Investigating an Analytical Basis for Improving Commercial Building Energy Audits: Early Results from a New Jersey Mall

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ABSTRACT

This paper describes an investigation of energy use by commercial buildings using early results from a case study shopping center in New Jersey (Figure 1). The purpose of this investigation is to discover what problems are occurring in each of the candidate stores and link these problems to indicators that could have led the energy analyst to those systems 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, lighting levels, and exterior envelope.

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 if certain equipment is oversized (causing excessive summertime demand), whether equipment is left operating during unoccupied periods and, in the case of two of the three case study buildings, whether economizers are functioning properly. The results yielded electricity energy savings from 5% to 15% (3-month payback for New Jersey buildings) and, of increasing importance, show that cooling-season electric demand can be reduced by 8% (costing about $50 /kW) by correcting operation and maintenance problems. We summarize this study by proposing a multi-level approach which utilizes these indices and comment on the usefulness of such an approach.

INTRODUCTION

Commercial Building Energy Audits

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 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 1989a). 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 ft^2 of conditioned 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 a national laboratory for ASHRAE concluded that audits are subject to considerable uncertainty and could benefit significantly if a preliminary analysis of a building's metered data was

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performed prior to the site visit (ASHRAE 1987c). The ASHRAE report recommended that a commercial building energy analysis be performed interactively using three levels: 1) an analysis of past utility information, followed by 2) a simple walk-through audit and brief analysis and then 3) a detailed engineering analysis. We have adopted this approach as a basis on which to formulate our investigation and suggestions concerning an expanded approach (Figure 2). The ASHRAE report also suggested the terminology "building energy analysis," which we use interchangeably with the phrase "energy audit."

Implications From Two Commercial Building Energy Audits. In order to compare our data-based conclusions with those obtained through a traditional audit, we arranged for a standard utility-sponsored audit to be conducted on the general merchandise store at the 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 company, 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 reveals, as well as some indication of the variability of results 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 1. 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 in a usable form, 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).

What's Ahead

In the sections that follow we describe the case study (the Jersey Mall) and focus on three stores, a general merchandise store, a stationery store, and a furniture store, that were intensively monitored. For each store annual, monthly, daily, and hourly indices were compared to notes taken during our site visits to see what was wrong with each of the HVAC and lighting systems (if anything), and, if something was discovered, if helpful clues could have been generated (prior to the site visit) that could have guided the building energy auditor during the site visit.

In the final section we attempt to pull together this diverse study and discuss what type of potential energy conservation measures can be suggested using an analysis of 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.

THE JERSEY MALL

General Description

The Jersey Mall (Figure 1) contains 52 individual businesses covering 220,000 ft^2 of conditioned space. The mall, originally built in 1953, consists of an open-air courtyard surrounded by tenant businesses. 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 (1989a, 1989b); and Komor et al. (1989a, 1989b).

Figure 3 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 provide additional indicators for extreme conditions that occurred during our investigation. 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 monthly maximum average daily temperature rather than to the profile of the monthly average daily temperature.

Exploring the Jersey Mall

In this section early results are presented from our efforts to conceive and test our method with data from the Jersey Mall. We focus on data from three commercial businesses: a 60,000 ft^2 general merchandise store, a 2,990 ft^2 stationery store, and a 2,700 ft^2 furniture store.

For each business we studied selected indices are compared, including: 1) a simple annual cost per ft^2 ($/$ft^2$); 2) energy usage per ft^2 of conditioned floor area using annual and monthly power levels (i.e., energy intensity defined as energy usage divided by conditioned floor area, see MacDonald [1988]) for average electricity use and peak electric demand and average daily power levels and average hourly power levels; 3) monthly electric load factors (ELF); 4) monthly occupancy load factors (OLF) (equations for ELF and OLF are contained in Table 2); 5) 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 what could have been obtained from a phone survey (i.e., ft^2 and operating hours). Then we investigated what could have been learned if daily information and hourly information were available, in advance, from each of the sites. Finally, we summarize the types of energy conservation measures that 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.

The General Merchandise Store. The general merchandise store at the Jersey Mall contains a total of 60,000 ft^2 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 ft^2 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 (AHU) serving both floors. Cooling is provided by a 150-ton ground water-cooled chiller which also utilizes the six constant-volume AHUs for distribution (along with local cabinet-type units above the entrances). Two AHUs on each floor have economizers. Large 4 ft. by 4 ft. pressure relief vents for use during economizer operation are located at in the roof. Control of the heating system is provided by an open-loop, outside-air-reset 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-gal. 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% (i.e., 0.84 x 137 = 115 kW) represents fluorescent fixtures, with the remaining 16% being primarily incandescent display fixtures. Measured illumination levels vary from 50 to 60 footcandles. Additional information concerning the store can be found in Table 3.

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 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 is 48%, which is slightly higher than the occupancy load factor 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 either 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 -- see ASHRAE 1987a, chpt.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 for a given building at a specific location. 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 purpose for using a PRISM analysis is to statistically determine the primary functions for which electricity is being used, and how consistent that use is. PRISM allows us to statistically 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 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 Komor et al. (1989b).

A PRISM CO analysis of the general merchandise store indicates that the building consumes electricity primarily for base level (80%) and cooling (20%), and is well determined (i.e., $R^2 = 0.954 > 0.70$, CV(NAC) = 1.9% < 6%) using the reliability criteria established by Reynolds and Fels (1988). 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 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 (80%) with a smaller portion (20%) being consumed for cooling.

Next, sliding PRISM CO is applied to the 22 months of electricity consumption, as shown in Figures 4a-c. 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 for the general merchandise store (Figure 4a) clearly shows a 5% increase in the NAC. There is also a 17% increase in the base level 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 nearly flat NAC.

Monthly utility records for electricity also contain electric demand information, shown in Figure 5a 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% during non-cooling periods and 2% during cooling periods. When one compares Figure 3 to Figure 5a, 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 Figures 6a-c also help to confirm two features: equipment or lights left operating during unoccupied periods and the 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, 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 consumption only. We calculated ELF using whole-building demand and consumption. Although it was not our intention 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 6a 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 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 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 this 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, as shown in Figures 10a-d. Here the electric demand for a typical non-cooling month (e.g., for February 1988 demand = 186 kW) is assigned to all hours the store is open (these were obtained by noting the posted store hours). The calculated electricity consumption (e.g., 186 kW * 291 h = 54,126 kWh) for this estimated portion is then subtracted from the actual electricity consumed during February 1988 (67,050 kWh), resulting in 12,924 kWh (19%). The 12,924 kWh is then assigned evenly over the remaining 405 unoccupied hours, which creates an unoccupied consumption level of 32 kW during this base level month.

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 (Press 1985) including singular value 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., measured electricity use for lights and fans during 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 use 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 7a 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 Figures 8a-c we illustrate data from simple minimum-maximum thermometers placed near the thermostat and read once per day in the early evening (during the period March 1988 to December 1988 for general merchandise). For the general merchandise store we show the data for the first floor in Figure 8a. 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's F (usually in the afternoon when the chiller was not running) or drop into the 50-60 F range (an isolated condition for this store only, occurring when the loading dock doors remained opened during a delivery and cold air enters the zone). During the cooling season (i.e., ambient temperatures of 55 F and above) interior temperatures can rise into the high 80's F or drop as low as the 60's F (the result of operating the chiller overnight).

Finally, we look at how hourly whole-building electricity data and zone temperatures can provide the building energy analyst with additional useful information. Figures 9 through 12 illustrate techniques for discovering how consistently comfort conditions and operation schedules are maintained.

Figure 9a shows the hourly power levels for the general merchandise store 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 occupied-period hourly power levels. The monthly electricity usage power level (monthly electricity usage divided by the product of ft^2 times the numbers of hours in the month) indicates the average of hourly power levels.

Figure 9a also indicates erratic first-floor temperatures (when compared to the stationery and furniture stores) -- 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 8a. The site visits to the store 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 in the heating season -- one reason for the abnormally low minimum temperatures in Figure 8a.

Figures 10a-d display the hourly energy use for the general merchandise store as three dimensional (3-D) profiles. 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. Figure 10a clearly exhibits features that remain hidden to us when viewed in daily, monthly, or annual graphs.

One of the methods developed by Reiter (1986), and others, and further investigated by Haberl et al. (1988a) provides us with a means of classifying the spatial profiles. For the general merchandise stores there is a dominant, scheduled daily electric base-level profile which represents lights, fans, and electrical receptacles.

Using techniques developed by Haberl and Vajda (1988) Figures 10a-d display some important points about how the building is being operated. To obtain these plots the base-level model (Figure 10b) is subtracted from the measured hourly electricity consumption and sorted into residuals representing positive (Figure 10c) and negative groups (Figure 10d). Doing so reveals several features that remain hidden to other techniques of unraveling the actual hourly electricity profile plot.

First, the goodness-of-fit for the base-level model can be readily observed, specifically, the electricity being used for lights and fans -- in this case the staff turn lights on 30 to 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 store was closed when the schedule indicated it should have been open (January 2, 1989 and January 6, 1989).

Summary - General Merchandise. In summary, the general merchandise store is an average consumer of electricity. 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 temperature data, therefore further information needs to be obtained about the HVAC systems. One significant opportunity that arises from a preliminary look at the building'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 prior to the site visit, a guided site visit could have been performed with results much improved over those seen in the commercial building audits performed on the store (Haberl and Komor 1989a).

To confirm the 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, 5) blocked return air grilles, and 6) slightly above-average illumination levels. A night walk-through revealed 10 kW being used for lighting, 3 kW being used to power 24 cash registers (which must be left running to maintain their internal program), and about 15 kW being used to unnecessarily idle a 50-hp D.C. motor-generator set in the freight elevator, with the remaining 4 kW being used for telephone switchgear and receptacle loads. All of these problems were suggested by a careful preliminary look at the metered consumption data.

The Stationery Store. The stationery store contains 2,990 ft^2 of conditioned space and about 2,900 ft^2 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 ft^2 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 conditioner 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 thermostat without night setback.

The total lighting load (i.e., 1st floor fluorescents plus basement incandescents) represents 9.5 kW. Fluorescents account for 68% of the total 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 3.

The annual indices indicate that the stationery store is a low-energy business consuming only \$0.65 of electricity per ft^2, 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. Average monthly ELF of 28% 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. When a base-level model is constructed (using information from the OLF, monthly base-level electric demand [kW], and monthly base-level electricity usage [kWh]), only 2% of the store's 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 (\$0.65/ft^2). However, several of the annual indices yield some additional hints as to why. First, the 2% unoccupied electricity consumption indicates that for most of the year (72% or 6,307 hours) very little electricity is consumed. 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 slide forward in one-month increments (in a similar fashion as sliding PRISM), as shown in Figure 4b. From this 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 6b) would most likely be due to very minor differences in kW and kWh levels and are probably not as meaningful in the case of the stationery store.

The monthly data (Figure 5b) help to confirm what could have been inferred from the annual indices -- a lack of air-conditioning. The monthly data also clearly indicate 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 7b). First, the store is consistently operated. 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.

The minimum-maximum zone temperatures for the store add a new dimension to the picture (Figure 8b). First, in contrast to the temperatures for the general merchandise store (Figure 8a), 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 consistently setback) when unoccupied.

The hourly data allow us a chance to begin to confirm the indications from the annual, monthly, and daily data. Figure 9b 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 11a-d). Remarkably, for the stationery store, actual electricity consumption (Figure 11a) is as consistent a shape as our base-level model (Figure 11b), with only a few exceptions. First, in Figure 11c we see that on a few occasions loads are left on for about one hour after closing (in the case of this store all lights are switched off at one panel when the owner leaves -- this could also represent the total load for only a partial hour). Likewise, in Figure 11d actual consumption is 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 - 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 setback. 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 unit 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 conditioner 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 relamped 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 measures could be identified for the stationery store. Subsequent visits did identify several envelope-related and system-related measures (e.g., a partially shut outside air vent 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 of the building's metered consumption data.

The Furniture Store. The furniture store at the Jersey Mall contains 2,700 ft^2 of conditioned space with about 1,000 ft^2 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. (The stationery store was exposed on the roof and three sides.) Single-pane windows account for 178 ft^2 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 is 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% of this load and incandescents, used to occasionally illuminate the basement, represent the remaining 6%. Measured illumination levels varied from 70 to 110 footcandles. The store has a 66-gal. 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 ft^2 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 indicates that there is a high base-level daytime electric demand and very 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 only slightly more 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 (77%) and cooling (23%) and is also well described (i.e., R^2 = 0.967, CV(NAC) = 1.9%). Sliding PRISM CO shows us that the store has been reducing the overall electricity usage (Figure 4c), 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 5c). First, peak electric demand levels (kW) are almost three times that of the general merchandise store. Yet, the electricity usage power level (kWh) of the furniture store remains similar to the general merchandise store. Erratic electric peak power levels are present during February and March 1988 without any corresponding increase in electricity usage (possibly a winter-time use of air-conditioning?). Finally, peak electric demand levels have decreased by 15% (both cooling and non-cooling periods), which infers a decrease in base-level energy consumption.

The monthly comparison of ELF and OLF for the furniture store (Figure 6c) seems to be more of a consistent indicator of excess electrical demand than 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 only a few days. Hence, peak electric demand rises to cooling season levels without the corresponding rise in electricity consumption, which causes the ELF to decrease (similar to these parameters for 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 consistently decreases the ELF ratio. Second, no other electrical device in the store has a rated load this large. Hence, using the air-conditioning equipment for infrequent periods (as little 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 6c.

The daily power levels (Figure 7c) 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, experimenting with new lighting arrangements, and remodeling the store).

The daily minimum-maximum zone temperatures for the furniture store reveal slightly erratic temperatures (Figure 8c). The flattened minimum temperatures indicate that the store is being heated (to at least 65 F) during unoccupied periods and that night setback (to temperatures below 65 F) 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 W "noise" level during both occupied and unoccupied periods (Figure 9c). Several types of electrical equipment can be causing this noise. Some possible candidates for further investigation with sub-metering include investigating whether 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 12a-d confirm what previous indicators had been hinting. First, the use of the store on Sundays can be seen clearly in Figure 12c as well as the extended hours in the evening. Figure 12d shows us an unexpected new detail -- sometimes the store opens later than scheduled, as witnessed by the ragged 10 a.m. negative residual "ridge." Figure 12d also confirms earlier indications (from the decreasing sliding PRISM CO analysis) 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 approximate 1 kW negative residuals (directly behind the 10 a.m. ridge) during most occupied hours.

Summary - Furniture Store. 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 high lighting levels are suspected. 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 footcandles).

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 ft^2 or 180 ft^2 per ton of air-conditioning, one-half the recommended 250 to 400 ft^2 per ton (ASHRAE 1987a). The furniture store also had an economizer that was not operational. Hence, the occupants were forced to use both air conditioners when they could have been taking advantage of free cooling through the use of the system's economizer.

DISCUSSION

General

We have studied commercial building energy use using three case studies from businesses at the Jersey Mall. In this study we have confined our analysis of metered data to whole-building electricity data, temperature, humidity, and lighting measurements and data gathered from several site visits. For each of the three 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 possible 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 ft^2 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.

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 was that such a pre-screening could guide the energy auditor during the site visit -- thus improving the consistency of the energy audit. During the course of this study we made 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.

Environment-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 for analyzing energy use in 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 environment-related electricity use could be statistically determined. PRISM CO, HO, and HC 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 levels: 4) absence of heating and cooling -- flat consumption, and 5) absence of heating and cooling -- erratic consumption. Knowing this about each store, in advance, can provide improved insight into what potential energy conservation measures need further investigation during the site visit.

Comparative Electricity Use PRISM HO, CO, and HC analysis of energy use at the Jersey Mall expressed in W/ft^2 (by dividing energy use by conditioned floor area) allows for a comparison of the electricity used by the seven businesses we studied at the Jersey Mall.

Energy Use During Unoccupied Periods. We discovered that energy use during unoccupied periods seems to be detectable when one compares calculated base-level energy use to actual energy use. In the general merchandise store such energy use was significant and accounted for 19% of the electricity use. Our site visit to that store revealed that this was due to a faulty relay in the elevator time-out control which was leaving the motor generator set running unnecessarily.

Excessive Electric Demand. In the furniture store we found that excessive electric demand, determined by scaling the electric demand to conditioned floor space, can possibly indicate over sized air-conditioning equipment or too much base-level lighting, and/or too many base-level appliances. Clearly, additional research needs to be performed on electric demand data, as demand appears to be a useful measure that most energy decisionmakers 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 cooling-season electric demand by modifying or upgrading air-conditioning equipment with appropriately sized equipment (at prices considerably below the $200+ per kW the utilities currently pay for peak electricity production).

Characteristics About Economizer Operation. Quite surprisingly, in the furniture store and in the general merchandise store, equipment was inoperative that could have utilized outside air for cooling during periods when conditions were appropriate. In two of the three stores 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 signature indicated that economizers were not functioning.

Recent Changes In Operation or Equipment. In several of the small commercial businesses studied at the Jersey Mall, significant changes occurred to either the occupancy, equipment, or building envelope. A sliding analysis allowed 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. A sliding analysis 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, a 66% decrease in cooling energy usage -- a valuable insight for a building that 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 chilled water coils).

Interior Environmental Conditions. An analysis of energy use in small commercial businesses must be accompanied by some measure of interior environmental conditions. Some examples: at the general merchandise store, measurements showed that the second-floor air temperature was too hot during the summer -- an indication that more 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.

Who Can Benefit From An 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 the building energy analyst, the utility customer, the building service contractor, the utility supplier, and local, state, and federal agencies.

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.

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 work described in the ASHRAE [1987c] study and by the multifamily 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 2, with indices for each store contained in Table 3, and contains the following primary tasks.

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

Level-2: Phone Call 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 ft^2, 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 energy conservation measures we encountered at the Jersey Mall, for example, over sized equipment and excessive energy used during unoccupied periods. Level-2 can also be used to facilitate a comparative energy consumption index.

Level-3: Site Visits. 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 eight hours or longer and concentrate 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 multifamily buildings).

Level-4: Follow-up. 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, lighting levels). Reporting to a standardized data base can also occur.

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

1. 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.

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

3. Utility companies should further promote the correct sizing (or re-sizing through rebate and bounty programs) of air-conditioning systems of small commercial customers. Such candidate stores could easily be prescreened with existing utility bill information, ft^2 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 (compare this to $250 to $300 $/kW currently being spent for combustion turbine technology - EPRI 1986).

4. Computerization in small commercial stores (i.e., microprocessor-controlled cash registers, copy 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 unnecessarily requiring more electricity (i.e., 24 hour-per-day operation of the computers and additional cooling loads for the air-conditioning systems).

5. Comparative analysis should be performed on inverse hourly modeling procedures to determine which models yield suitable results (Rabl 1988; Reddy 1989). For example, singular

value decomposition, principle components 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 best for which purposes. Then the results and public domain versions of generic models should be made available -- in a similar fashion as DOE-2 or BLAST are used for design.

6. "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.

7. 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 maintaining 12 to 14 months.

8. 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. At a minimum, daily minimum-maximum temperature readings and lighting measurements should be performed in order to assess the quality of the maintained interior environment.

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Table 1 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 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 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	AUDIT #1 Estimated Payback (yr.)	AUDIT #2 Recommendations	AUDIT #2 Estimated Payback (yr.)
Heating	Boiler Maintenance	0.6	None	
	Vent Damper	3.9		
Cooling		None	None	
DHW	Insulate Pipes	2.9	None	
	Insulate DHW Tank	3.0		
Lighting	Screw-in fluor.	1.3	Screw-in fluor.	0.9
	High Eff. Fluor.	2.6	High Eff. Fluor.	2.1
	Replace ballasts	13.7	Replace ballasts	10.8
	Circular fluor.	0.3		
	Elliptical Incan.	0.8		
Distr.	Insulate pipes	6.8	None	
Process		None	None	
Envelope	Weatherstrip	9.1	None	
	Insulate walls	20.5		
	Insulate roof	22.1		
	Install thermal pane	35.3		

Table 2 Description of ELF and OLF calculations. Electric Load Factor (ELF) and Occupancy Load Factor (OLF) are calculated as follows:

$$ELF = \frac{\text{kWh(for the period)}}{\text{kW(max in period)} \times \text{hours in period}} \qquad OLF = \frac{\text{occupied hours}}{\text{total hours}}$$

Table 3 General merchandise, stationery, and furniture store information. This table contains information about the general merchandise, stationery, and furniture stores.

ITEM:	GENERAL MERCHANDISE	STATIONERY STORE	FURNITURE STORE
GENERAL:			
SIC Code:	5311	5943	5712
Size (ft^2):	60,000	2,990	2,700
Building Age (yrs):	36	36	36
Roof Type:	Bituminous roof	Bit.roof,	Bit.roof,
Wall Type:	Masonry walls	Masonry walls	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	$1.77
Ele.Use ($\$/ft^2$-yr):	$0.92	$0.39	$0.90
Ele.Demand ($\$/ft^2$-yr):	$0.42	$0.26	$0.86
Ele.Demand (% tot-$):	31.4%	40.0%	49.0%
Ann.Ele. Use (W/ft^2):	1.75	0.78	1.46
Base level Ele. (W/ft^2):	1.39	0.78	1.13
Cooling Ele. (W/ft^2):	0.35	0.0	0.33
Heating Ele. (W/ft^2):	0.0	0.0	0.0
Ann Ele.Demand (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. (% unoccupied):	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%)
NAC(CV) (kWh/yr):	886,200(1.9%)	19,000(6.4%)	43,600(1.9%)
Cool Slope(CV) (kWh/F-day):	60.5(10.2%)	-286.7(-85.3%)	7.34(22.1%)
R squared:	0.954	0.203	0.967
Cooling(%):	20.3%	--	22.7%
Base-level(%):	79.7%	100% (see note 2)	77.3%
OTHER			
Period:	8/87-9/88	8/87-9/88	8/87-9/88
Mean (kWh/mo):	72,769	1,553	3,369
Sdev (%):	15.0%	15.0%	33.2%
LIGHTING:			
Fluor (kW):	115.1	6.5	9.3
Incand (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

ITEM:	GENERAL MERCHANDISE	STATIONERY STORE	FURNITURE STORE
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/O 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.	C/O Stat. w/o S.B.
Cool Sys. Dist:	6 AHU,Plen.	1 AHU,Dir.	1 AHU,Plen.
Economizer:	Yes	Yes	Yes
# of Cool Sys:	1-chill.6-coils	1 compr.1 coils	2 compr. 2 coil
Other Equip:	75 Gal N.G.DHW 24 cash regis. 2-10hp.Escal., 1-50hp.D.C.Elev., 1-25hp.C.W. pump, 6-7hp.AHUs 1-phone switchboard. 1-aux. 5-ton A/C	2-cash regs. 1-copy machine 1-0.1Mbtu N.G.heat (in the basement)	66 gal. Ele. D.H.W. 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 that uses low-pressure steam controlled with an open-loop, outside-reset timer. Three air-handling units (AHUs) on each floor distribute cooling and heating. The AHUs turn on and off with a timeclock and are manually switched on and 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 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 which was circulated through the cooling coils and is suspected of causing the severe fouling.

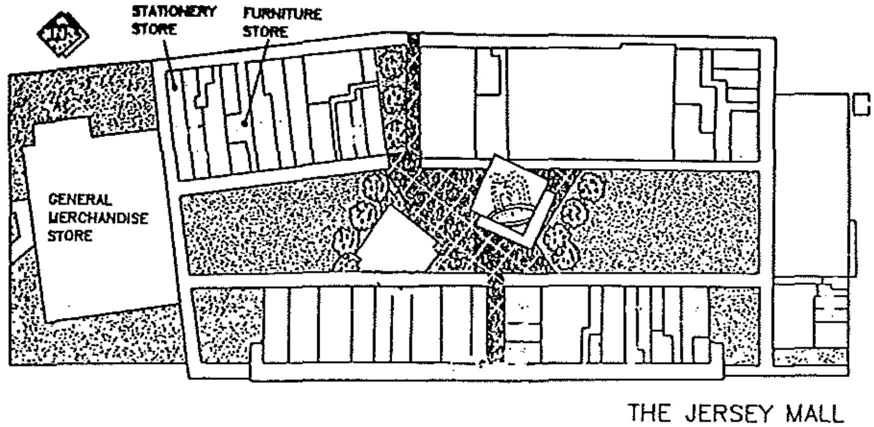

Figure 1. *Diagram of the Jersey Mall in plan view. The mall contains 220,000 sq. ft. of conditioned space and has 52 tenant businesses. Electricity, natural gas, and fuel oil are the primary fuels consumed. The location of the general merchandise, stationery, and furniture stores is as shown.*

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.

Figure 2. *Outline of proposed commercial building energy analysis. This figure contains the multi-level analysis that serves as an outline for our 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.*

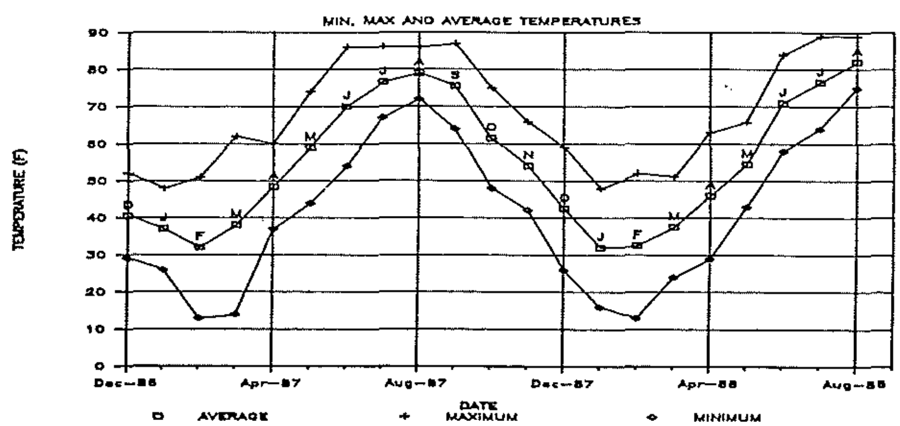

Figure 3. *Minimum, maximum and average monthly outdoor temperatures. This figure illustrates the approximate monthly weather information available from the National Weather Service. The values shown are for the Newark, NJ, station. The monthly average, minimum and maximum, daily temperature values correspond to the utility billing period for the mall (i.e., the utility meters are read about the 10th of each month).*

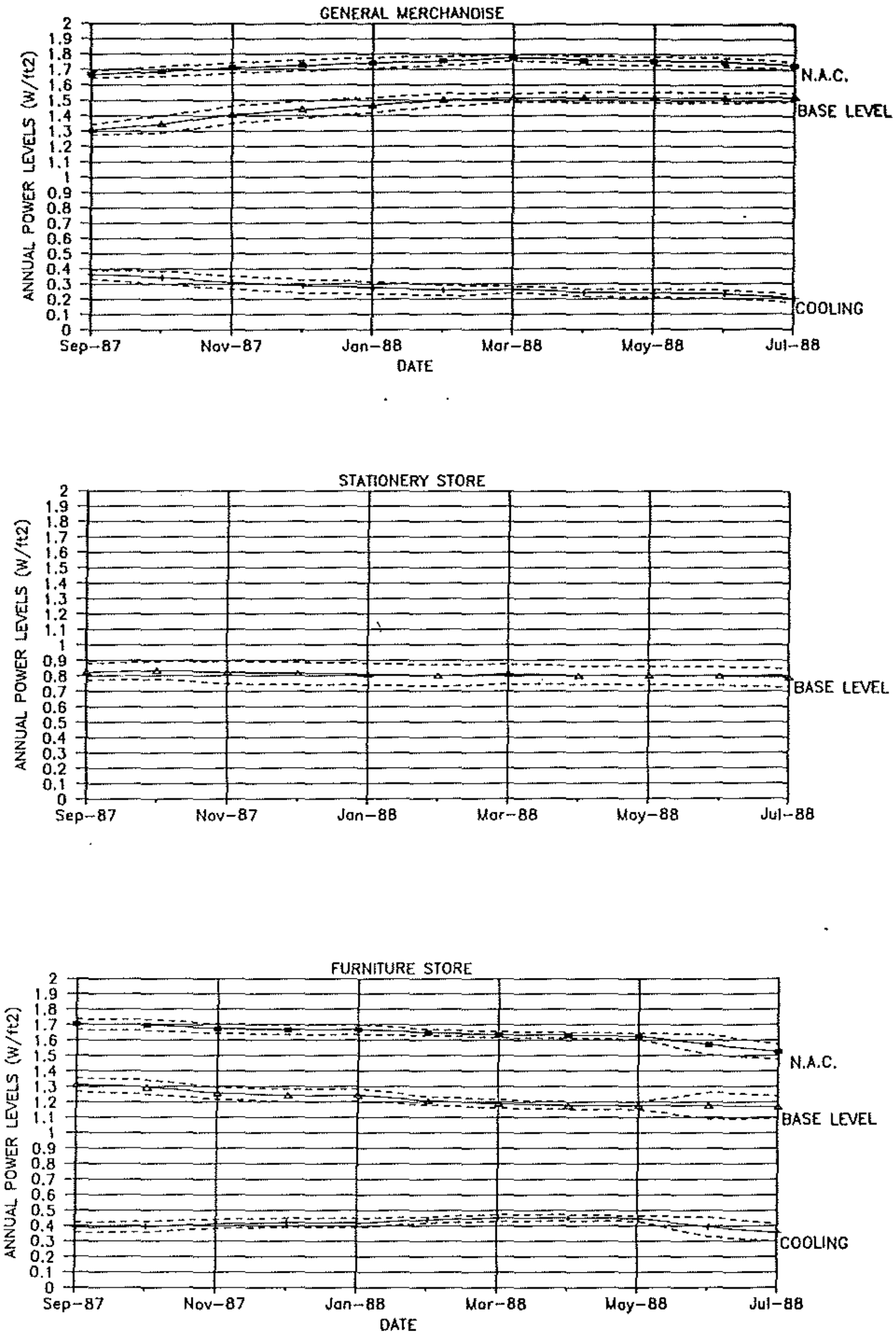

Figure 4. *Weather-normalized annual electricity usage (a,b.d). This figure shows weather-normalized annual power levels for the general merchandise and furniture stores, the NAC, base-level and cooling curves represent results of the sliding PRISM CO analysis expressed in units of W/ft^2. Sliding PRISM CO is the PRISM CO model applied in successive 12-month increments, in this case to 22 months of utility billing data. The base-level curve for the stationery store represents the average of 12 months applied in successive 12-month increments. The dashed lines are standard errors.*

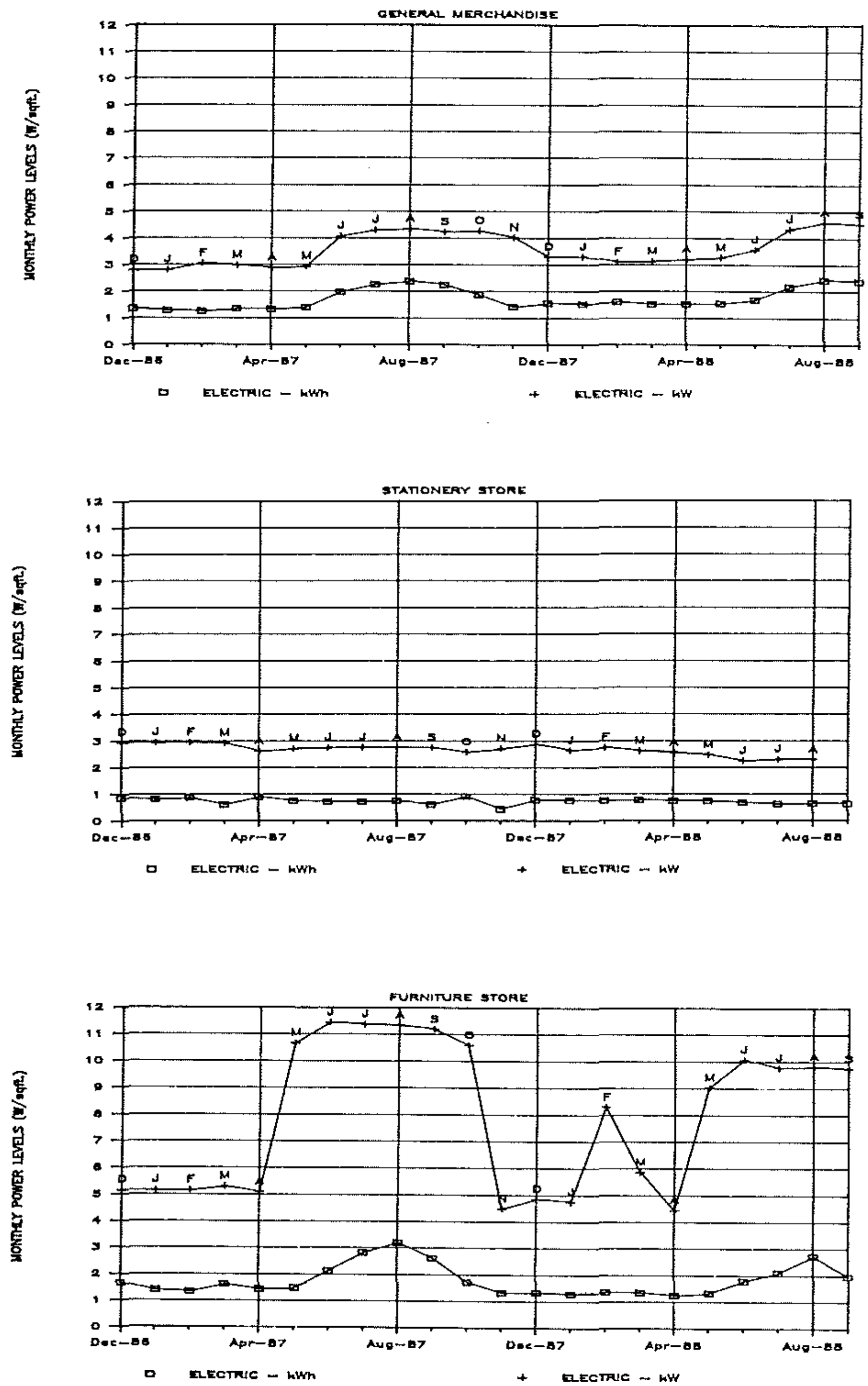

Figure 5. Monthly electricity use (a,b,c). These figures show monthly power levels for the general merchandise (a), stationery (b), and furniture (c) stores. Power levels (W/ft^2) are shown for both usage (kWh) and demand (kW).

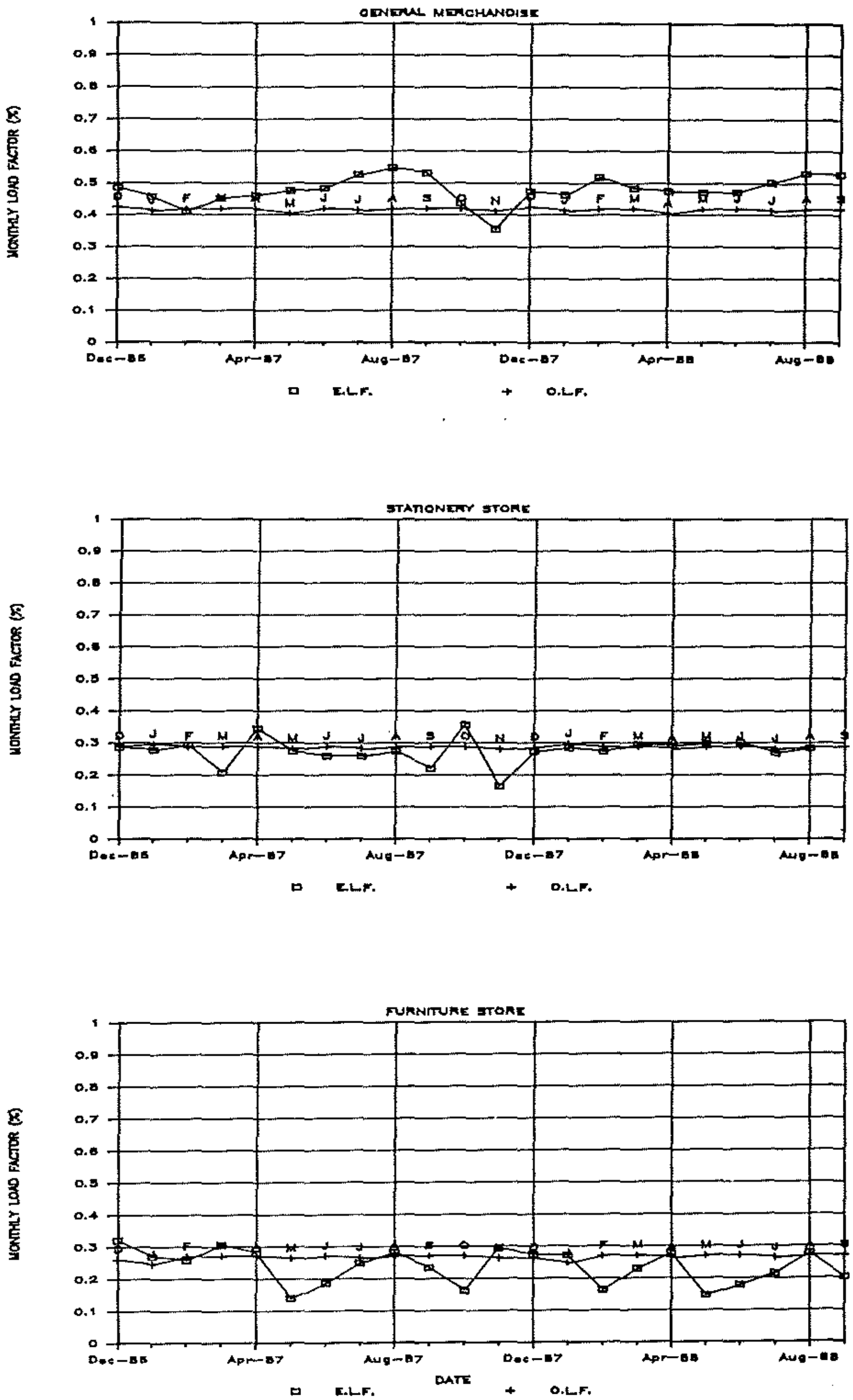

Figure 6. *Monthly electricity and occupancy load factors (a,b,c). This figure contains monthly load factors for the general merchandise (a), stationery (b), and furniture (c) stores. Monthly electric load factors (ELF) and occupancy load factors (OLF) are shown for each store.*

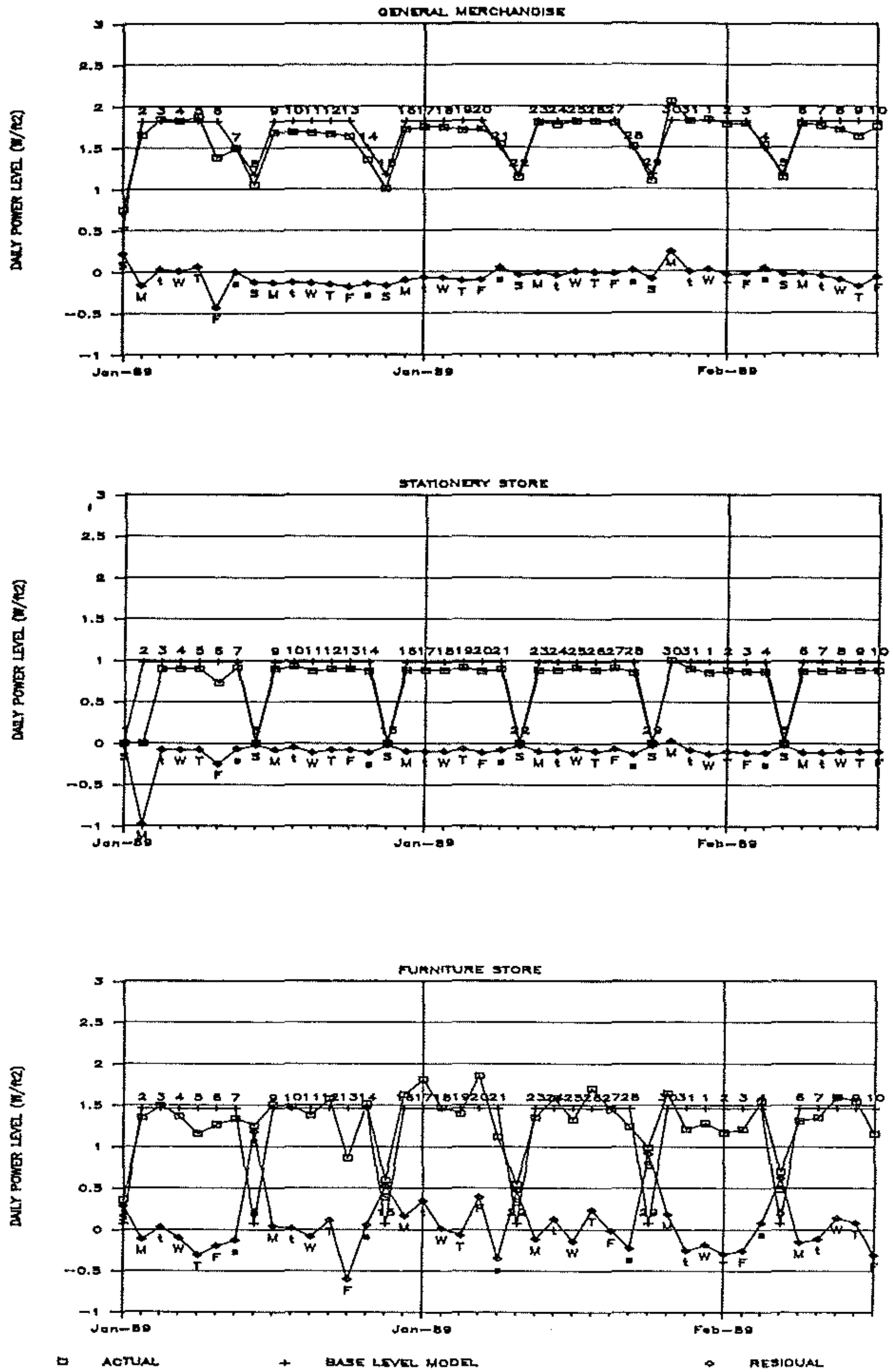

Figure 7. *Daily electricity use (a,b,c). This figure shows daily electricity usage (W/ft^2) from January 1, 1989 to February 10, 1989 for the general merchandise (1), stationery (b), and furniture (c) stores. Data for each store include actual, base-level model, and residuals.*

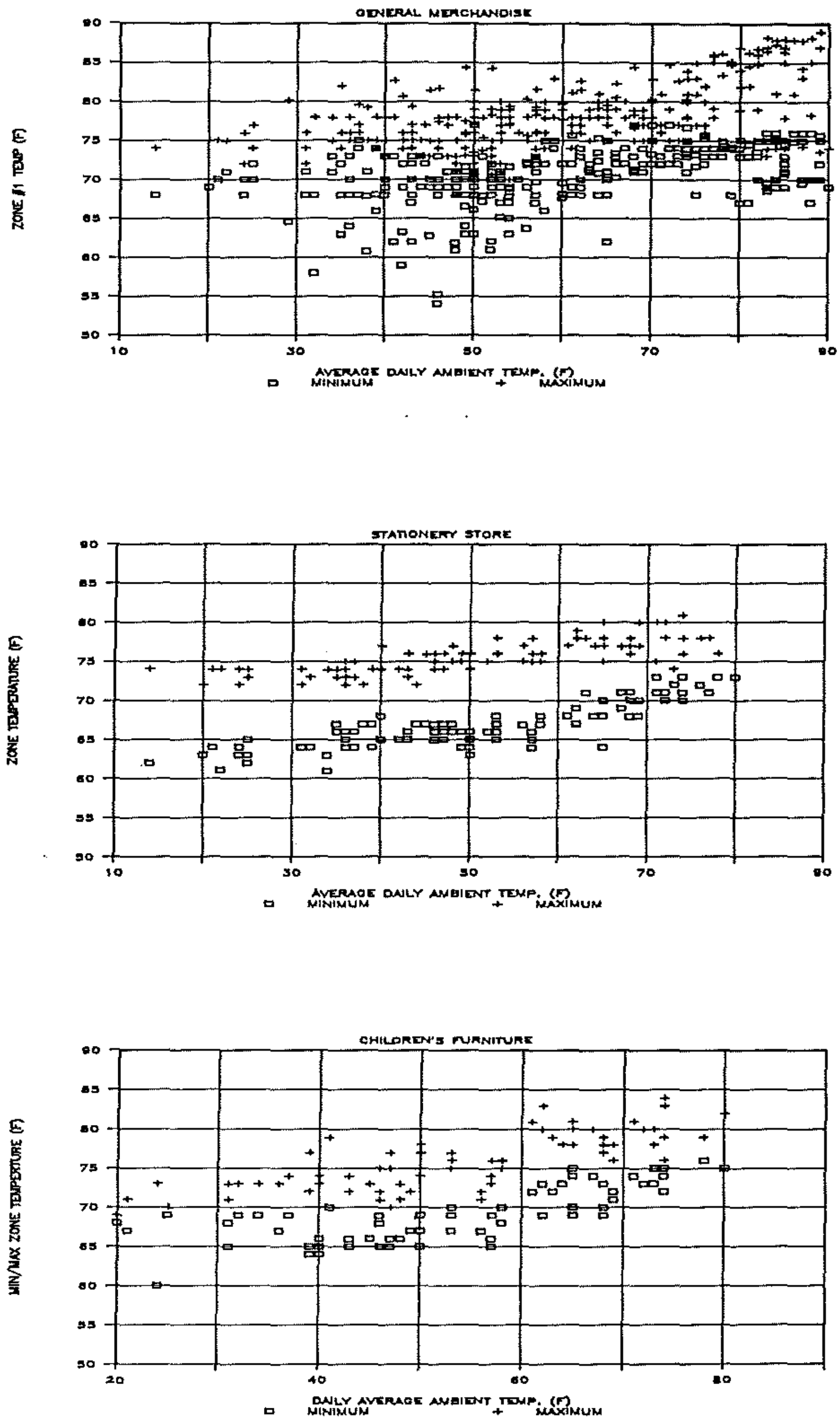

Figure 8. *Daily min/max zone temperatures (a,b,c). This figure shows minimum and maximum zone temperatures for the general merchandise during March 1988 through February 1989 (a), stationery store during September 1988 through February 1989 (b), and furniture store during September 1988 through February 1989 (c). The zone temperatures are displayed against average daily ambient temperature.*

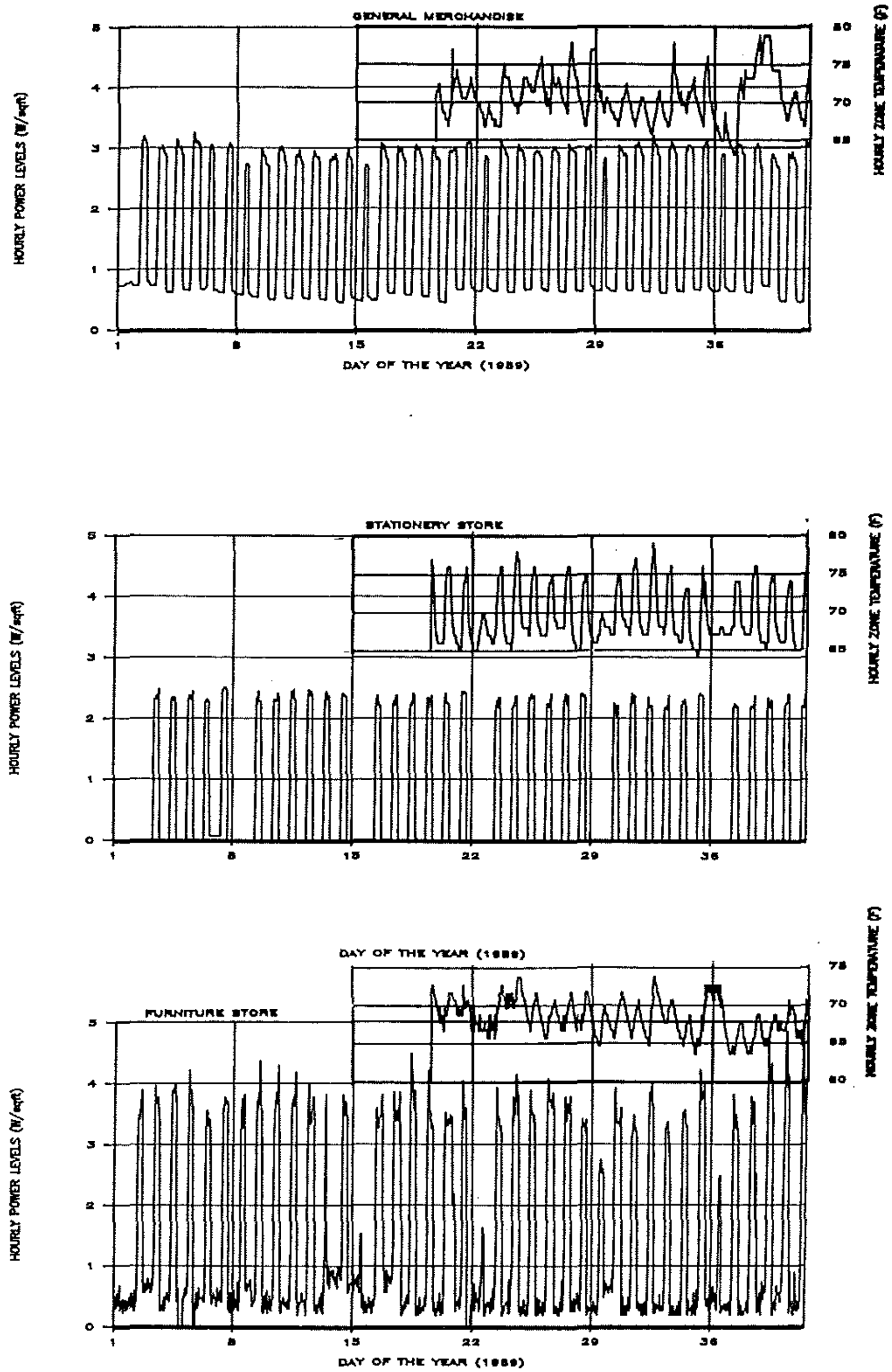

Figure 9. Hourly electricity use and zone temperatures (a,b,c). This figure shows hourly power levels (W/ft^2) and hourly zone temperatures from January 1, 1989 to February 10, 1989 for the general merchandise (1), stationery (b), and furniture (c) stores.

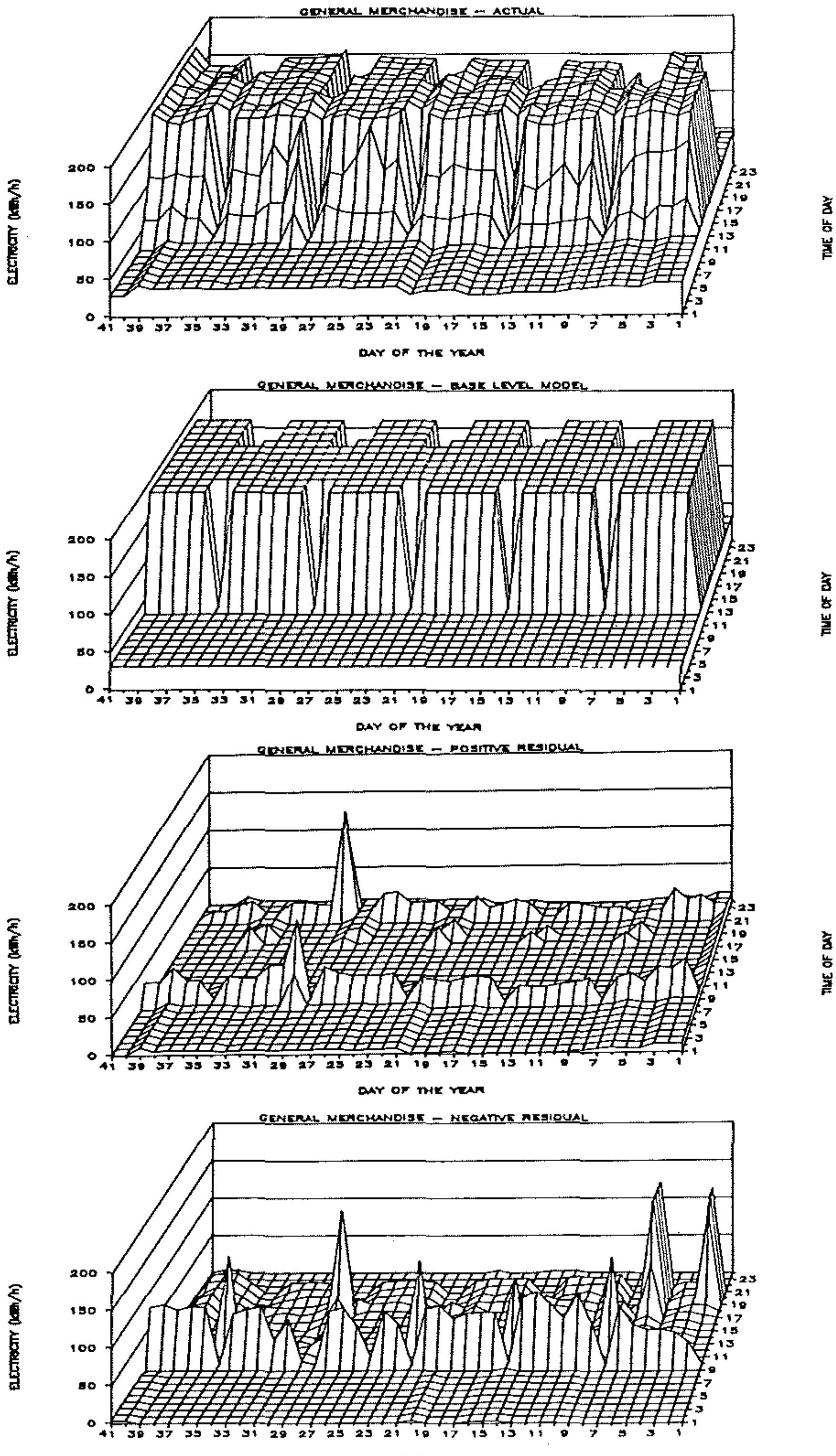

Figure 10. *Hourly electricity profiles: general merchandise (a,b,c,d). This figure shows hourly electricity usage profiles for the general merchandise store. Hourly profiles for the actual electricity use (a), base-level model (b), positive residual (c), and negative residual (d) are shown. In each plot the day-of-the-year (beginning January 1, 1989) 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.*

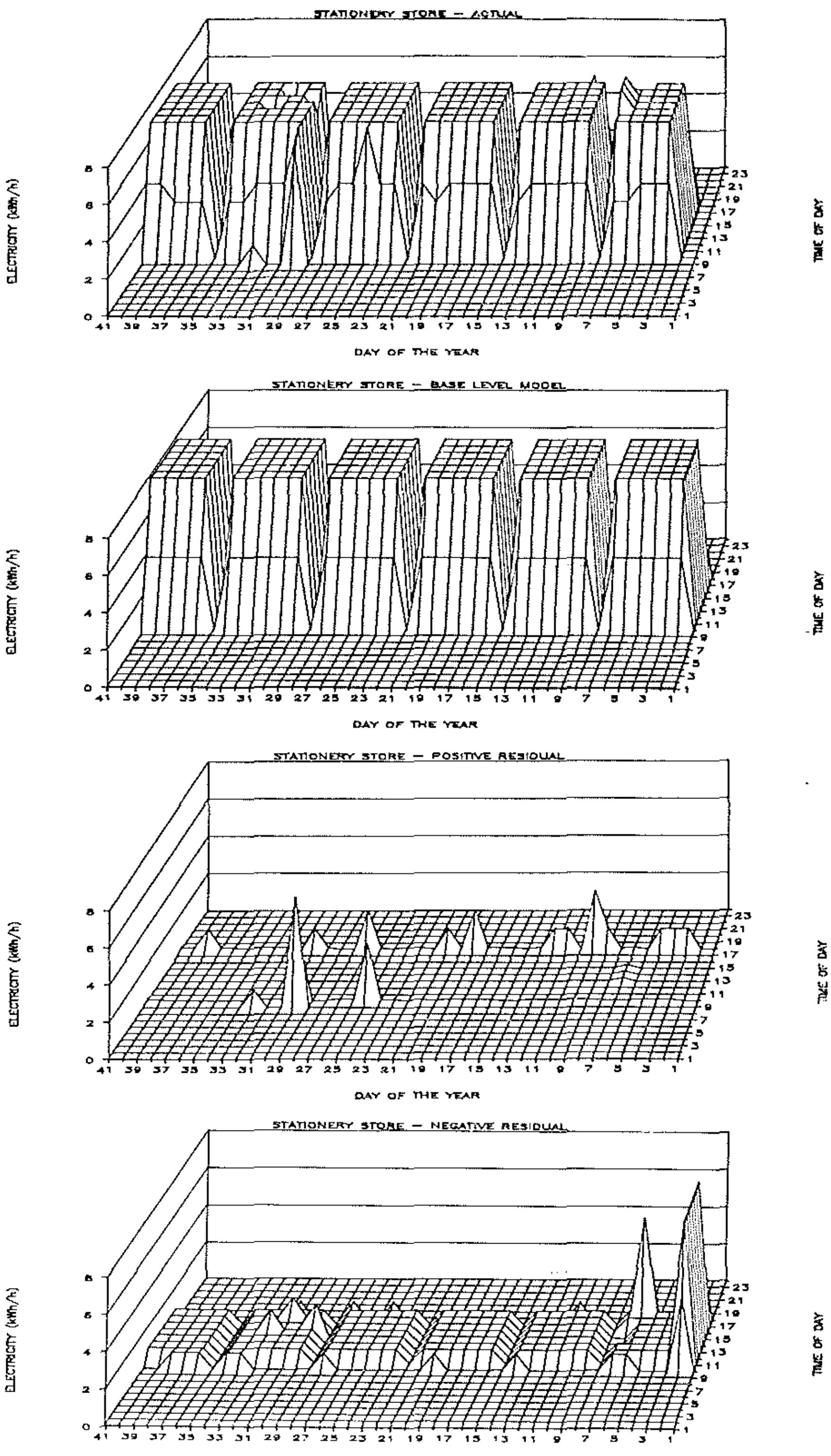

Figure 11. *Hourly electricity profiles; stationery store (a,b,c,d). This figure shows hourly electricity usage profiles for the stationery store. Hourly profiles for the actual electricity use (a), base-level model (b), positive residual (c), and negative residual (d) are shown. In each plot the day-of-the-year (beginning January 1, 1989) 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.*

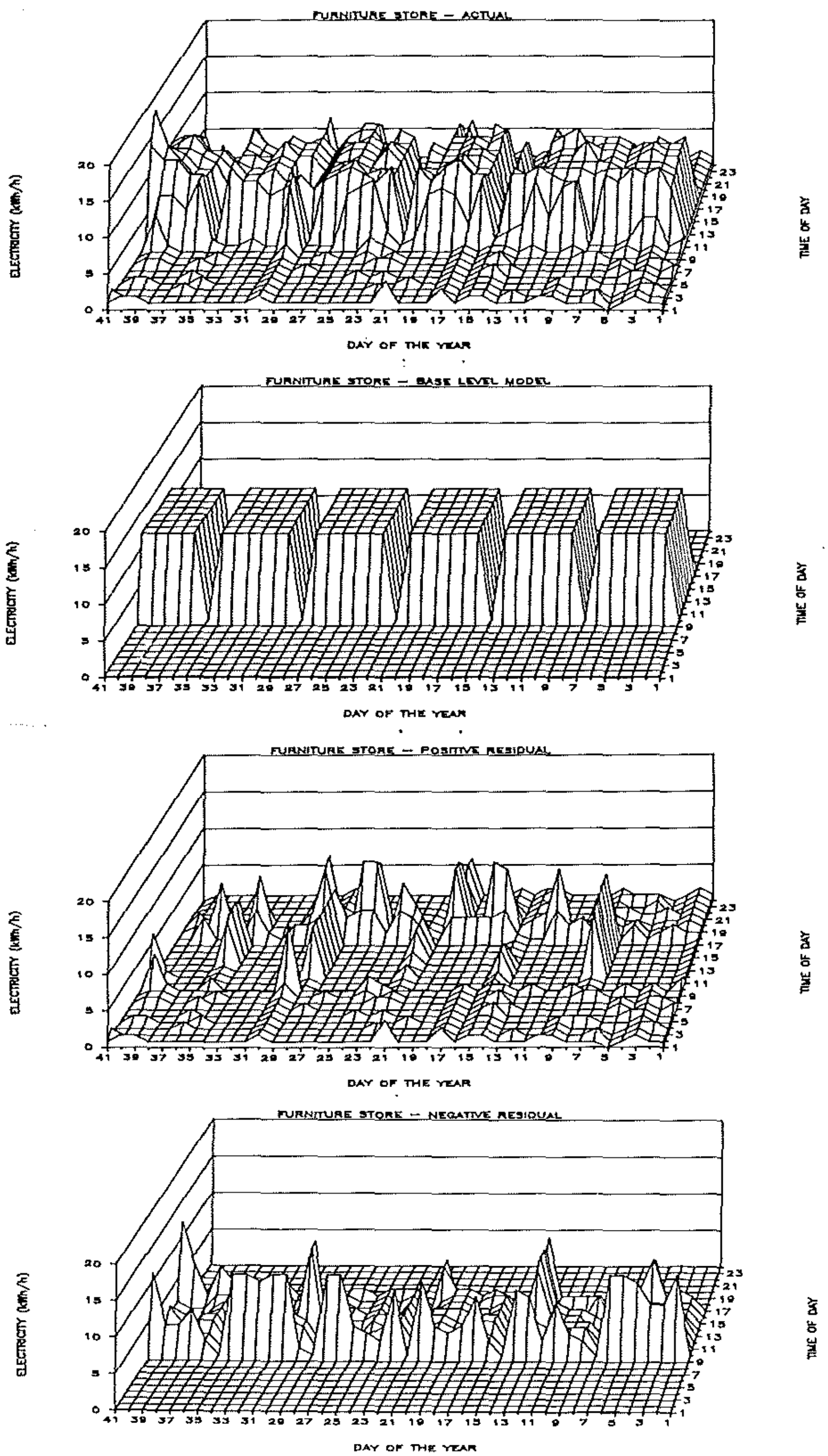

Figure 12. Hourly electricity profiles: furniture store (a,b,c,d). This figure shows hourly electricity usage profiles for the furniture store. Hourly profiles for the actual electricity use (a), base-level model (b), positive residual (c), and negative residual (d) are shown. In each plot the day-of-the-year (beginning January 1, 1989) 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.