

## HOURLY LOAD IMPACTS OF RESIDENTIAL WEATHERIZATION

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### ABSTRACT

The costs and benefits of conservation to electric utilities is critically dependent upon the time pattern of the savings. This paper describes the analysis of actual hourly load savings from the installation of selected conservation measures including heat pumps, insulation, and storm windows. The study entailed the analysis of hourly load data for 119 homes. The data was collected over a three year period; two years prior to retrofit and one year after retrofit.

The objectives of this paper are to: (1) describe the methodology that was developed to estimate hourly load changes; (2) summarize the results; and (3) review the issues and problems in analyzing and summarizing the results of hourly load changes.

The data set consists of hourly load data before and after weatherization, as well as data for a control group of homes. The methodology used to analyze the data is conceptually, quite simple. First, the data were weather normalized to control for the year to year changes in weather. Second, load curves were developed for the experimental groups (i.e. subsets of the group of the households that were weatherized) and the control groups. The hourly savings were computed from the differences in the load curves for the experimental and control groups.

The major methodological issues include: (1) the weather normalization procedures; (2) identifying subgroups with similar consumption patterns; and (3) developing methods that allow one to evaluate and interpret the results. Weather normalization equations were developed for each household. Extensive diagnostics were evaluated to assess the effect of the weather normalization procedure on the estimates of the hourly load savings. Cluster analysis was used to identify customer segments. The customer segments exhibited distinct differences in load patterns and patterns of savings. Several types of plots were developed to facilitate evaluation and interpretation of the results. The results are summarized in graphs that show load shapes before and after weatherization, the hourly savings and the confidence interval for these savings estimates.

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### INTRODUCTION

The actual benefits of conservation are critically dependant upon the time pattern of the savings. While there has been a lot of speculation and engineering estimates of the time pattern of savings, there have not been estimates developed from measured data. Since the Bonneville Power Administration (BPA) has a substantial commitment to promoting conservation, BPA decided that they require high quality data on the hourly load patterns. Thus, BPA has undertaken major efforts to collect and analyze hourly load data.

Hourly load data were collected for a sample of 119 homes for a three year period (1981 through 1984): two years before weatherization, and one year after weatherization. A portion of the homes (44) were not weatherized so that they could be used as a control group. The weatherization measures included storm windows, weatherstripping, insulation and heat pumps. To our knowledge, this is the first time that hourly load data has been analyzed in order to estimate hourly load impacts of energy savings.

The objectives of the analysis included: (1) evaluation of weather normalization methods; (2) evaluation of the load impacts of weatherization and heat pumps in terms of energy savings, peak capacity savings and changes in load shapes; and (3) evaluation of alternative methods of presenting the results.

This paper first describes the approach that was used. Next, the development of the weather normalization procedure is described. This is followed by a discussion of the development and analysis of savings by customer segment. We found that various subgroups of the population exhibited widely differing patterns of energy consumption and changes in consumption. The final section provides some selected results and the conclusions from the overall study.

This paper summarizes only portions of the work that has been conducted. Analysis of this data set is continuing. More detailed study documentation are reported in (SRC, 1985a) and (SRC, 1985b).

### APPROACH

The analytic approach consists of two major steps. First, the data were weather normalized to control for the effects of the year to year variations in weather. Second, typical day load curves were developed for various subgroups of the sample for the pre-weatherization period and the post-weatherization period. The differences between these load curves are the estimated load impacts of weatherization.

The sample consisted of 119 homes with electric space and water heat that were classified into four groups:

- **Control Sites** - residences which were randomly selected to serve as a control group for the duration of the study, and whose level of weatherization did not change as a result of the study. Number of sites: 15.
- **Weatherized Sites** - residences that were weatherized as part of the study. Weatherization measures included installation of ceiling, wall, floor or duct insulation, storm doors, and insulated windows. Number of sites: 68.
- **Heat Pump Sites** - residences where heat pumps were installed as part of the study. The heat pumps replaced the existing electric resistance heating system. Number of sites: 7.
- **Low Savings Sites** - residences which were originally targeted for weatherization but which were identified during the audit as having low potential for additional weatherization. Number of sites: 29.

The 119 sites were spread throughout the states of Oregon and Washington. Hourly load data were collected for a period of three years. An average of two years of data were collected before the homes were weatherized, or heat pumps were installed and data were collected for one year after weatherization. In addition, hourly load consumption data for space heating and water heating were collected for 19 of the houses.

There are several limitations of both the data set and this study. The 119 homes were not randomly selected. The sample is biased towards large electricity users. No on-site weather data was collected. In many instances, the closest weather station was a long distance from the house. Analysis of this data is continuing and the analytical methodology is being refined.

#### WEATHER NORMALIZATION

The sample of homes was geographically dispersed and the hourly data spanned three years. Thus, in order to compare consumption across households or across years, it is necessary to control for the weather variations.

The issues in weather normalization include: (1) can appropriate models be estimated on whole house loads or must one first estimate a separate space heat load; (2) can the same model be used for all households; (3) can one use the same model for both pre- and post-retrofit; (4) what is the appropriate form of the model? Our findings relative to each of these issues are summarized below. Detailed descriptions and diagnostic statistics for the various models that were tested are documented in other reports (SRC, 1985a; SRC, 1985b).

A number of alternative econometric and time series models were tested. The relative performance of alternative models was evaluated using the following criteria:

- **Goodness of fit (R<sup>2</sup>)** - the ratio of variance of the predicted dependent variable to the variance of the actual dependent variable values.
- **Weather Proportionate Error Variance (WPEV)** - the ratio of the square of the predicted errors to the square of the adjustments.
- **Reasonableness and Significance of Parameters** - the signs of estimated coefficients should be corrected, the coefficients should be significant, and the coefficients should be reasonably stable. That is, small changes in the data set shouldn't cause large changes in signs.
- **Correlation between Prediction Error and Adjustment** - if the correlation was significantly different from zero, then there is evidence that an important factor was omitted from the model.

Eight different regression models were tested for use for weather adjustment. Each of these models were estimated separately for each of the households for the pre-weatherization and the post-weatherization period. Specifications using the current hour temperature, a three hour moving average temperature, and a six hour moving average temperature were tested.

Figure 1 provides a box plot of the R<sup>2</sup> for each of the eight specifications. The eight specifications include the following:

- **NDV-1** - kWh is a function of only the difference between the current hour's temperature and 60 degrees F.
- **DVM** - monthly dummy variables on the intercept are added to the NDV specification.
- **DVD** - day of the week dummy variables are added to the DVM specifications.

The 1, 3 and 6 in the model designations refer to current hour, the three hour moving average, and the 6 hour moving average temperature difference specifications. The conclusions from examining Figure 1 include:

- **Inclusion of monthly dummies significantly improves the performance, but day of the week dummies do not improve performance**

- Use of three hour and six hour moving average temperature difference does not improve model performance.

We also found that there were only small differences in the weather adjustment coefficient across specifications, as shown in Figure 2. A nonlinear model was also estimated, because we observed nonlinear relationships for some of the houses for some households.

We tested estimating the adjustment models on the sample of 19 homes with end-use metered data using just the space heating loads and using the total household loads. The coefficients for the weather adjustments were not significantly different. Thus, we could estimate the weather adjustment model using total household data.

We found significantly different coefficients for different households. This results from the numerous factors that were omitted from the simple weather adjustment models including household occupancy patterns, ownership of other appliances, the characteristics of the house, and micro-climate effects. Thus, a separate model was estimated for each house. Similarly, we observed significantly different coefficients for the same house for the pre- and post-weatherization periods.

Four final weather adjustments were selected and estimated for each hour for each house. The first was a no weather adjustment model. The second, was a model with monthly dummies on the intercept terms. Third, was a model with monthly dummies for both the intercept and slope terms. Fourth, was a piece-wise linear approximation to a non-linear model. The model providing the best results using the criteria listed above was selected for weather adjusting the consumption for each house. Table 1 provides tabulations showing the number of households for which type of model was selected.

#### CUSTOMER SEGMENTS

The households in the sample were quite heterogeneous and consequently, there was a considerable range of estimates for individual household annual savings.

The consumption patterns for several different subgroups of the weatherized homes were examined. In particular, three different subgroups or segments of the weatherized homes were studied. First, the participants were grouped on the bases of similarity of demographic and dwelling characteristics. Four distinct groups were identified based on house size, appliance holdings, thermal integrity, size of household, age of household head and income using cluster analysis. The four groups that were identified are:

- **CHAR1** - Small, older homes with generally elderly and low income occupants, few appliances, baseboard heat and high daytime occupancy.

Figure 1

Comparison of RBAR=2 for Different Specifications

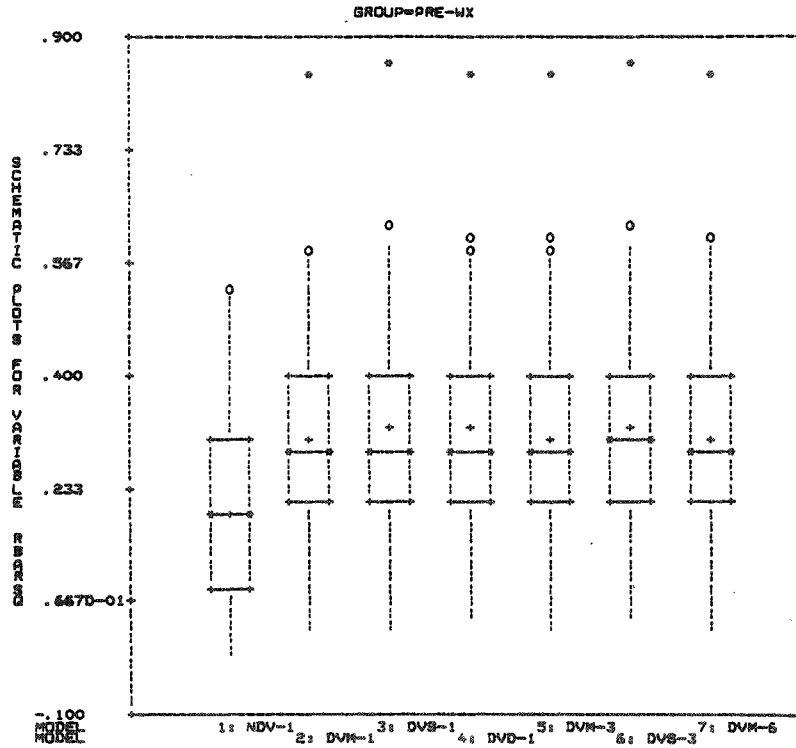


Figure 2

Comparison of Slope Coefficients for Different Specifications

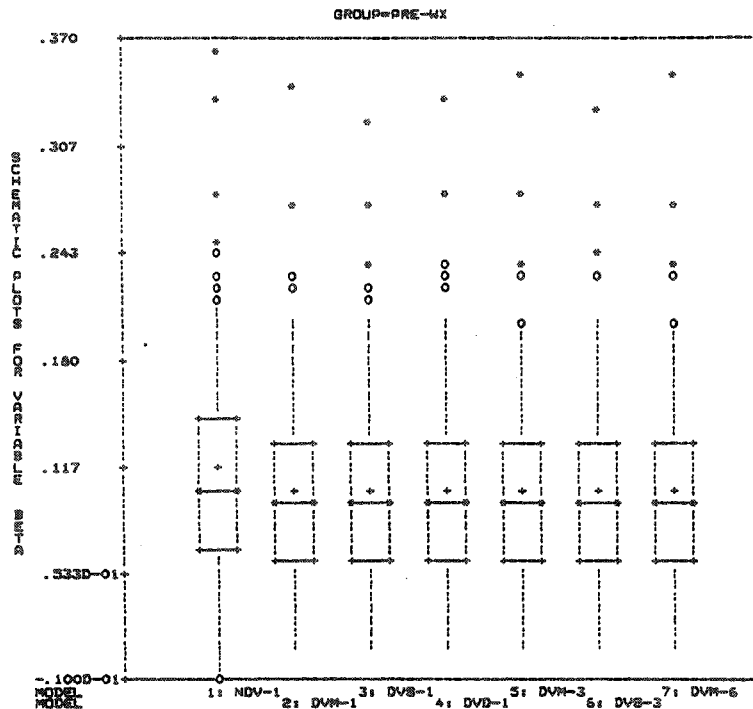


Table 1

CHOICE OF ADJUSTMENT MODEL

## 1. PRE vs. POST Weatherization Period.

<u>ADJ. MODEL (PRE)</u>	<u>ADJUSTMENT MODEL (POST)</u>				<u>Total</u>
	<u>None</u>	<u>DVM</u>	<u>DVS</u>	<u>NLM</u>	
No adjustment Model	16 (13.1%)	3 ( 2.5%)	2 ( 1.6%)		21 (17.2%)
DVM - Monthly Intercept	1 ( .8%)	4 ( 3.3%)	2 ( 1.6%)	1 ( .8%)	8 ( 6.6%)
DVS - Monthly Slope	3 ( 2.5%)	1 ( .8%)	59 (48.4%)	9 ( 7.4%)	72 (59.0%)
NLM - Non Linear Model	1 ( .8%)	4 ( 3.3%)	8 ( 6.6%)	8 ( 6.6%)	21 (17.2%)
Total	21 (17.2%)	12 ( 9.8%)	71 (58.2%)	18 (14.8%)	122 (100.0%)

N of Cases = 122 Sites.

## 2. By Primary Electric Space Heat Type

<u>ADJUSTMENT MODEL</u>	<u>PRIMARY ELECTRIC SPACE HEAT TYPE</u>				<u>Total</u>
	<u>Base- Board</u>	<u>Forced Air</u>	<u>Heat Pump</u>	<u>Unknown</u>	
No adjustment Model	10 (11.2%)	16 (21.9%)	4 (13.8%)	2 (25.0%)	32 (16.1%)
DVM - Monthly Intercept	10 (11.2%)	3 ( 4.1%)	4 (13.8%)	1 (12.5%)	18 ( 9.0%)
DVS - Monthly Slope	47 (52.8%)	41 (56.2%)	15 (65.5%)	9 (62.5%)	112 (56.3%)
NLM - Non Linear Model	22 (24.7%)	13 (17.8%)	2 ( 6.9%)		37 (18.6%)
Total	89 (44.7%)	73 (36.7%)	29 (14.6%)	8 ( 4.0%)	199 (100.0%)

N of Cases = 199 Regression Model Choices.

- **CHAR2** - Small homes with generally younger, low income occupants with one or two children. These homes used predominantly baseboard heat.
- **CHAR3** - Average size houses with middle income occupants who generally are not home during the day. The homes generally have forced air furnaces and a relatively large amount of wood heat is used.
- **CHAR4** - Large homes with high income occupants and large families. These homes have the most appliances, use electric furnaces and are largely comprised of relatively new homes.

There are significant differences in the energy consumption patterns among these clusters of households. Figure 3 shows the load shape for each of these four groups and for the average of the four groups. This figure shows that there are differences in the pattern of energy use as well as the amount of energy that is used. For example, the shape for the first two clusters is considerably flatter than for the last two clusters.

Figure 4 compares the percentage change in annual and January energy consumption, and in the group peak demand for the four clusters. The pattern of savings for the third cluster is clearly different from that of the other three clusters. The high income cluster (CHAR4) had the smallest percentage decrease, although their baseline energy consumption was the highest.

The houses were also disaggregated into five clusters based on the types of weatherization measures that were installed. There were smaller differences in savings between these weatherization clusters than were observed for the characteristics clusters. The cluster of homes in which storm windows were the primary measure installed had much smaller savings than any of the other clusters.

Finally, the pattern of savings by type of heating system was examined. The houses with baseboard heat showed the smallest savings (from the lowest usage levels) while the largest percentage savings occurred in the houses with forced air heat; although the largest absolute savings were in the heat pump houses.

## CONCLUSIONS & RESULTS

The principal conclusions from this project are the estimated changes in hourly load patterns for weatherization and installation of heat pumps as illustrated in Figures 5 through 8. In developing these estimates, a number of other conclusions were developed.

Some of these conclusions are based on analyses that we were not able to summarize within this paper. The interested reader should refer to the project reports (SRC 1985a, SRC 1985b).

Figure 3

### Pre-Period Load Shapes Comparison by Household Characteristics Cluster

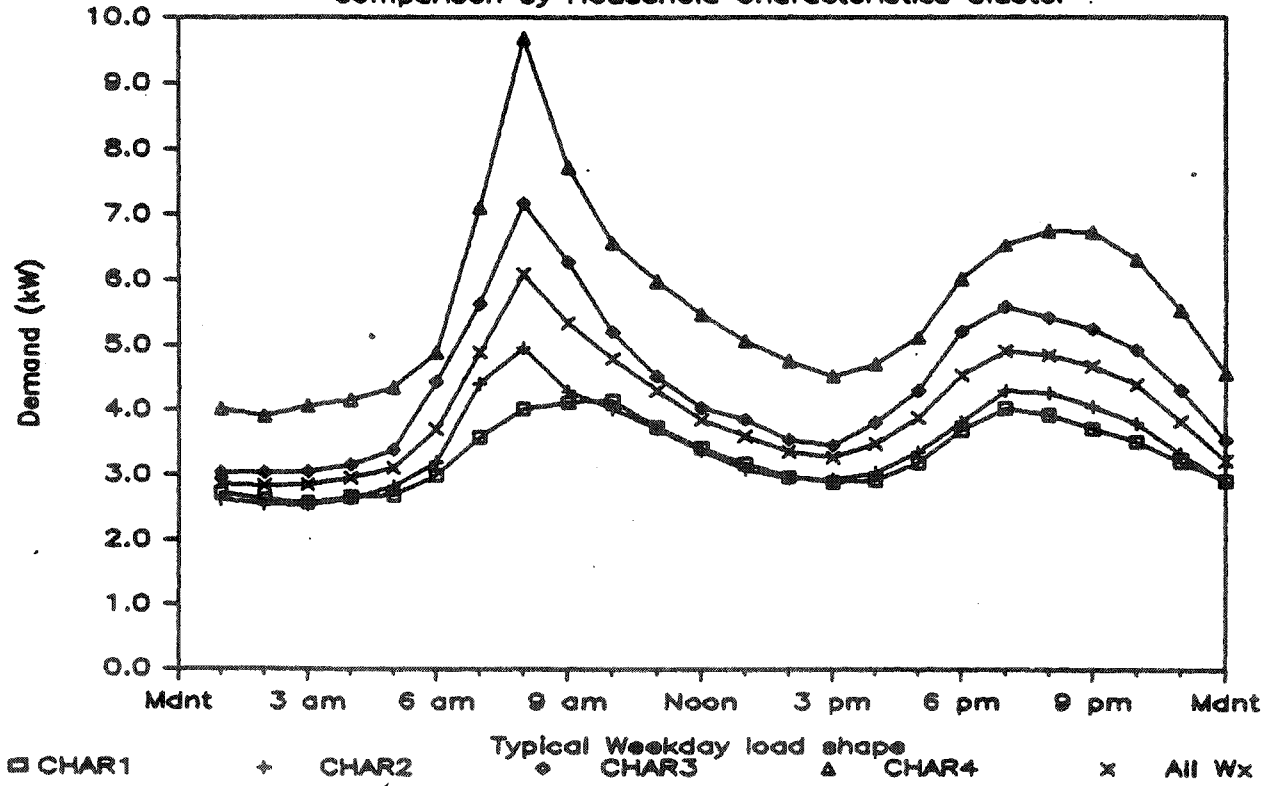


Figure 4

### Changes In Consumption Comparison by Characteristics Cluster

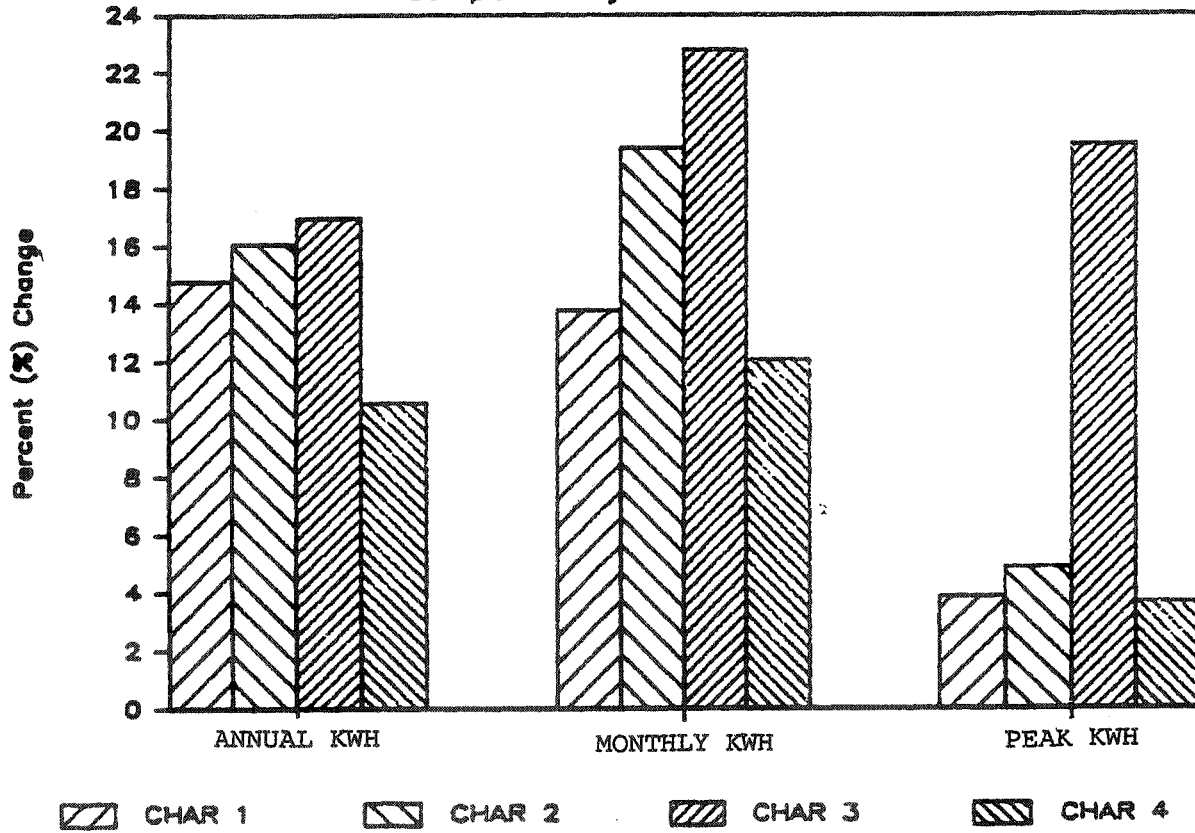


Figure 5

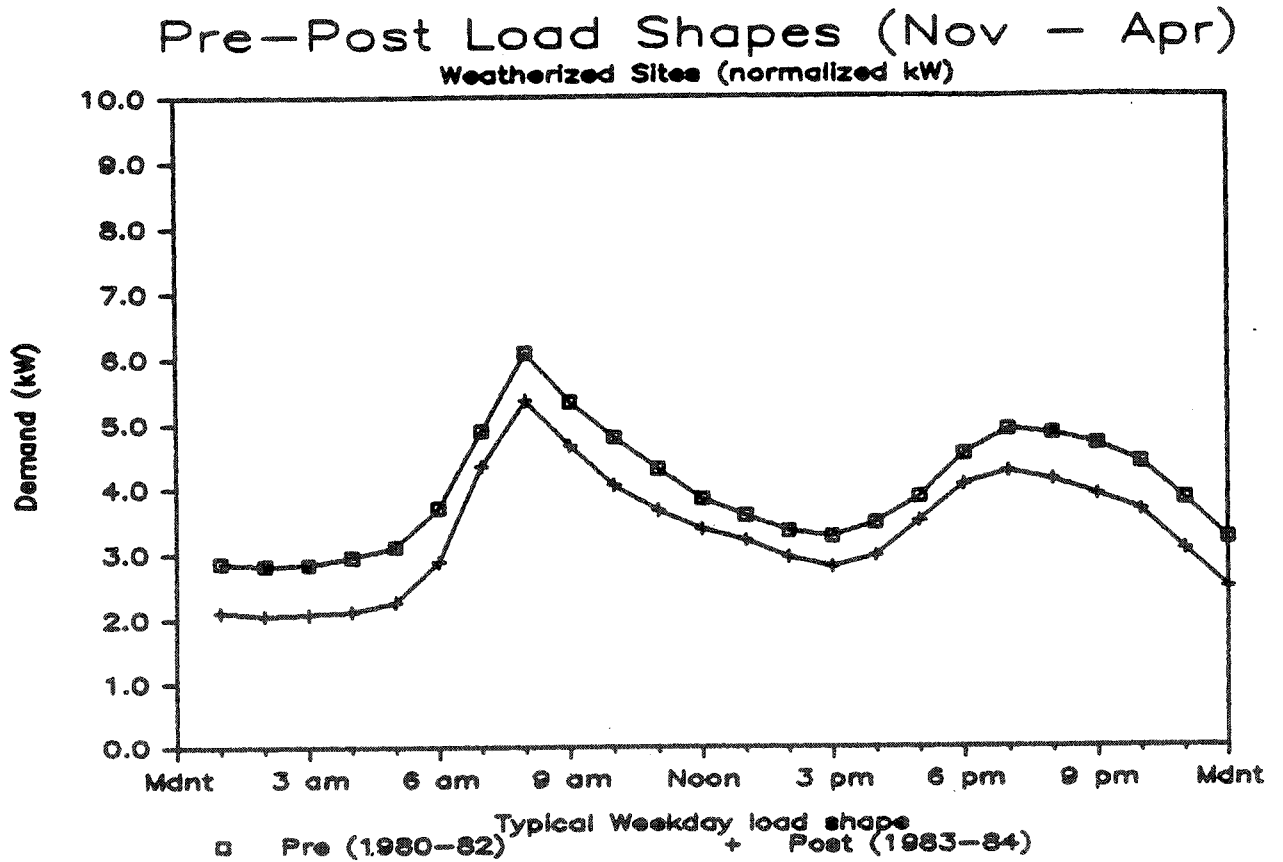


Figure 6

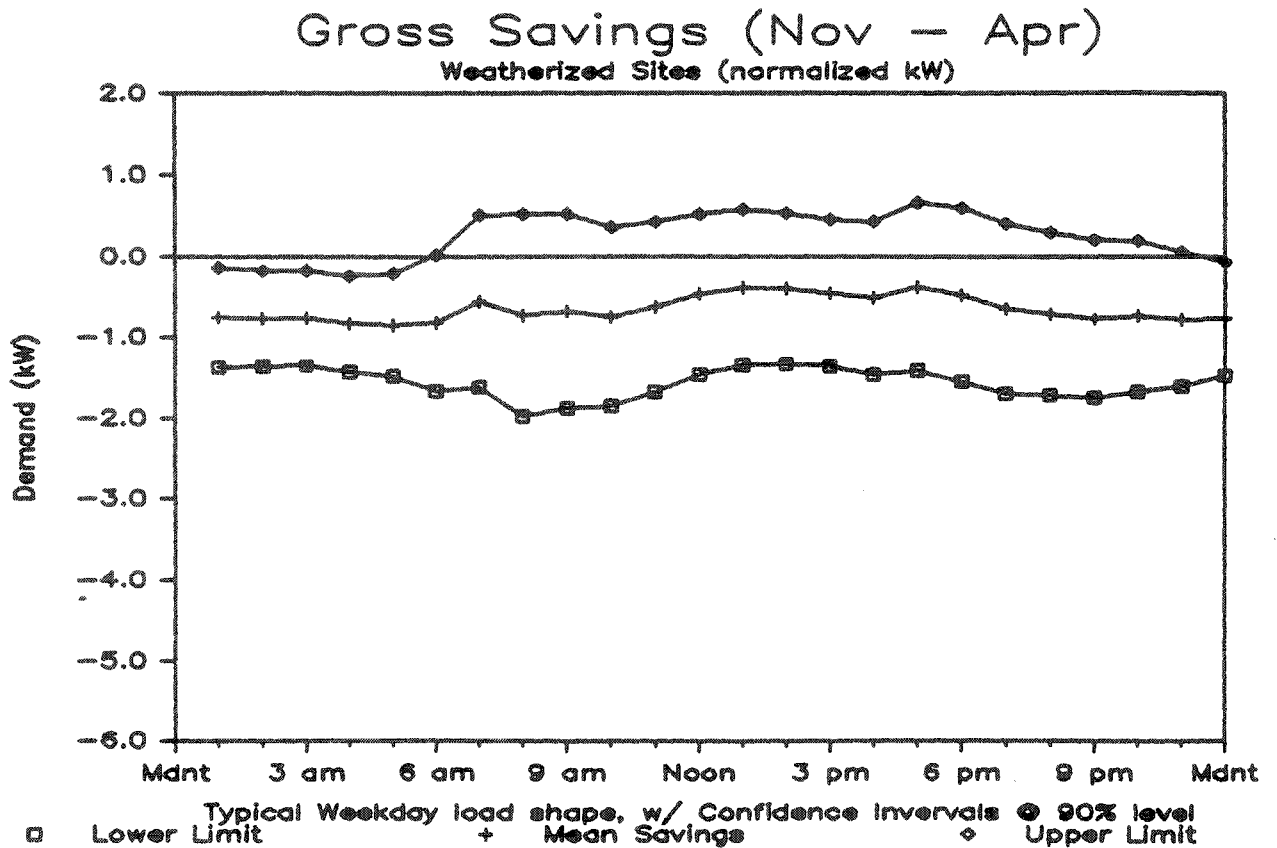


Figure 7

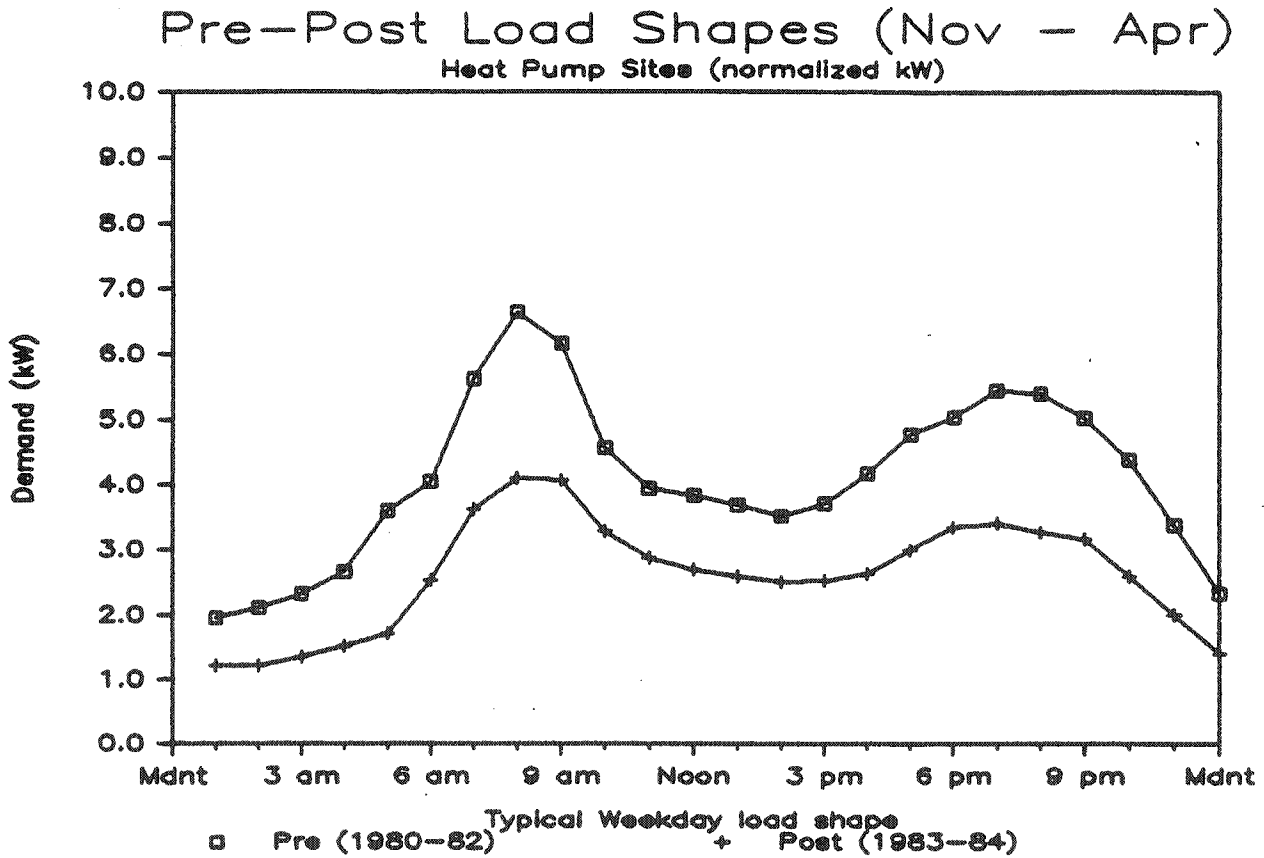
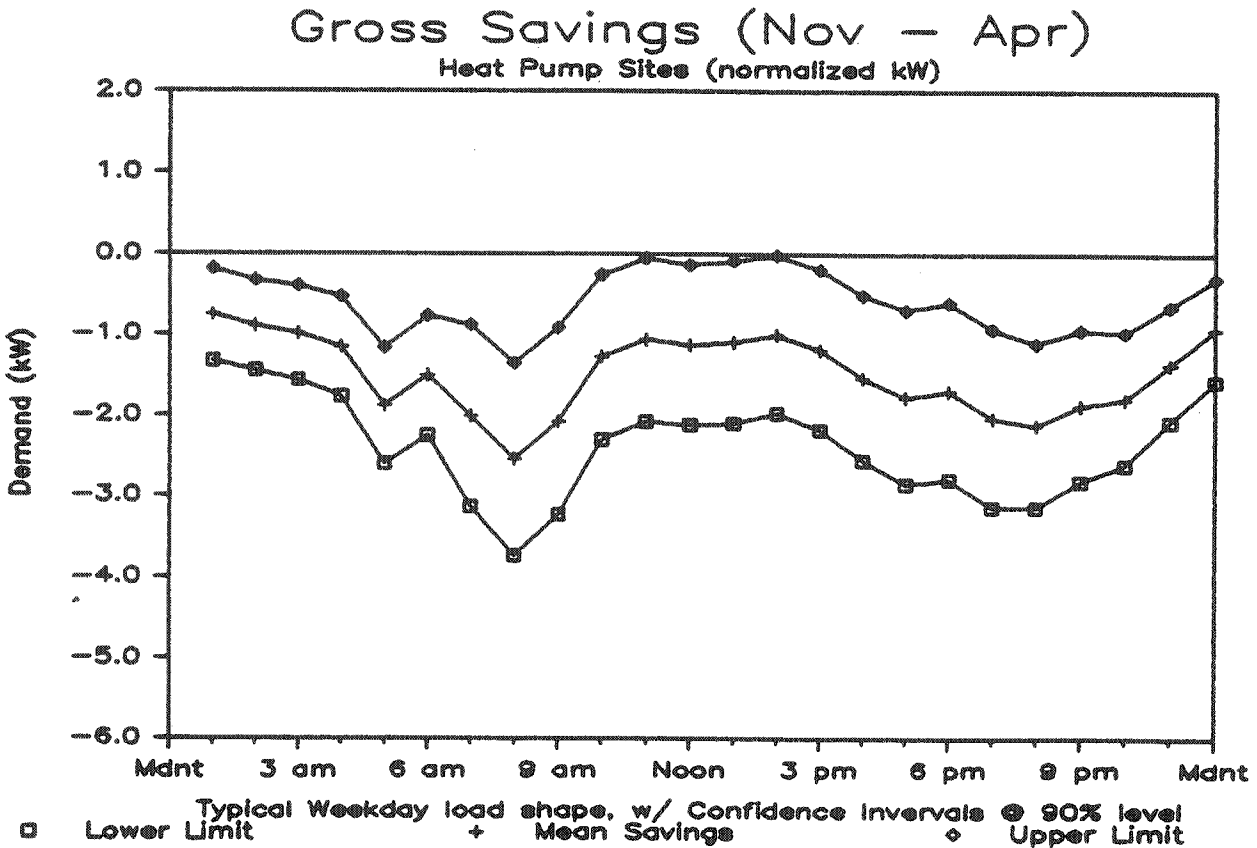


Figure 8



- Development of hourly weather adjustment models is of critical importance. When estimating such models on individual household data, it is difficult to explain much of the day to day variation in loads, although the weather adjustment coefficients are statistically significant. Some important factors in developing weather adjustment models include:
  - One must use a specification that accounts for significant monthly variation in usage of non-space heating appliances.
  - The weather adjustments for individual households are relatively insensitive to the choice of a balance point over a broad range of 50°F to 60°F.
  - To minimize the influence of the weather adjustment models on the results, it is desirable to match the normal weather days with the days to be adjusted based on their rankings in terms of heating degree day requirements.
  - Essentially the same weather adjustment model is obtained whether one uses total household load or only the space heating load.
  - Weather adjustment coefficients tend to be small and tend to be less significant during peak use periods compared to nighttime hours.
- In estimating the response of a population to a program, e.g., weatherization, it is important to examine the responses of homogeneous subgroups. Reporting the mean response can be misleading because of the tremendous variation in responses.
- Weatherization measures and heat pumps tend to reduce load factors. There tends to be a greater percentage savings for the nighttime hours than for the daylight hours.
- The largest percentage of savings in both energy usage and peak demand were for those households with middle income occupants and forced-air furnaces. The low-income homes with baseboard heat had relatively smaller savings (both in terms of percentage and total kWh). The high income, large family group with high initial consumption showed the largest absolute savings, but the smallest percentage savings.
- In estimating hourly load patterns it is of critical importance to identify and control for factors likely to affect these patterns, such as heating equipment type and household schedule (as reflected in age, employment status, and incomes of occupants).

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