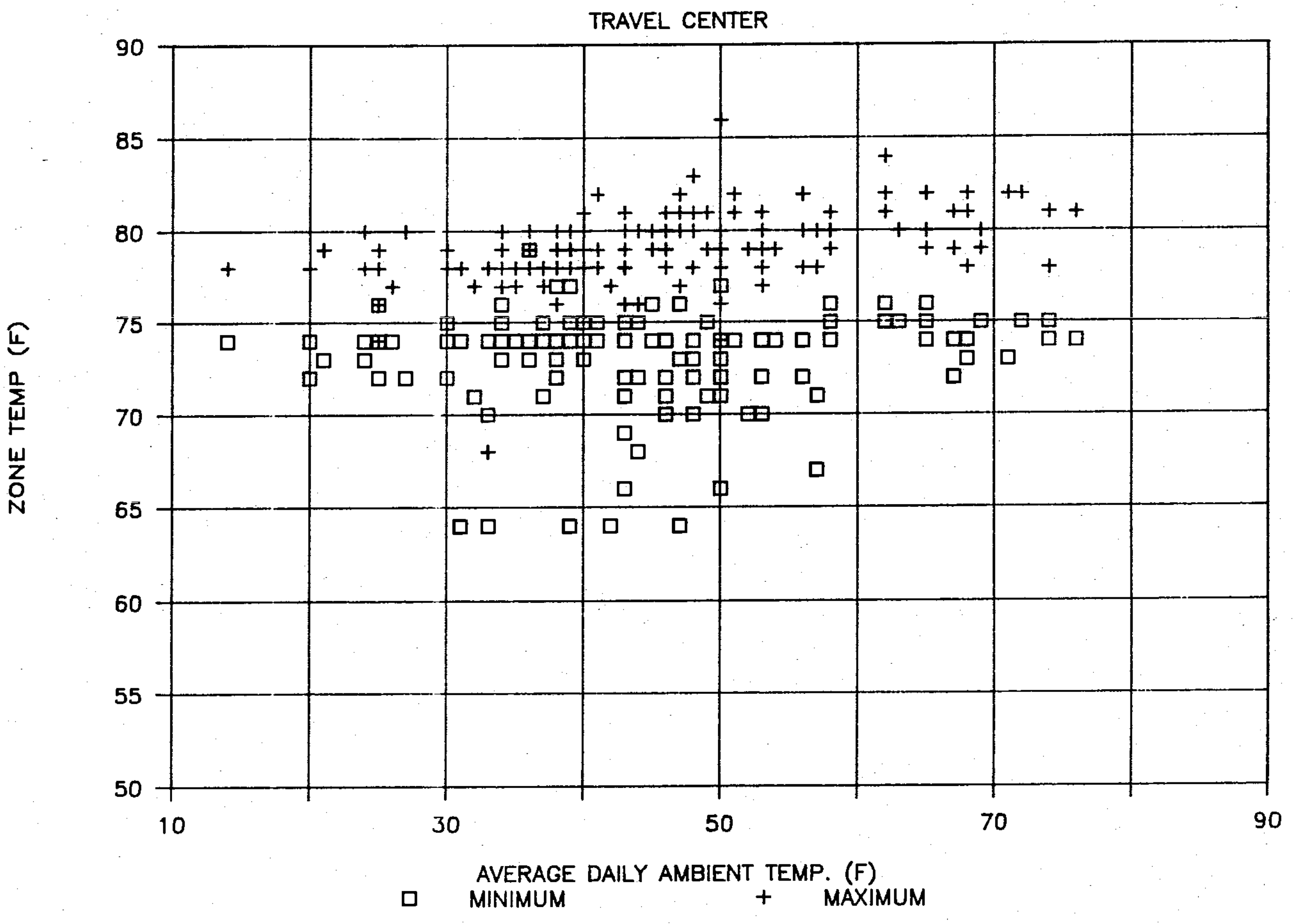


Figure 47: *Monthly Electricity Use (Video Store).* This figure shows monthly power levels for the video store. Power levels (W/ft^2) are shown for both electricity usage (kWh) and peak monthly electric demand (kW). The store was unoccupied during the months of August and September 1988.

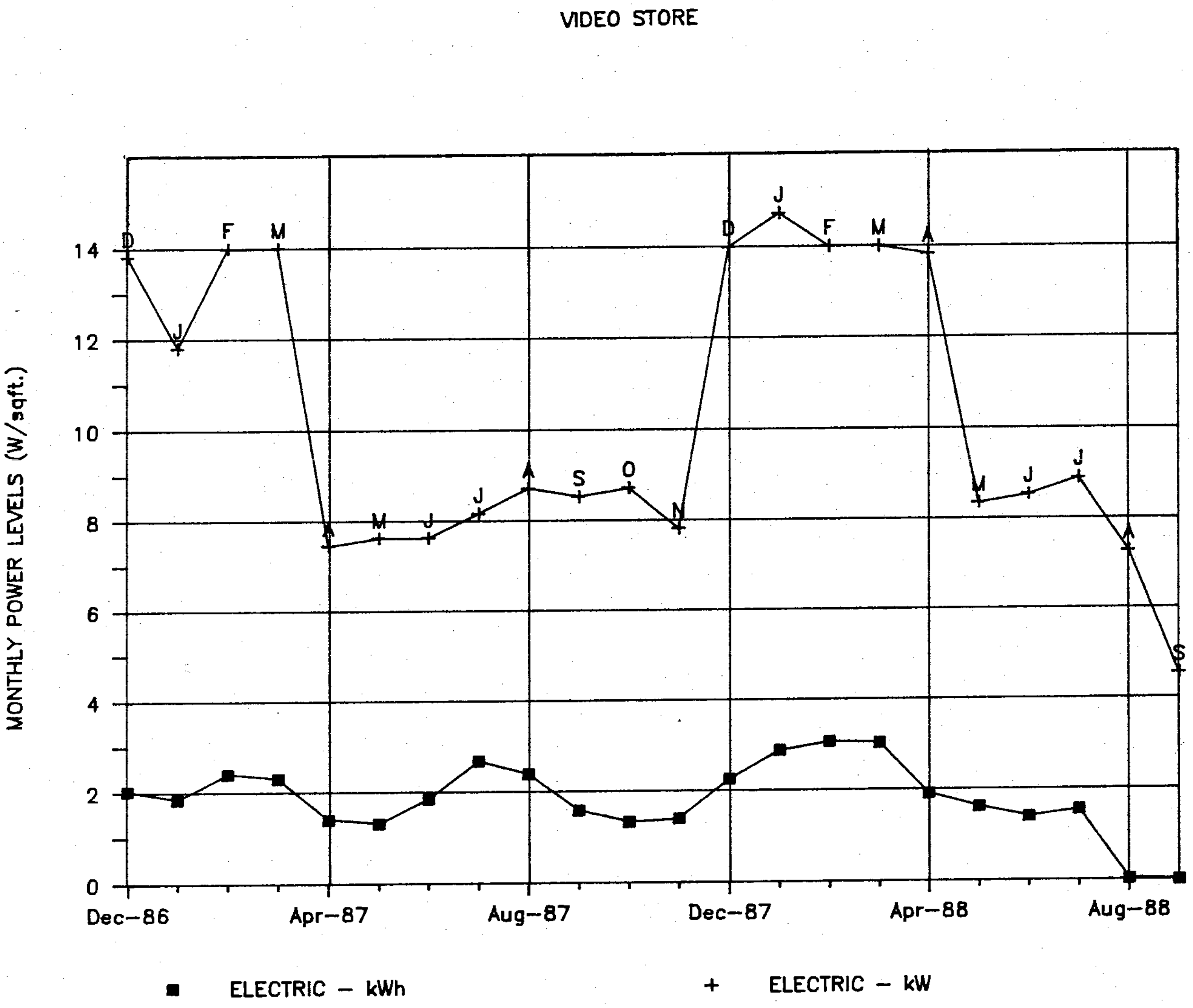


Figure 48: *Monthly Electricity Use versus Ambient Temperature (Video Store).* This figure shows average monthly electricity power levels versus average monthly ambient temperature for the video store. Power levels (W/ft^2) are shown for both electricity usage (kWh) and peak monthly electric demand (kW).

NOTE: For intervals spanning more than a day, degree-days are well known to be a much better indicator of energy consumption than are average outdoor temperatures (averaged over all days in the interval). Since computation of degree-days requires an assumed reference temperature (such as that estimated in the PRISM model), and since cooling and heating related degree-days are both relevant in this study, average temperatures are shown here as a surrogate for degree-day information.

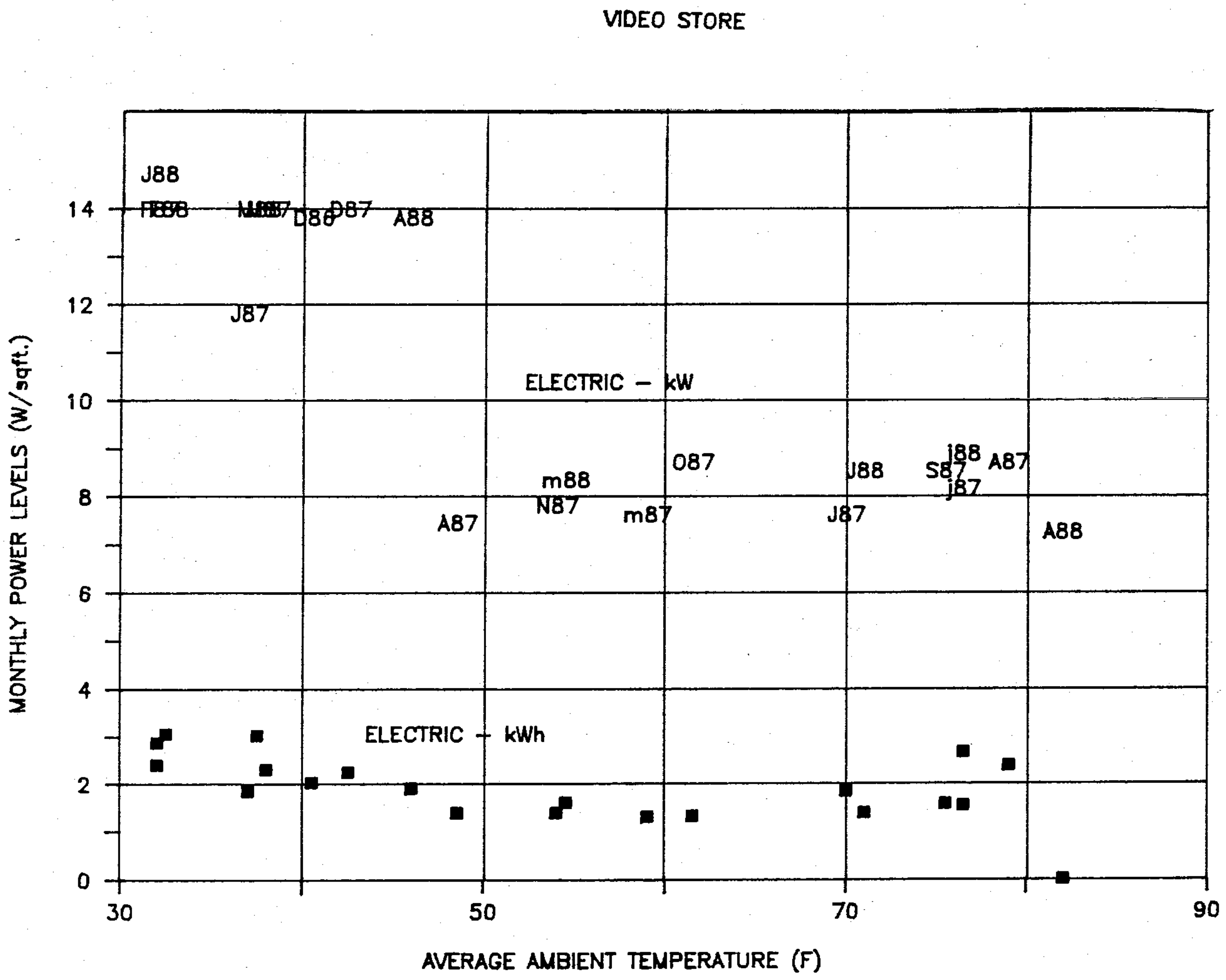


***Figure 49:** Example of Probable kWh Billing Error*. This figure illustrates a probable electricity usage (kWh) billing error for one of the small commercial businesses at the Jersey Mall. Figure (a) is the electricity usage (kWh), Figure (b) is the monthly ELF, and Figure (c) is the electric demand. All values represent unadjusted utility billing data.

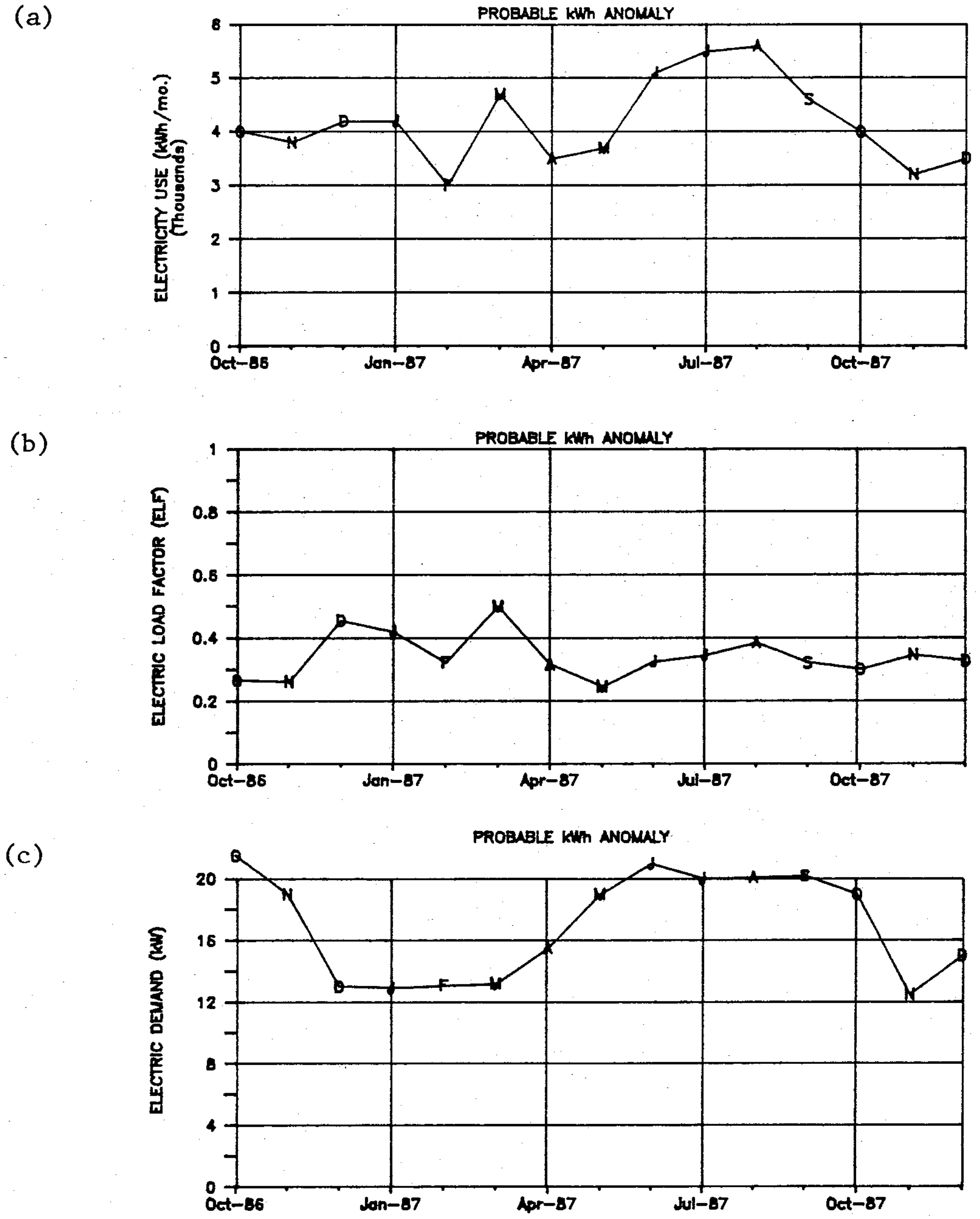


Figure 50: *Example of Probable kW Billing Error.* This figure illustrates a probable electric demand (kW) billing error for one of the small commercial businesses at the Jersey Mall. Figure (a) is the electricity usage (kWh), Figure (b) is the monthly ELF, and Figure (c) is the electric demand. All values represent unadjusted utility billing data.

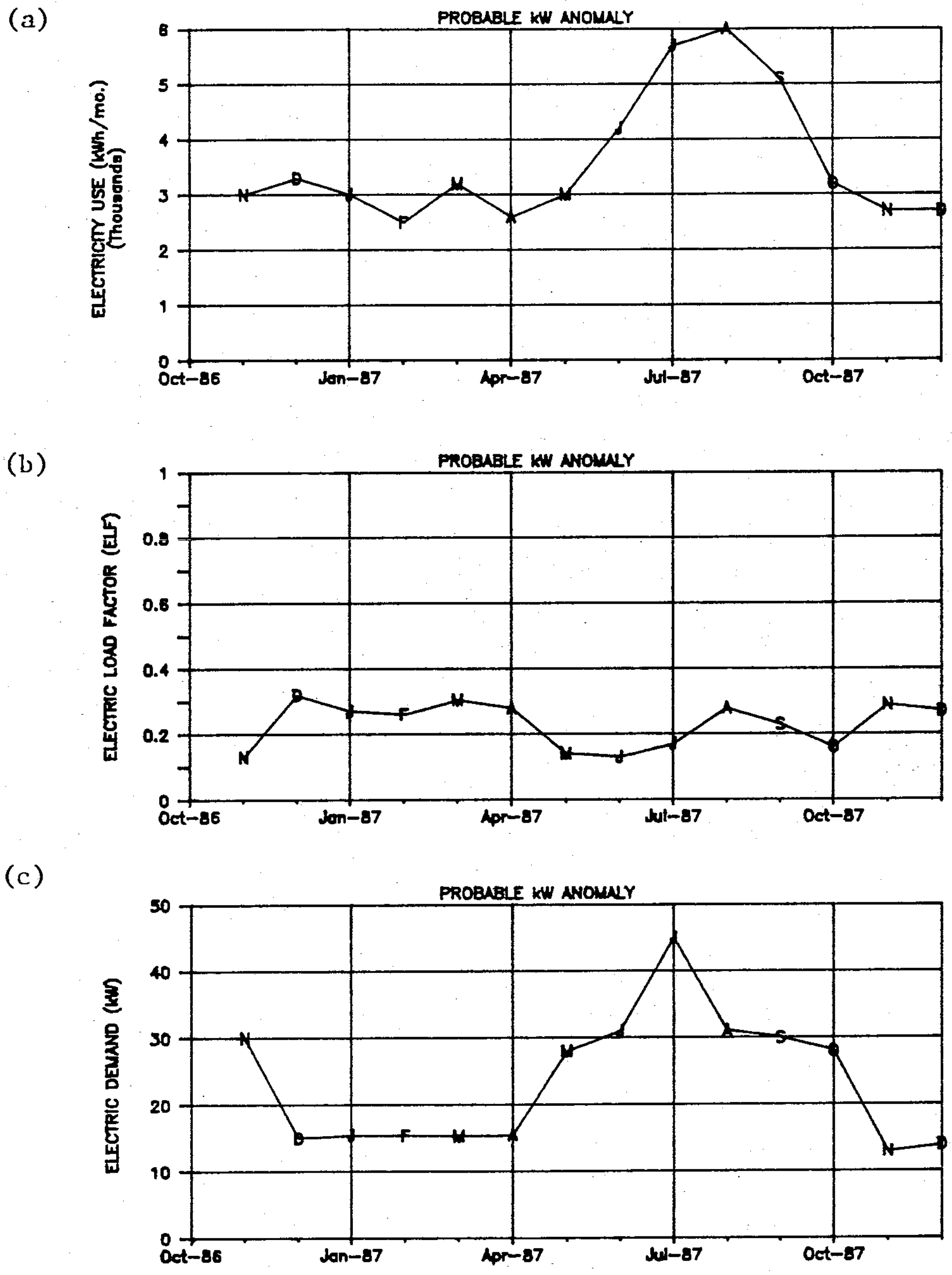


Figure 51: *Example of Probable Compound kW Billing Error.* This figure illustrates a probable compound electric demand (kW) billing error for one of the small commercial businesses at the Jersey Mall. Figure (a) is the electricity usage (kWh), Figure (b) is the monthly ELF, and Figure (c) is the electric demand. All values represent unadjusted utility billing data.

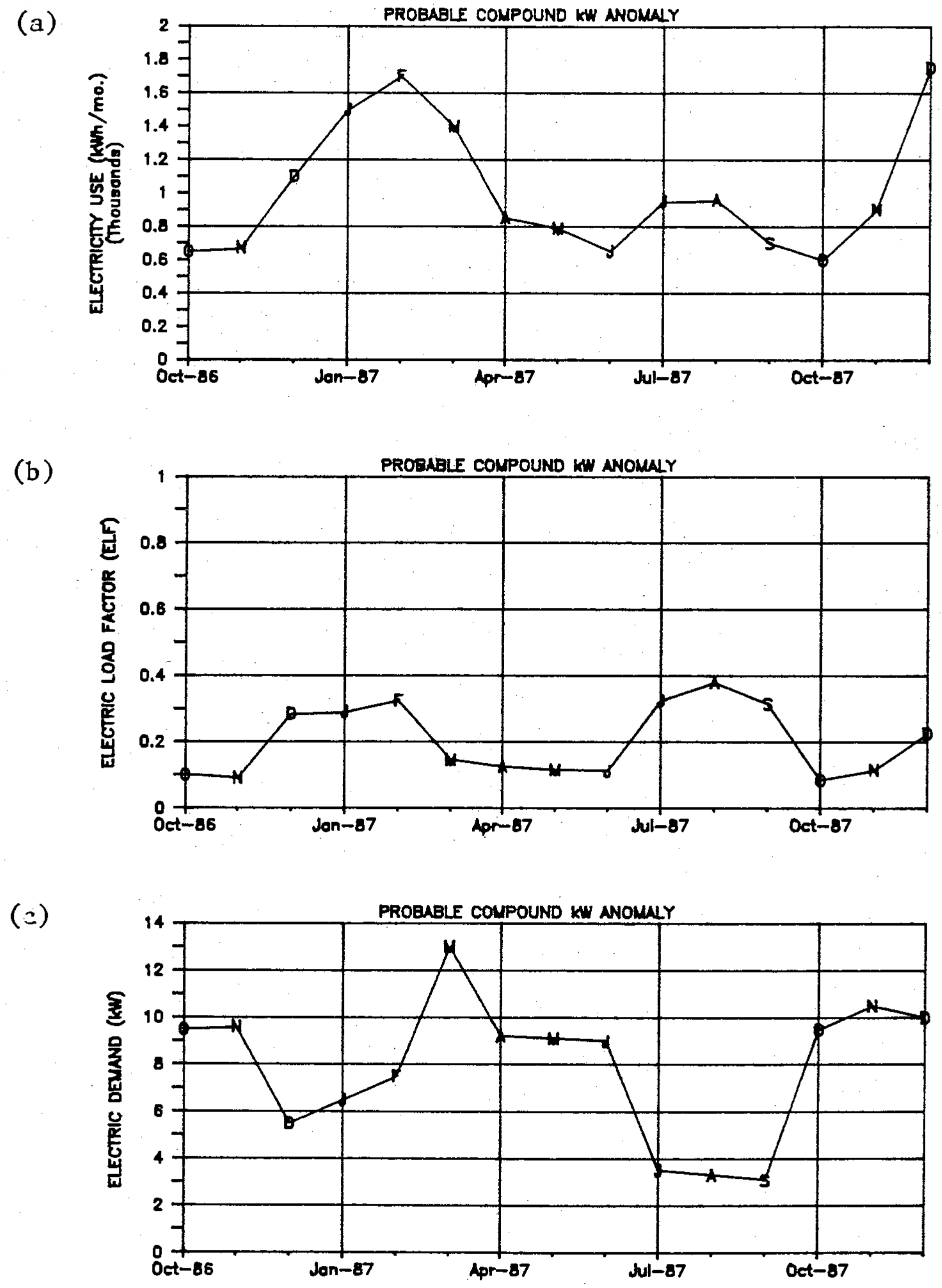


Figure 52: *Probable Cause of Compound kW Error.* This figure illustrates the dial-and-pointer demand register display used to record electric demand for the customer that is experiencing the probable compound electric demand error. Figure (a) shows the registers at the beginning of the billing period (true reading = 0.945). Figure (b) shows the registers at the end of the billing period (false reading = 1.945). Our daily inspections of the meter revealed that the pointer for the C register continued to move (from a 0.xxx position to a 1.xxx position) without a corresponding movement in the B or A registers.

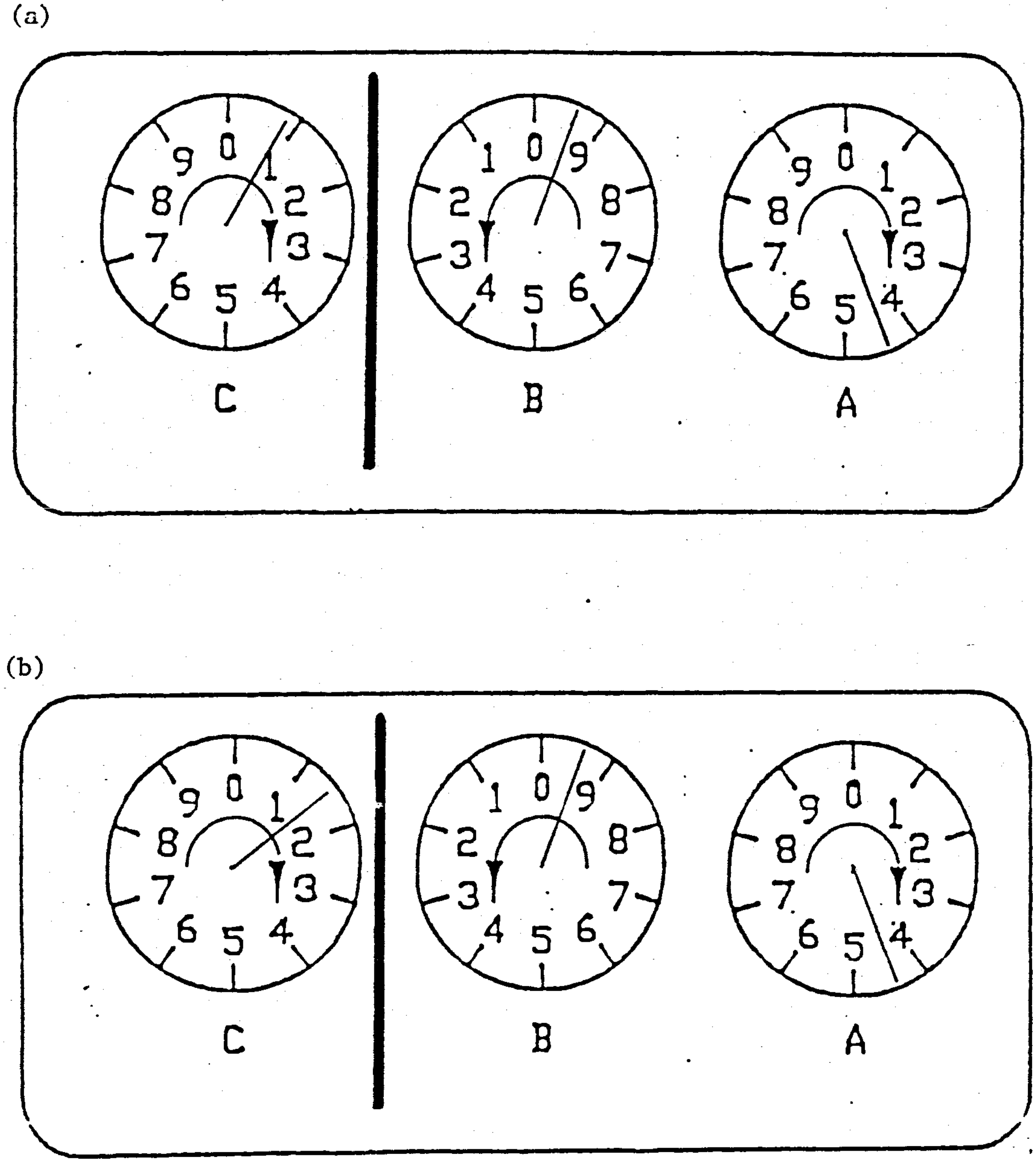


Figure 53: *Comparative Electricity Usage.* This figure displays comparative electricity use (average annual W/ft^2) for the seven stores studied at the Jersey Mall. Base-level, cooling and heating portions were calculated with PRISM HC for the drive-up bank, video store and travel center; PRISM CO was used for the general merchandise and furniture stores. Base-level only was assigned to the exercise center and stationery store since a PRISM analysis could not detect heating-season or cooling-season related loads and since consumptions varied less than 15% over one year.

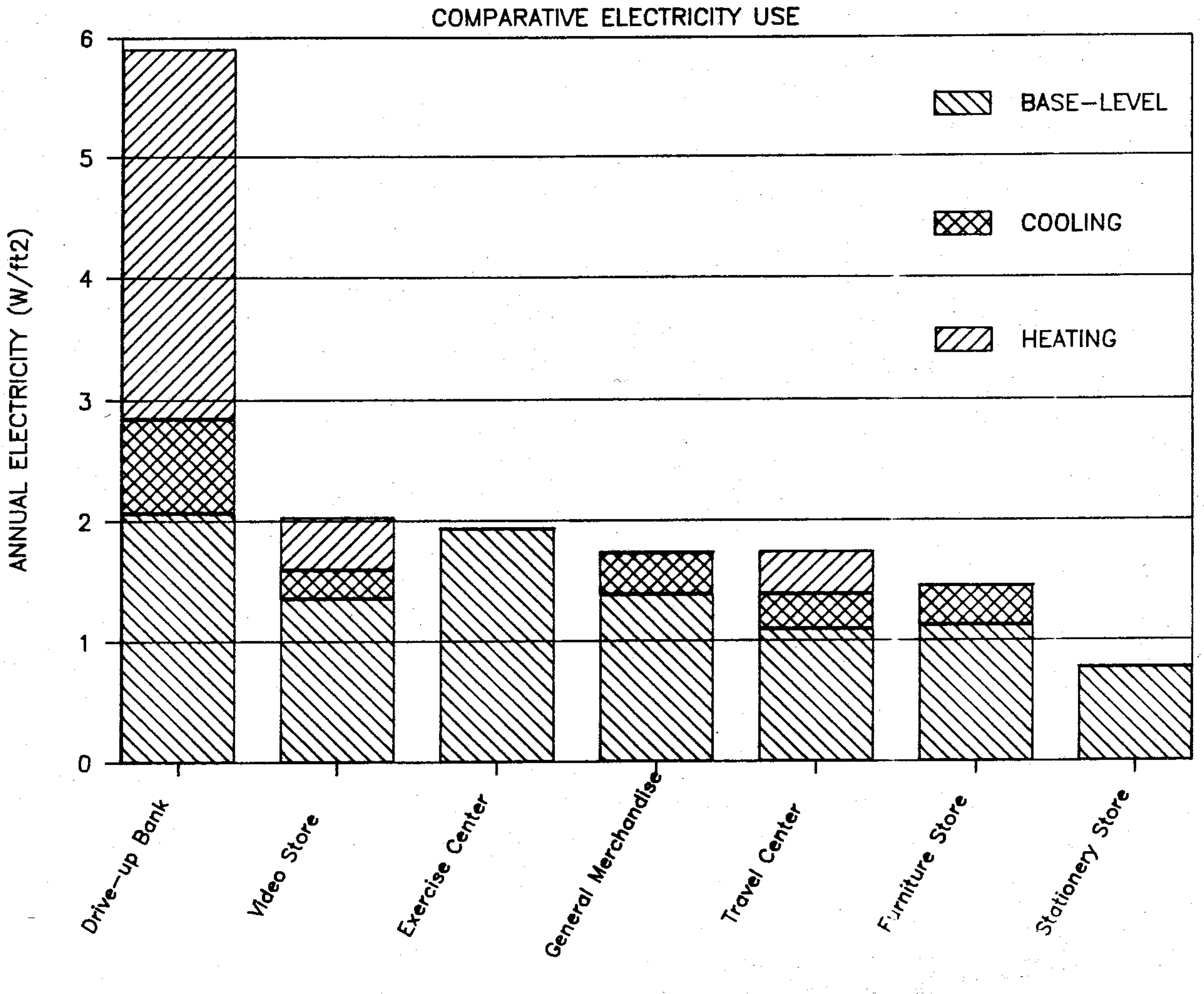
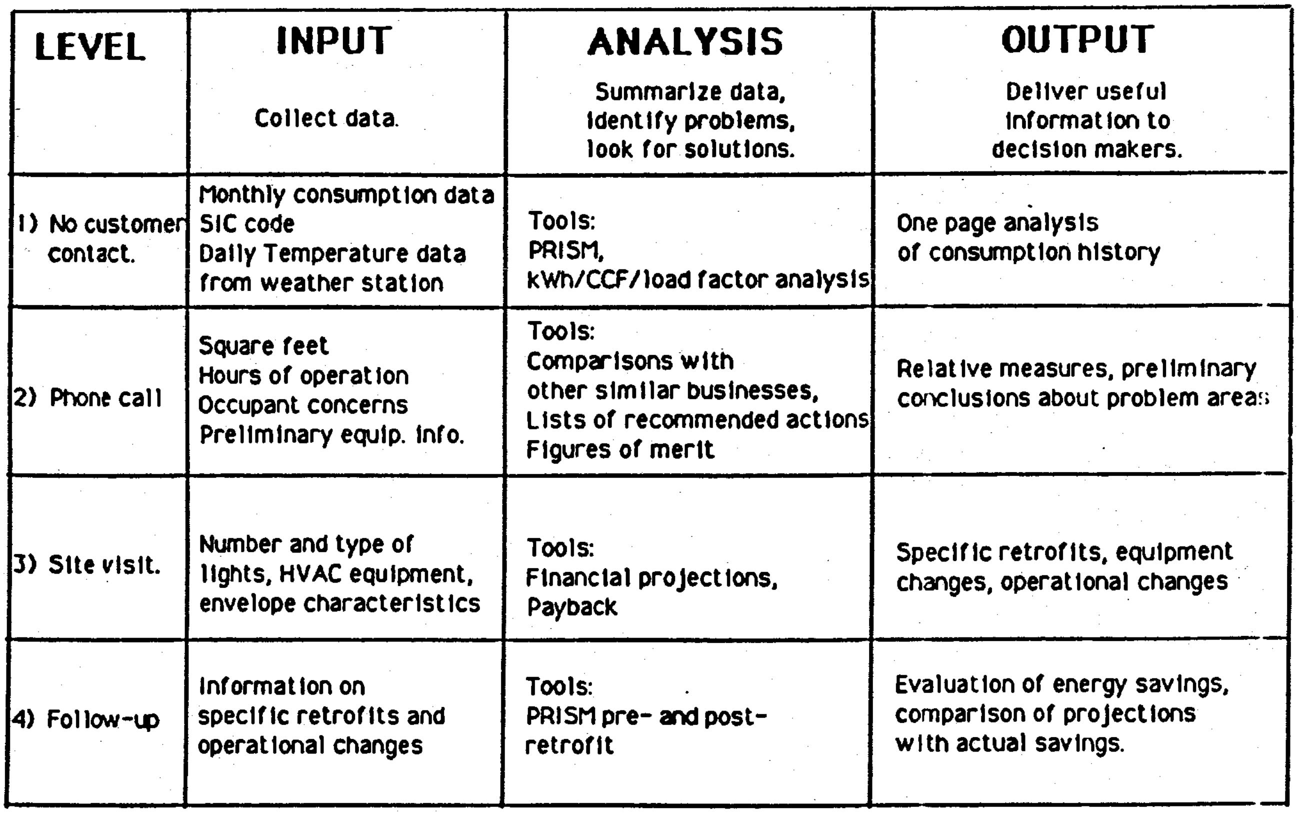


Figure 54: *Proposed Commercial Building Energy Analysis Procedure.* This figure contains the multi-level analysis that serves as an outline for a proposed commercial building energy analysis. The input, analysis and output required for the different levels are shown. Information produced in Level 1 is meant to pass to Level 2 and so forth.



LEVEL	INPUT Collect data.	ANALYSIS Summarize data, identify problems, look for solutions.	OUTPUT Deliver useful information to decision makers.
1) No customer contact.	Monthly consumption data SIC code Daily Temperature data from weather station	Tools: PRISM, kWh/CCF/load factor analysis	One page analysis of consumption history
2) Phone call	Square feet Hours of operation Occupant concerns Preliminary equip. info.	Tools: Comparisons with other similar businesses, Lists of recommended actions Figures of merit	Relative measures, preliminary conclusions about problem areas
3) Site visit.	Number and type of lights, HVAC equipment, envelope characteristics	Tools: Financial projections, Payback	Specific retrofits, equipment changes, operational changes
4) Follow-up	Information on specific retrofits and operational changes	Tools: PRISM pre- and post-retrofit	Evaluation of energy savings, comparison of projections with actual savings.