END USE LOADS IN MULTIFAMILY BUILDINGS: SOME PRELIMINARY FINDINGS

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ABSTRACT

Seattle City Light is currently conducting a research project in which three multifamily buildings (with a total of thirty-eight individually metered, electrically heated apartment units) are being monitored at the hourly end use level. The overall purpose of the project is to understand existing electrical consumption patterns and thus to assess the conservation potential in this residential subsector.

This paper presents the preliminary analyses conducted on the size and shape of the end use loads in one building with thirteen apartment units. Winter load for the entire building was three times the average summer month's consumption, and there were no outstanding differences between weekday and weekend levels of consumption in either season. It was the daily patterns in various apartment units that most clearly reflected the behavior of occupants and the daily temperature fluctuations. Domestic hot water was found to be the largest annual single end use (41 percent of the average unit's annual load) and was the dominant factor in producing daily peaks. Space heating was the most strongly seasonal and shaped the annual peak. Appliances, lights and other outlets comprised about 23 percent of the annual usage and showed the least seasonal variation. The "housemeter", or common area usage, showed minimal seasonal variation and was equivalent to the total consumption of two average apartments.

Since space heating was the dominant winter load in the dwelling units, this end use is a logical target for utility energy conservation efforts. Shell improvements would be highly recommended. However, in terms of contribution to daily peaks, domestic water heating, the largest annual load, would be an appropriate candidate for peak shaving or peak shifting strategies.

Finally, recommendations for further exploratory multivariate analysis using structural, demographic, and weather-related factors that may explain the wide variations observed among the dwelling units are discussed.

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BACKGROUND

Until very recently, the majority of energy conservation programs in Seattle and the Northwest served only small residential structures. In 1983 Seattle City Light (SCL) initiated exploratory research in the more complex and varied multifamily sector, defined as buildings with five or more residential units. This subsector was targeted because apartment owners and renters were not served by existing conservation programs and because an earlier conservation potential assessment estimated a substantial potential in these buildings. Of futher concern is that a considerable proportion of apartment renters (about 25 percent) have low incomes and therefore are most susceptible to rising energy costs. Additionally, there were very little reliable data regarding the structural characteristics, energy usage, applicable conservation measures, or the cost-effectiveness of conservation retrofits.

By the end of 1985, significant progress had been made and important information compiled through audits, simulations, billing histories, hourly end use metering, and finally, actual retrofits. The energy consumption, costs of measures, and market information gathered through this research were the cornerstones for planning the Multifamily Conservation Program approved by the Seattle City Council in October 1985.

To put things in perspective, in the utility's service area, there are approximately 90,000 apartment units in 4,600 buildings with 5+ units. Eighty-four percent of them have electric heat (mostly individually metered), 70 percent use electricity for water heating, and the average cost for electricity for residential customers is about 3¢ per kWh.

One of the unique aspects of this extensive research effort is that of monitoring how loads vary over time at the end use level. Over a year and a half of hourly end use data has been gathered on three multifamily buildings which collectively house a total of 38 apartment units. This paper concentrates on baseline electrical consumption data for one of these buildings, covering the period from November 1984 through October 1985.

RESEARCH PURPOSE

The major goal of this research effort is to understand the value of the energy that can be saved in apartment buildings so that SCL can most effectively tap the potential conservation in this residential subsector. The information is needed at the hourly level because the utility values energy depending not only on magnitude, but also its temporal distribution. The end use disaggregation assists in targeting the potential energy savings because the nature of the patterns for various end uses is better understood.

To serve this overall purpose, four objectives have been identified:

1. To characterize the existing energy consumption by end use over time;

2. To identify cost-effective conservation strategies through simulations;

3. To retrofit the buildings with these measures and to continue monitoring the building's performance at the hourly level; and

4. To understand how structural characteristics and occupant demographics affect conservation potential.

Three individually metered electrically heated multifamily buildings, which had been audited earlier, were chosen to be subjected to continuous hourly monitoring of end use loads. They were quite typical of many buildings in the sector in terms of size, annual electric usage and basic structural characteristics. These three buildings had all been simulated using DOE 2.1A to identify cost-effective conservation measures. These recommended measures were installed in the building by early 1986. The end use monitoring is continuing in order to assess the effects of these improvements on an hourly basis.

This paper concentrates on analyses being done to fulfill Objective #1.

BUILDING DESCRIPTION

Again, the one building analyzed in detail in this paper is typical of many of the apartment buildings in SCL's service territory. It is a woodframed, brick veneer, four-story walk-up built in the late 1950's. It has a flat roof and houses thirteen apartments plus a laundry/storage room. Figure 1 shows an isometric sketch of the subject building.

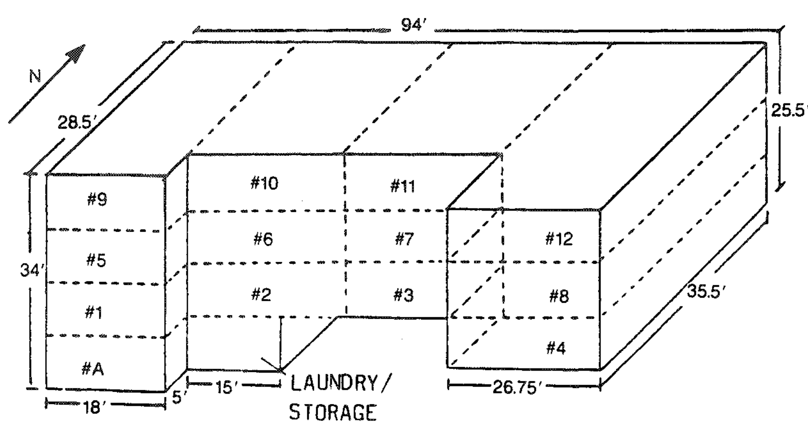

FIG. 1: MULTIFAMILY CASE STUDY BUILDING.

DATA COLLECTION

Equipment

In order to sense, process and record the hourly end use consumption, a specially developed multi-channel, microprocessor based data logging system was installed in the building's storage room. Solid core current transformers, which encircle the various wires in the main electrical service panel, pick up the electrical signals and measure the electrical current passing through the selected circuits. A signal convertor records the amperes measured by the current transformers. A voltage transformer senses the building voltage at a main location in the wiring network. Temperature sensors measure outdoor ambient temperature and indoor temperature inside each unit. A multi-conductor cable is routed to each apartment and used to connect each current transformer and temperature sensor to the proper channel of the microprocessor.

Data Checking

All the hourly data is recorded in binary format on data cassette tapes, which are collected once a month, translated into ASCII and copied onto a 9-track magnetic tape. The data is then transferred to a mainframe computer at the University of Washington, where, prior to loading into random access files, the data are run through a quality checking routine: missing hours and invalid channel values, e.g., small negative numbers, are documented and edited (i.e., replaced with -9's), and relevant calibration factors including zero offsets and conversion to appropriate units are completed. Finally, the micro recordings are compared with SCL's meter consumption values for the month.

Instrumentation Plan

Points for measuring loads were identified and the monitoring equipment wired appropriately to capture these loads disaggregated by major end use in each apartment. For the test building discussed here, hourly values of the energy consumed for space heating (electric baseboards), domestic water heating and the total in each apartment were recorded. By subtracting the space and water heating loads from the total, a record of "outlet" consumption could be obtained. This end use included major appliances, mostly stoves and refrigerators, lights and other such plug-in uses. None of the apartments had air conditioners or dishwashers. Indoor air temperature was also measured every hour because of its importance in predicting heating loads.

"House meter," or what is sometimes referred to as "common area consumption," is also disaggregated into its major end uses. This is the electricity that is billed to the building owner at the commercial rate and includes domestic water heating for the laundry, exterior and laundry room lights, the washer and the dryer. One additional channel is reserved for recording outdoor air temperature.

DATA ANALYSIS

Electrical consumption disaggregated by various end uses offers the opportunity to examine baseline loads and their interactions in considerable detail.

Data Quality Checks

Table I shows the results of some initial data validation and data quality checks.

Table I. Quantity and quality of data collected.

Month	Data Capture	Micro to Meter Comparison
Nov 84	70.5%	-4.8%
Dec 84	79.4	-1.9
Jan 85	43.7	--
Feb 85	99.8	-2.6
Mar 85	99.7	-1.2
Apr 85	99.6	-0.1
May 85	99.9	-0.1
Jun 85	99.8	1.9
Jul 85	99.7	4.8
Aug 85	99.5	5.5
Sep 85	99.4	3.3
Oct 85	94.3	0.1

The overall data capture rate for the study year was 87 percent. Whenever the equipment was working well, the sum of the individual readings was within 5.5 percent of the utility meter, which is well within the expected accuracy range of the instruments (6 to 9 percent).

Preliminary Building Level Analysis

Data analysis began with an examination of consumption patterns taking the whole building as one entity. To help put the end use analysis in perspective, this may be a good point to discuss the general nature of Seattle's climate. Basically, Seattle has mild temperatures that are moderated by its proximity to large bodies of water and the topography of the region. Five thousand heating degree days (HDD) are considered normal for this area. For utility billing purposes, winter rates apply for usage from October through March. Summer rates apply the rest of the year.

Figure 2 graphically displays the consumption pattern of the end use shares for the whole building over the study year, i.e., it is not weather adjusted.

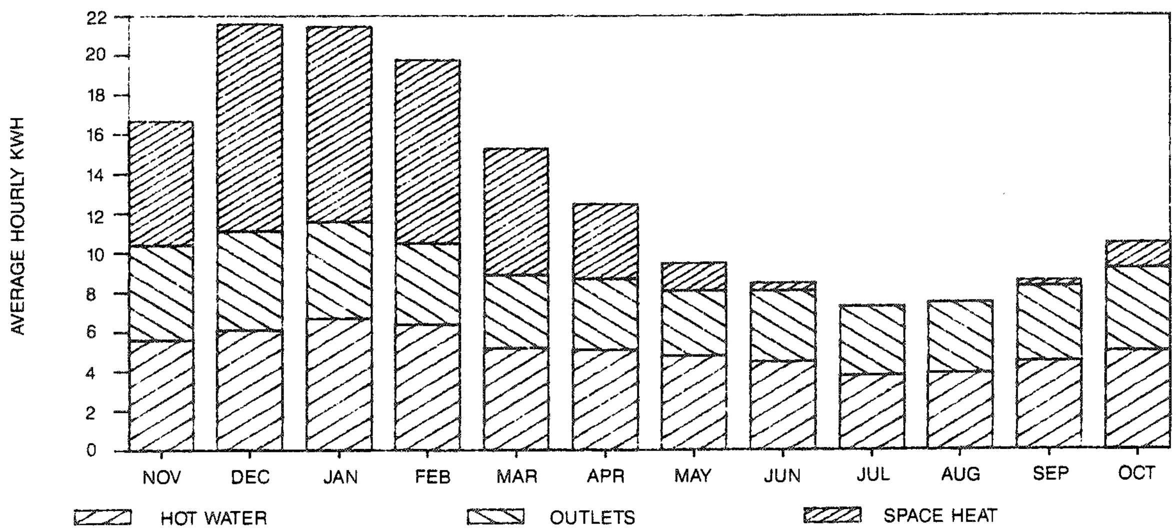

FIG 2: ANNUAL END-USE PATTERN: NOV '84 - OCT '85.
(TOTAL OF ALL METERS IN THE BUILDING)

Note that the units for the Y-axis are the average hourly kilowatt-hours used in a particular month. The building total ranged from a high of approximately 22 kWh/hr (or about 16,000 kWh/month) in December to a low in July of approximately 7 kWh/hr (or about 5,000 kWh/month). In other words, the peak winter usage was more than three times the minimum summer consumption. It is also apparent that the building's usage over the months is shaped primarily by the space heating load. Water heating ranges from 6.17 kWh/hr (4,600 kWh in January) to 3.49 kWh/hr (2,600 kWh in July), a factor of 1.75. It also turns out to be the largest proportion of the annual apartment load (40 percent), although not nearly as seasonal. Least in terms of both magnitude (20 percent of Total) and variability, is "outlets," which includes lights and appliances. Again, this graph depicts the building's total consumption, i.e., the "hot water" includes the laundry and "outlets" includes exterior lights and laundry appliances.

Next, the building's total load was disaggregated into the electricity consumed each month by all the dwelling units for various end uses and that which is on the commercial rate "house" or common area meter. Figure 3 displays the results.

Seasonal effects on the house meter consumption appear to be almost nil. This is a very steady load from month to month, accounting for about 15 percent of the total annual building load. The house meter consumption is somewhat less than the total outlet usage for all the dwelling units combined, but equivalent to greater than two apartment unit's consumption annually. Over the year, water heating shows a fairly gentle undulation, but ranges from 25 percent to 50 percent of any given month's load. Not surprisingly, the overall "Total" curve closely follows the space heating pattern.

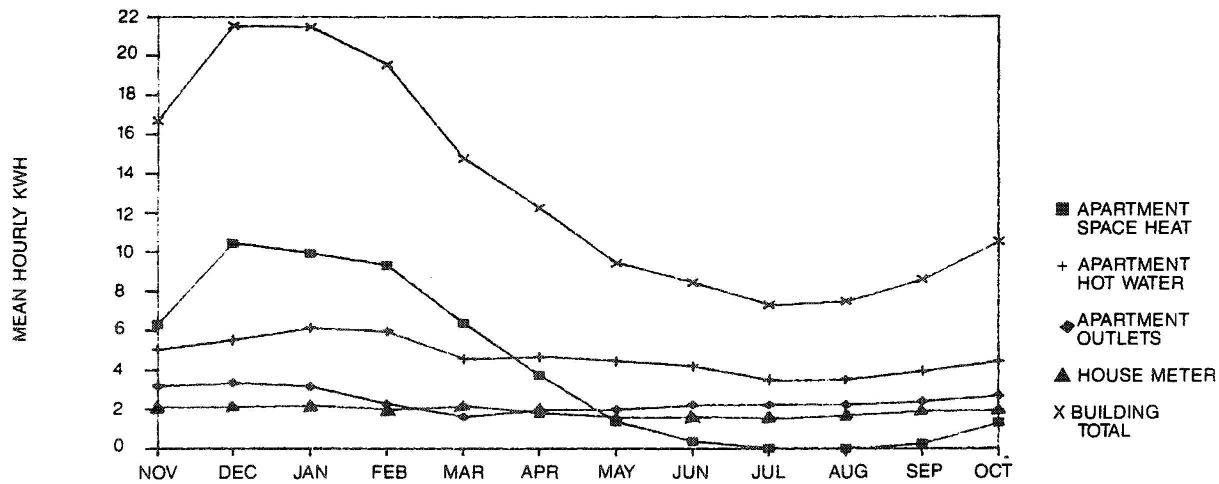

FIG 3: MONTHLY END-USE PROFILES: NOV '84 - OCT '85

The annual and seasonal breakdowns by end use for the total building loads are shown in Figure 4. This figure is basically a visual representation of the relative importance of various end uses over the seasons and throughout the year.

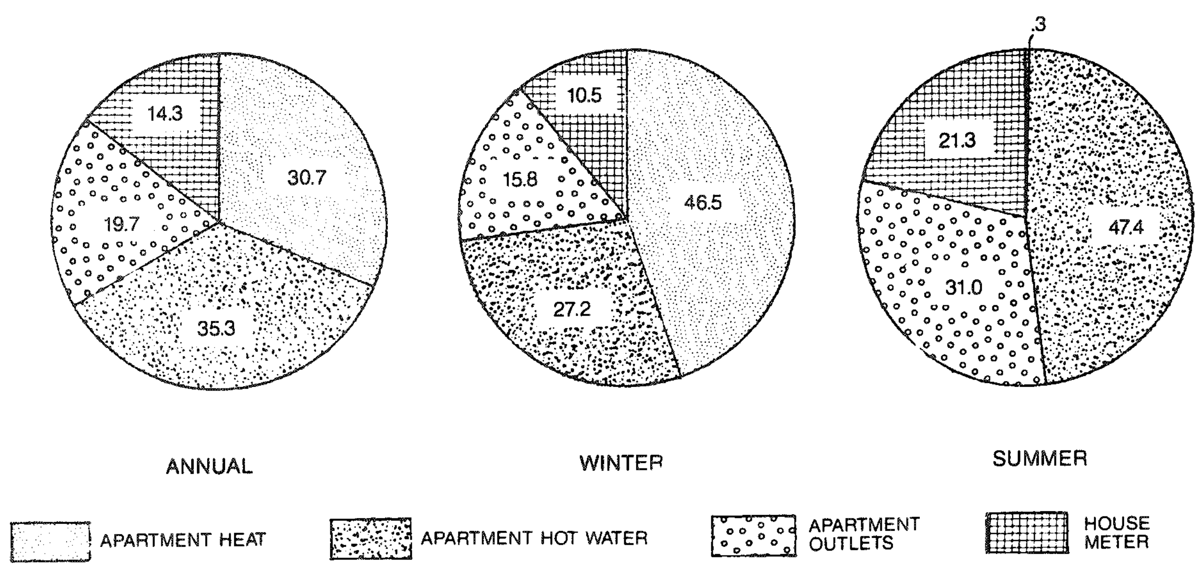

FIG 4: SEASONAL VARIATIONS IN END-USE SPLITS

Next, the building's end use patterns were examined in greater detail, disaggregating the loads into even smaller time units.

Figures 5 through 8 show the average usage for one week and for one day for each of two seasons, winter and summer. In other words, all the heating load on Mondays in November, December and January were added up and averaged over the hours that there was any heating at all. Similarly, all the "outlet" consumption for the hour ending at 9:00 a.m. in the month of July were added up and averaged. Winter was defined as November through January, and Summer included only July in order to examine the month with the lowest consumption.

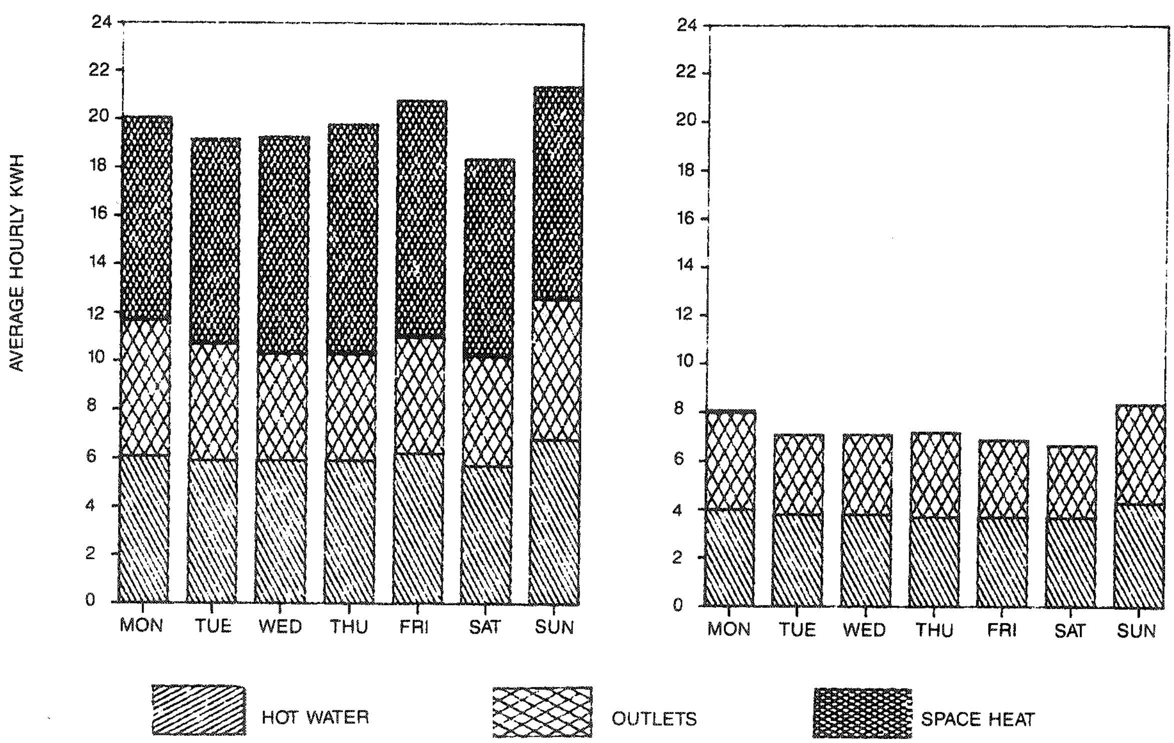

FIG 5: AVERAGE WINTER WEEK
NOV '84 - JAN '85

FIG 6: AVERAGE SUMMER WEEK
JULY '85

Figures 5 and 6 show seven average days for each end use for the three winter months and the one summer month. There is very little variation in total consumption or in various end uses between weekdays and weekends for either summer or winter. The end use with the largest variation from day to day appears to be the appliances and outlets. Water heating, on the other hand, is a strikingly steady load regardless of which day of the week it is.

Graphs of average days are helpful in analyzing the effects of work schedules and daily temperature fluctuation.

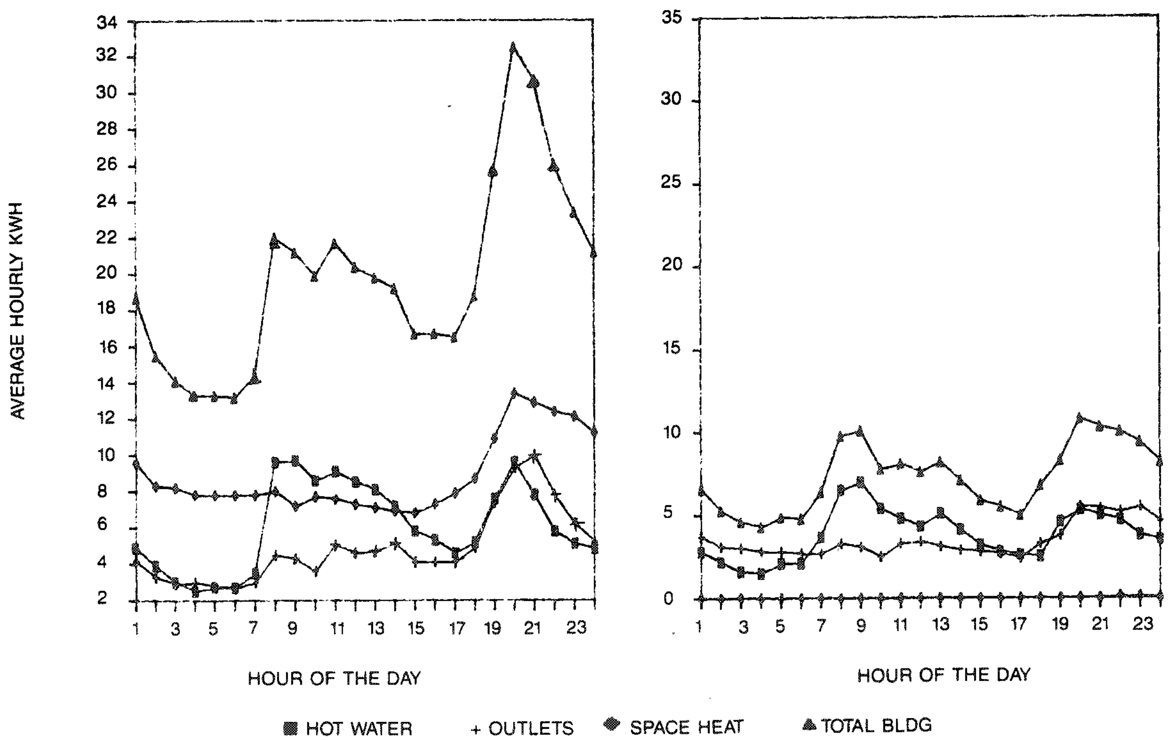

FIG 7: AVERAGE WINTER DAY

FIG 8: AVERAGE SUMMER DAY

Figure 7 shows that in the winter, heat is on all day long and accounts for about one-half the total load. There are two steep peaks in the average day (8 a.m. and 8 p.m.) caused mainly by hot water consumption. The evening peak is particularly, high, being half again as high as the morning peak. In Figure 8, the overall total in summer is less than one-half the average winter day's usage. Again, there are two main peaks at 8 a.m. and 8 p.m.

Preliminary Unit Level Analysis

Unit level end use consumption patterns were examined using exploratory analysis methods similar to those used for the building level data. Again, these results are considered preliminary because they are not adjusted in any way for weather, vacancies or tenant turnover.

Electrical consumption in all the dwelling units was first added up, i.e., the house meter was completely excluded from the building total. The units range from using 4,359 kWh/year to a high of 13,018 kWh/year for total electrical consumption. Depending on how dominant the space heating load is, the water heating share can account for up to 61 percent of the total annual usage. "Outlets" seem to vary much less from unit to unit averaging about 23 percent of the annual load.

Table II shows the breakdown of end use proportions for annual usage and for winter and summer months for the consumption in the dwelling units.

Table II. End use consumption for dwelling units only.

End Use	Annual kWh/yr.	Annual Average kWh/mo.	Winter kWh/mo.	Summer kWh/mo.
Apartments Heat	36,011	3,001	7,049	16
Apartments DHW	41,413	3,451	4,124	2,591
Apartments Outlets	23,100	1,925	2,396	1,693
Apartments Total	100,900	8,408	13,569	4,300

Water heating is clearly the largest overall load on an annual basis. Space heating tapers off to almost zero in the summer, but even in July, it does not disappear completely. Appliances, lights and other "outlet" consumption ranges from 18 percent of the total in winter to 39 percent in the summer.

Annual consumption patterns were also examined for relationship to apartment size. Table III shows this breakdown. It is interesting to note that the space heating does increase in absolute magnitude as the apartment gets bigger, but the end use when normalized for area, shows the opposite trend, i.e., the small studio apartments use 5.2 kWh/ft^2 for heating while the larger two bedroom ones use 3.4 kWh/ft^2.

Table III. Annual consumption in apartment units, grouped by size.

	Studio	1-Bedroom	2-Bedroom
Space Heating	2,686 kWh/unit (5.2 kWh/ft^2)	2,646 kWh/unit (4.6 kWh/ft^2)	3,198 kWh/unit (3.4 kWh/ft^2)
Hot Water	3,075 kWh/unit	3,150 kWh/unit	3,407 kWh/unit
Outlets	1,340 kWh/unit	1,714 kWh/unit	2,216 kWh/unit
Total	7,101 kWh/unit	7,510 kWh/unit	8,820 kWh/unit

Next, the total monthly usage in each of the thirteen dwelling units were examined. Figure 9 gives a quick overview of their monthly distribution. It is clear that energy usage in dwelling units ranges widely. In fact, the typical monthly consumption for the highest is almost four times that of the lowest user. Also, the units with low variation are the ones that have the lowest space heating usage.

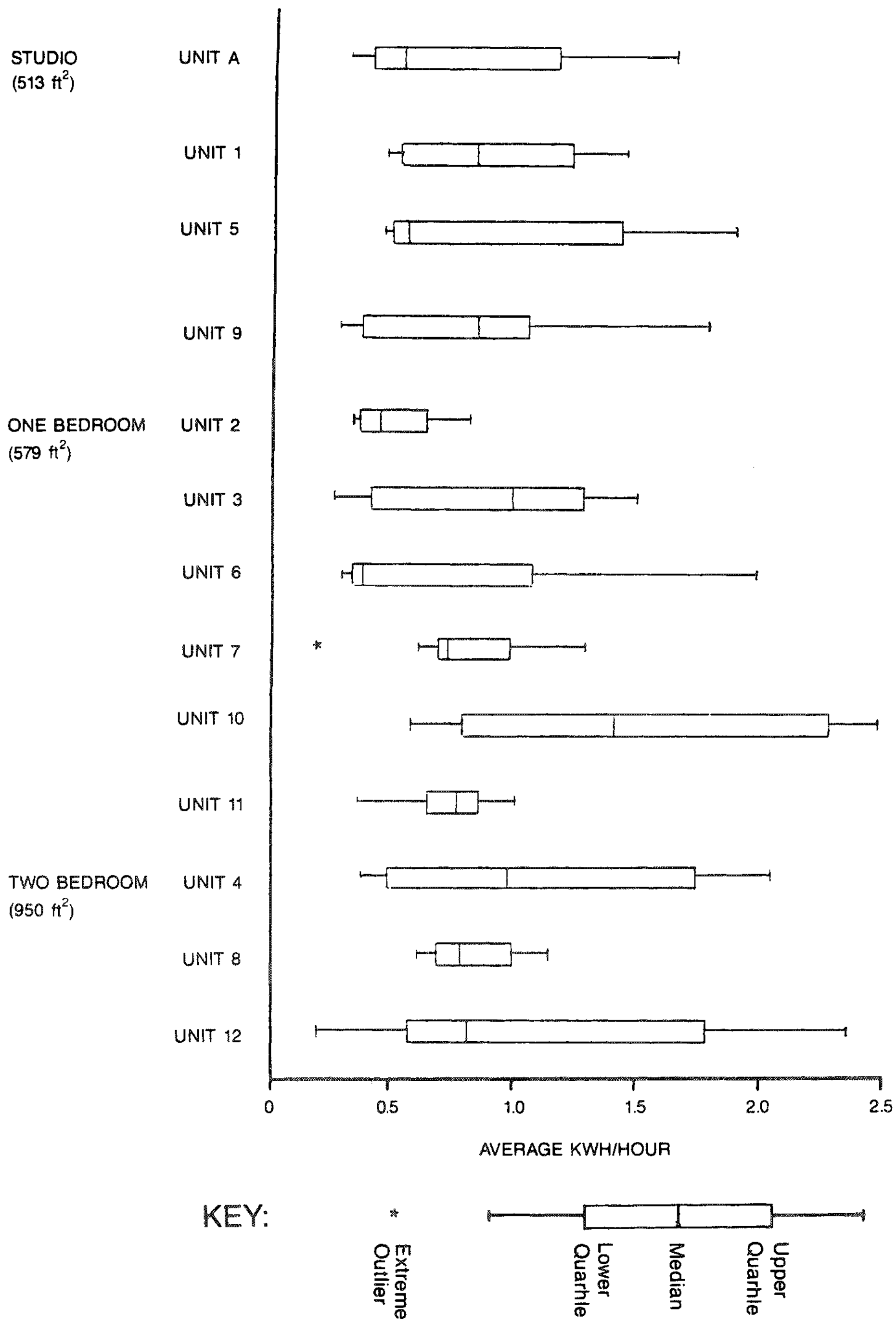

FIG. 9: DISTRIBUTION OF MONTHLY USAGE FOR THIRTEEN UNITS.

Preliminary Findings

In summary, the following observations can be made from examining the one year data set for the case study multifamily structure:

- The building consumed about 118,000 kWh/year, which translates to an average rate of about 12.3 kWh per gross square foot of area.
- The house meter, which included the laundry and some other "common" uses, and accounted for about 15 percent of the annual building load, was relatively invariant from month to month and was equivalent to about 2.3 times the average unit's consumption over the year.
- Summer consumption was about one-third the magnitude of that in an average winter month.
- There were no outstanding differences between the weekday and weekend levels of consumption in either an average winter or summer week.
- The daily patterns of end use consumption reflected the aggregate behavior of the occupants. In general, there were two sharp peaks at 8 a.m. and 8 p.m. that clearly showed up in the daily pattern with a third, smaller one at mid-day, indicating that in this building there was probably a combination of tenants who are gone during the day and some who are home most of the time.
- There was a very wide range of consumption levels between apartment units. The highest consumer used four times the electricity of the lowest user's typical monthly consumption.
- The average consumption for space heating in the dwelling units was about 2,800 kWh/unit, or 4.3 kWh/ft^2.
- The average annual end use breakdowns for the dwelling units were 41 percent, 36 percent, and 23 percent for water heating, space heating and outlets, respectively.
- Since space heating was the dominant winter load with the most variability over the year, this end use is a logical target for energy conservation efforts and shell improvements are likely to be highly recommended. However, in terms of contribution to daily peaks, hot water consumption, which was the largest annual load, seemed to be a major contributor -- making this load an appropriate candidate for peak shaving or peak shifting strategies.

NEXT STEPS: FOLLOW UP RESEARCH

Plots of the hourly usage patterns for each dwelling unit over a typical summer day and a typical winter day again showed large variation between units. In some units, heat is always on to a certain extent all day long in the winter, while in others heat is on only for a few hours in the evening. One customer's daily peak may occur at mid-day, while another's consumption exhibits two peaks at 7 a.m. and again at 7 p.m., reflecting a variety of work schedules and lifestyles.

The variability that one sees in the magnitude as well as patterns of electrical usage between various units is significant. To make sense of the information acquired through this study, the next steps, clearly, are to conduct further exploratory analysis that may explain some of the differences. While some of these variations between units are undoubtedly due to tenant behavior and customer traits, others can perhaps be traced to structural characteristics such as area of heated space, location of the unit in the building, the configuration of the windows in the unit, etc. Weather-related data, including outdoor temperature, should also be examined. Demographic variables such as the number of occupants, vacancy rates, household income and employment status are also expected to give important insights into the usage patterns. Tenant surveys and continued further statistical analysis of this wealth of information are planned for the near future. These analyses should help explain some of the reasons for the observed consumption patterns, thus improving the utility's ability to appropriately market conservation strategies in this residential sector.