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November 1987

Load Analysis

Final Report

The Hood River Conservation Project

Bonneville Power Administration • Hood River Electric Cooperative
Natural Resources Defense Council • Northwest Public Power Association
Northwest Power Planning Council • Pacific Northwest Utilities Conference Committee
Pacific Power & Light Company

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LOAD ANALYSIS

Final Report

By
Therese K. Stovall*

November 1987

Work Performed Under Contract No. DE-AC-79-83BP11287

Prepared for
U.S. Department of Energy
Bonneville Power Administration

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Acronyms and Definitions of Terms

average load	mean load over a period of time
Bonneville	Bonneville Power Administration
coincidence factor	the reciprocal of the diversity factor
coincident	occurring at the same time
contribution factor	the demand of a subdivision, at the time of occurrence of the maximum system demand, divided by the maximum system demand
diversified load	average load of a large number of customers at a given point in time
diversity factor	ratio of the sum of the individual maximum demands of various system subdivisions to the maximum demand of the whole system, always 1.0
EPRI	Electric Power Research Institute
Project	Hood River Conservation Project
HVAC	heating, ventilating, and air conditioning
LBL	Lawrence Berkeley Laboratory
load factor	average load divided by peak load
noncoincident	occurring at different times
peak load	highest, or maximum, load during a period of time
Pacific	Pacific Power & Light Company
R^2	Squared multiple correlation coefficient

Executive Summary

Introduction

As the costs of energy and energy-producing facilities have risen during the last 15 years, many people have suggested that investments in conservation would show greater economic benefits than similar investments in power plants. The Hood River Conservation Project (Project) was designed to determine whether such a concept was feasible in the Northwest.

This report evaluates the Project load, or capacity, savings, as opposed to overall energy savings. The data from 314 monitored homes form the cornerstone for this analysis. A three-phase feeder line was also monitored to assess the capacity savings on a primarily residential feeder.

At the monitored homes, total electrical load, space heating load, water heating load (in about 200 homes), wood stove heat output (in about 100 homes), and indoor temperature were monitored on a 15-minute basis. To allow an investigation of residential load shapes and magnitudes before and after conservation, data were collected for one full year before and one full year after the homes were retrofit with conservation measures.

Weather normalization was crucial to the load analysis because no local control group was available for comparison. Such normalizations on a 15-minute basis are not commonly found, but two methods were adapted to our requirements: a regression-based modeling technique and a technique based on choosing pairs of days with comparable weather. Both methods of weather normalization were used to evaluate the seasonal winter load savings and showed close agreement.

The following are the major findings:

Load Savings on the Monitored Feeder

Relationships between feeder savings and residential end-use savings could not be defined because of the unmeasured commercial loads and the timing of the residential retrofits.

Peak-Day Load Savings

The diversified load profiles for November 25, a system peak day, are shown in Figure S-1. The weather-normalized postconservation peak load was lowered by 0.56 kW/household on the Hood River area peak day and by 0.52 kW/household on the Pacific Power & Light peak day. The time of the peak appears to advance by 15 to 30 minutes as well.

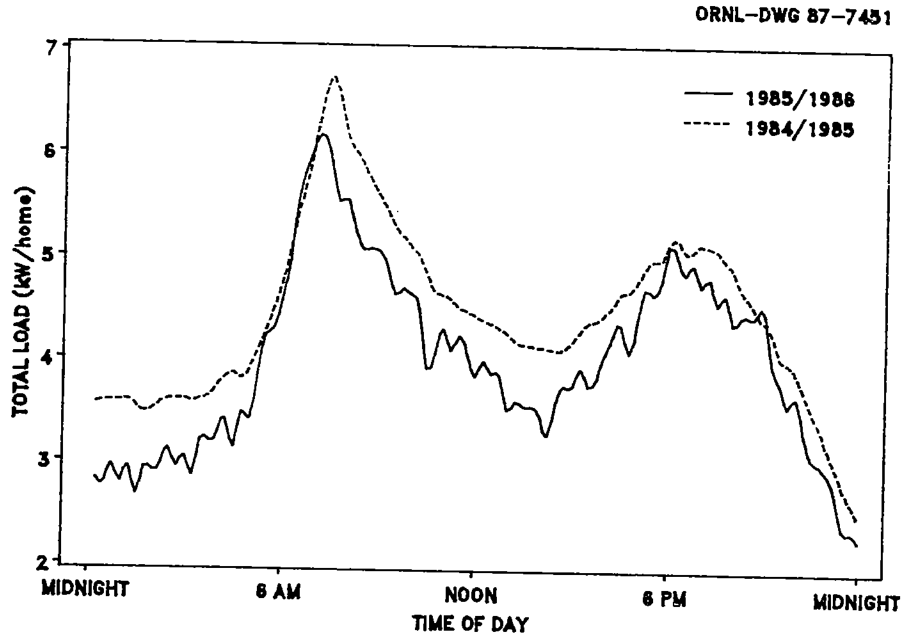

Figure S-1. Diversified total residential load on Hood River area peak day, November 25, 1985, weather-normalized using regression model.

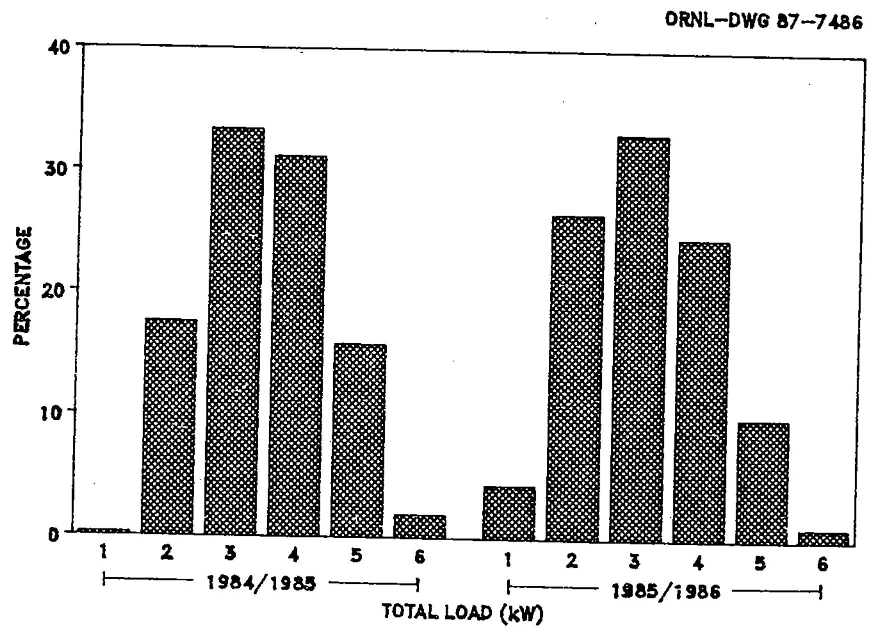

Figure S-2. Distribution of winter diversified residential loads.

Load Distribution Shows Savings

A distribution of the winter diversified load is shown in Figure S-2. During the first season, the load was greater than 5.4 kW/household for 224

15-minute periods. During the second season, the load exceeded this level for only 144 15-minute periods. Diversified loads up to 6.8 kW/household were measured the first season; the second season showed loads only up to 6.4 kW/household.

Single Family Electrically Heated Homes Show Largest Savings

Table S-1 summarizes the load savings for the total monitored sample and shows that single-family electrically heated homes had much greater savings than other homes. Figure S-3 shows the average winter weekday load profile before and after retrofit of the total monitored sample. This total load, both before and after the conservation retrofits, is lower than winter weekday load profiles measured in other conservation programs in the Northwest (Perry et al. 1985). The average winter load profile for single-family homes with all-electric heat in these other programs showed a preconservation peak load of 6.0 kW/household and a postconservation peak load of 5.4 kW/household. The Hood River loads were probably lower because wood-heated and mobile homes were included in the Project. The diversified load for the subset of all single-family homes heated mainly with electricity was, therefore, examined. Their diversified load profiles for two comparable cold weekdays are shown in Figure S-4. The magnitude of these loads is more comparable to those found in the other programs, and the savings are also larger. Table S-2 summarizes the measured savings for this cold winter weekday.

Load Savings Are Greater During Colder Weather

Analysis of these load data suggests that the load reductions attributable to the Project retrofits increase with decreasing ambient temperature. Thus, the project reduced the electric system's sensitivity to extremely cold weather (which is precisely when system demands peak).

Load Factor Is Reduced Following Weatherization Retrofits

The winter load factors for individual customers shifted from higher to lower values, matching the drop in the load factor for the diversified load. (This effect is also noted in Perry et al. for other conservation programs in the Northwest.) This drop was caused by peak load savings that were proportionally less than the average load savings. To avoid such load factor reductions, a conservation program may need to address heating, ventilating, and air conditioning equipment and appliance improvements, along with the weatherization retrofits used in Project. Such equipment improvements would be likely to reduce the maximum demand per household, which was relatively unaffected by the Project weatherization improvements.

Table S-1. Electricity demands by season in Hood River

Season	Period	Total load (kW/house) Average	Maximum	Load factor (%)
		Total sample of monitored homes		
Spring	Before	2.0	4.6	45
	After	1.9	4.1	47
Summer	Before	1.4	2.4	61
	After	1.4	2.2	64
Fall	Before	1.9	4.3	44
	After	1.8	4.1	44
Winter[a]	Before	3.4	6.1	55
	After	3.0	5.9	50
		Single-family electrically heated homes		
Winter	Before	4.0	6.2	65
	After	3.4	5.4	61

[a] Use of the regression method gave the same average winter loads but very different peak loads: 6.7 and 6.2 kW/house. Thus, the regression method shows a reduction in peak load of 0.5 kW/house.

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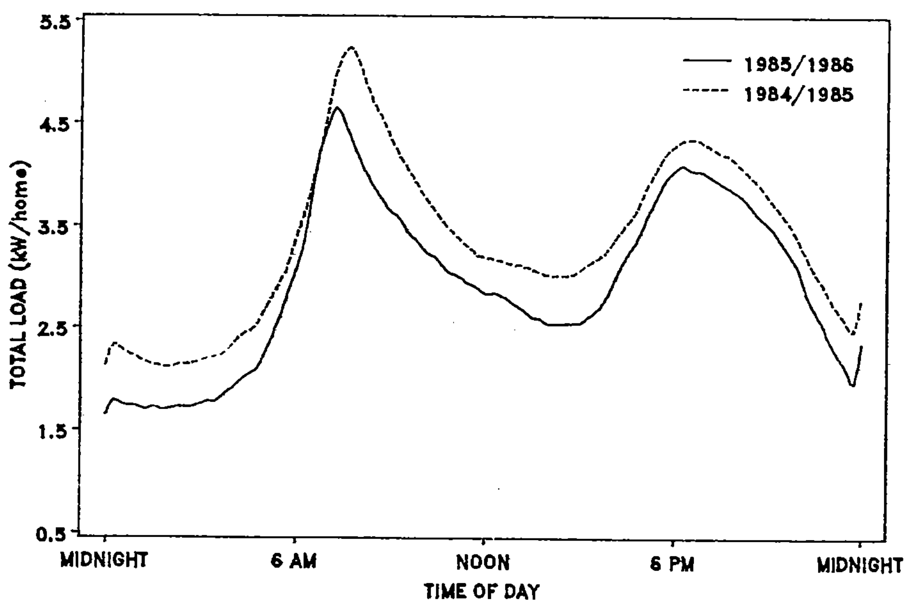

Figure S-3. Diversified winter-weekday total load profile, comparison based on regression model.

Table S-2. Diversified loads on selected similar cold days

Weather-normalization method	Total load (kW/house) Average	Maximum
Total sample of monitored homes		
Regression model		
January 15, 1986[a]	3.3	5.2
January 15, 1986	2.9	4.7
Savings	0.4	0.5
Similar days		
January 16, 1985	3.4	5.4
January 15, 1986	2.9	4.7
Savings	0.5	0.7
Single-family electrically heated homes		
Similar days		
January 16, 1985	4.2	6.2
January 15, 1986	3.2	4.8
Savings	1.0	1.4

[a] Loads were estimated for this day's weather by using the preconservation regression model.

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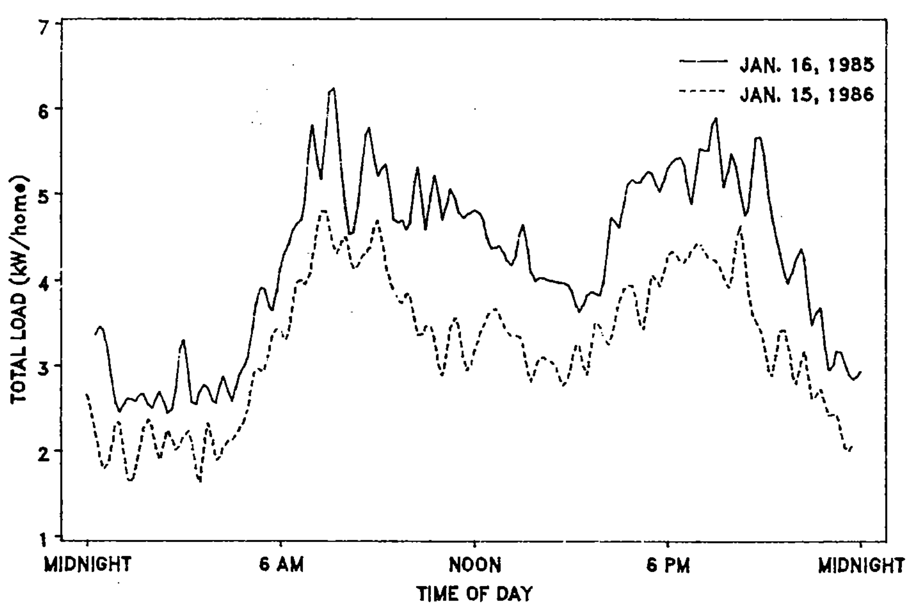

Figure S-4. Diversified total load profiles for electrically heated single-family homes, January 16, 1985, and January 15, 1986.

Mobile Home Retrofits Were Less Successful In Saving Energy

The average demand savings for single-family homes (0.48 kW) was almost twice that of the mobile homes (0.26 kW). Single-family homes saved an average of 24 percent of their space heating energy compared with only eight percent for the mobile homes. Therefore, research in new conservation methods for mobile homes would appear to be warranted.

Inclusion of Wood-Heated Homes in Conservation Programs Requires Close Examination

The average demand savings for the wood-heated homes (0.17 kW) is less than one-third of the savings in electrically heated homes (0.62 kW). However, those customers who used electricity exclusively did not decrease their average load any more than those customers who claimed to use electricity as their main heating fuel, with or without supplementary wood heating (0.63 vs 0.62 kW). It would, therefore, appear that conservation programs aimed at saving electric energy in the near term need not rule out all customers with wood stoves but, rather, only those who use the wood stove as their main heating source.

Electrically heated homes contributed slightly less than twice as much to the system peak loads as wood-heated homes. This would indicate that if a large proportion of customers currently using alternate fuels decided to switch back to electricity, their contribution to peak loads could increase by up to 100 percent. However, the measured heat output of the wood stoves in wood-heated homes decreased significantly (by 28%), showing that these homes are conserving energy, even if not in the form of electricity (Tonn and White 1987). The inclusion of wood-heated homes in conservation programs may, therefore, serve as a form of insurance against sudden large load increases in the future.

Abstract

As a part of the Hood River Conservation Project (Project), 314 homes were monitored to measure electrical energy use on a 15-minute basis. The total electrical load, space heating load, water heating load (in about 200 homes), wood-stove heat output (in about 100 homes), and indoor temperature were monitored. Data were collected for one full year before and one full year after these homes were retrofit with conservation measures. Weather stations were used to collect detailed local weather information, also on a 15-minute basis.

This data base was used to evaluate the load savings attributable to Project. Two methods of weather normalization were used and showed close agreement. The weather-normalized diversified residential load savings on the Pacific Power & Light system and Hood River area peak days were greater than 0.5 kW/household. The average wintertime load savings were 0.4 kW/household. Savings were larger in single-family electrically heated homes where the average demand reduction was 0.6 kW/household and the diversified seasonal peak was reduced by 0.8 kW/household. The average spring, summer, and fall savings were much smaller, less than 0.1 kW/household. The load factor for the diversified residential load decreased following the conservation retrofit actions.

A three-phase feeder was also monitored to measure the effect of the program. No such effect was measured on the feeder because of the confounding effect of unmeasured commercial loads and the timing of retrofit applications for residential customers on the feeder.

1. Introduction

As the costs of energy and energy-producing facilities have risen during the last 15 years, many people have suggested that investments in conservation would show economic benefits greater than those attributable to similar investments in power plants. To displace a power-producing facility, energy conservation must save not only energy (kiloWatt-hours) but also capacity (kiloWatts), especially at system peak times. Several questions must therefore be answered before such a suggestion can be implemented. What is the conservation potential? How much will this conservation cost? How quickly can this conservation be achieved? What is the nature of the load reduction and how does it affect the total system load? Will the load reduction be permanent or will customers take back some of the conservation in the form of higher indoor temperatures? What proportion of the residential sector will be willing to participate? Will the retrofit resources (i.e., contractors, auditors, and suppliers) of a limited geographic area be sufficient?

The Hood River Conservation Project (Project) was designed to answer as many of these questions as possible for the Northwest and focused on the Hood River, Oregon, community. The project participants included Bonneville Power Administration (Bonneville), Pacific Power & Light (Pacific), Hood River Electric Cooperative, the Northwest Power Planning Council, the Pacific Northwest Utilities Conference Committee, the Natural Resources Defense Council, and the Northwest Public Power Association.

The study identified achievable market penetration levels by vigorously marketing residential conservation services and measures. These measures were provided without direct expense to all qualified customers (over 3,000 homes with permanently installed electric heating systems) within the study area. Community perceptions and social issues were addressed through a series of interviews and discussion groups. A special group of 314 homes was statistically chosen to represent a cross section of the community. These homes were monitored for one year before and one year after the retrofit measures were applied. A feeder (a part of the distribution system that provides power to about 500 customers) was also monitored to help provide a measure of the effect of the program on the system load. Three weather stations were used to closely monitor many weather indicators in the study area. These weather stations and the monitored feeder area are shown in Figure 1-1.

The evaluation of the Project is multifaceted and is aimed at answering the above questions to the maximum extent possible. This report addresses those questions dealing with the load (kiloWatts), or capacity, savings, as opposed to overall energy savings (kiloWatt-hours). The energy savings from the project are described in a companion report (see Hirst et al. 1987).

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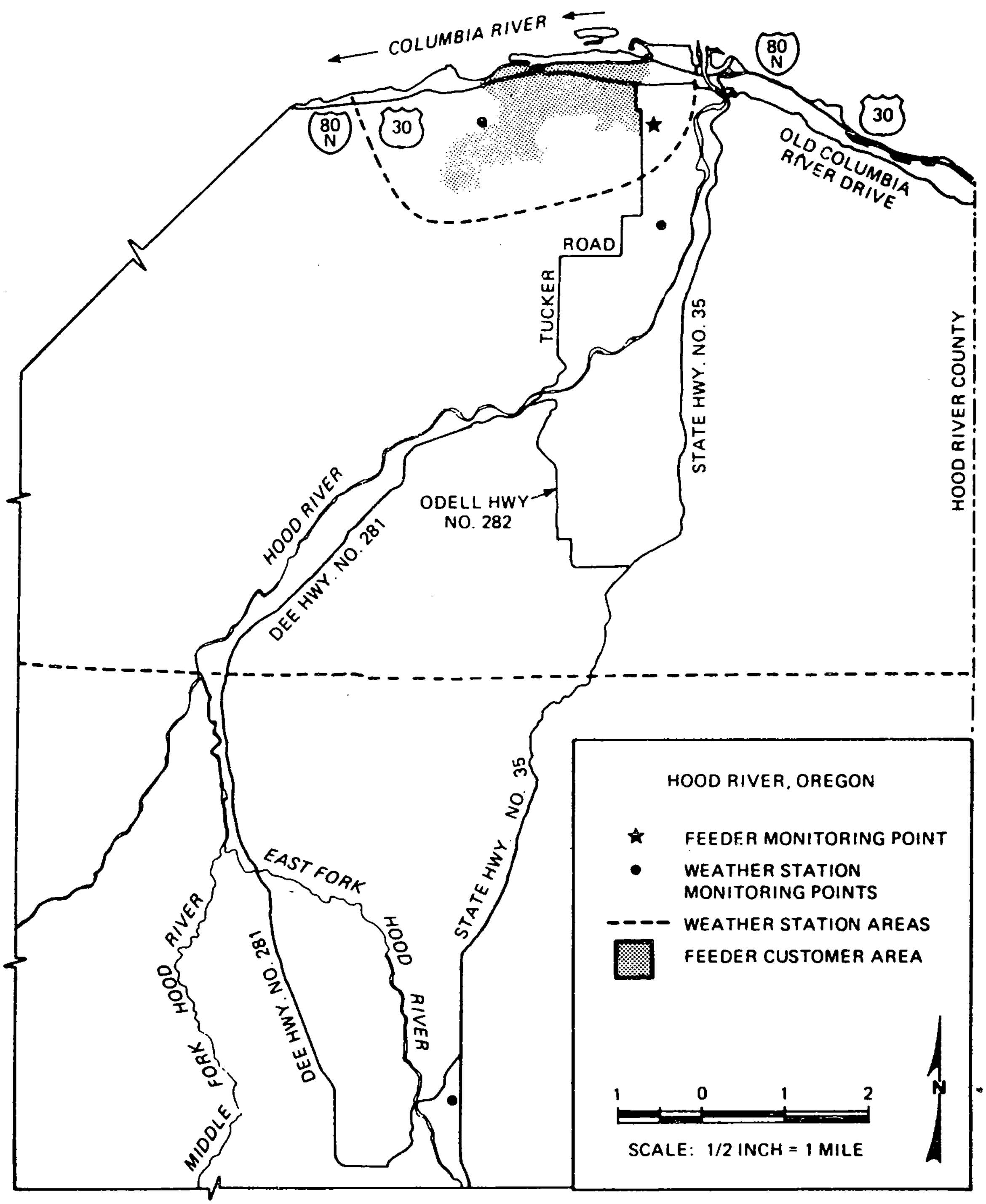

Figure 1-1. Map of Hood River area showing weather station locations and the feeder service area.

The data from 314 monitored homes and the monitored feeder loads form the cornerstone for this load analysis. At the monitored homes, total electrical loads, as well as several end-use loads, were measured on a 15-minute basis to permit investigation of residential load shapes and magnitudes before and after conservation. The magnitude of the data base is staggering. The number of data points is equal to 96 points per day times four measured points per household (total electrical load, space heating electrical load, water heating electrical load or wood-stove heat output, and indoor temperature) times 314 households times 365 days/year times two years. This amounts to almost 90 million data points and does not include the weatherization data, surveys, and billing data describing each household, the detailed 15-minute weather data, or the monitored three-phase feeder. The data analysis methods used to handle this enormous data base are described in Section 2.

No control group was used because it would have interfered with the maximum possible penetration goal of the project. Therefore, it was necessary to weather-normalize the load data on a 15-minute basis. This part of the analysis is discussed in Section 3. The effect of the program on the feeder is discussed in Section 4 and on the monitored residential sector, in Section 5. Measures of load diversity are given in Section 6, an introduction to a new approach to conservation-based load relief in Section 7, and the analysis summary in Section 8. A bibliography of Hood River publications is also included.

2. Analysis Methodology

2.1 Data Management

The data were received from Pacific in four separate sets: (1) customer pulse values corresponding to 15-minute consumption data, (2) weather pulse values corresponding to 15-minute weather information, (3) monthly billing data, and (4) project data for each customer. The data set used for this analysis contained over 90 million data points. A commercial statistical data handling system, SAS, was used for all of the data management and analysis tasks.

Data quality flags for each measured value were checked, and data values were set to missing when indicated. Load data from a three-phase feeder line serving about 500 customers and for a sawmill served by that feeder were transmitted with the residential load data and were treated in the same manner.

The weather data were collected at three weather stations and included: solar azimuth, solar altitude, horizontal radiation, direct beam radiation, diffuse radiation, wind direction, wind speed, dry-bulb air temperature, relative humidity, absolute humidity, 4-inch soil temperature, 20-inch soil temperature, 40-inch soil temperature, and barometric pressure. Not all of these channels were recorded at each station, and there were large blocks of missing data (some as long as two weeks) because of equipment problems. For these reasons and because the analyses used diversified load, the weather data from all three stations were averaged. Dinan (1987) used the weather data from each station independently to examine savings differences among customers. Also, the three measures of solar radiation -- horizontal, direct beam, and diffuse -- were averaged for use in the normalization regressions discussed in Section 3.1. These measures of solar radiation were examined individually in the similar-day analysis discussed in Section 3.2.

2.2 Data Quality

The data base itself went through several revisions, each one based on a more complete screening and tighter error checking. Even after the final screening, less than six percent of the data values for any channel were set to missing during the winter months.

Wood heat was measured using radiometers placed near the wood stoves. These radiometers were calibrated by Lawrence Berkeley Laboratory (LBL) to measure the energy output of specific brands and models of wood stoves (see Modera et al. 1984). These conversion factors were found by LBL to vary widely between brands and were strongly affected by radiometer position relative to the stove. The Pacific staff were very careful to ascertain the exact positions of these monitors and to correct the conversion factors to match the LBL correlations before generating another revision of the data base. Comparing daily summaries from this last revision to the data set used for this analysis, the wood-heat channel showed differences in 13 percent of the data points (the electrical load and indoor temperature channels showed little change). Additionally, only about one-half of the stoves monitored in Hood River corresponded to the brands tested by LBL. Thus, the wood-heat data used for this analysis include errors introduced by radiometer placement (affecting 13% of the data points), as well as potentially large errors introduced by wood-stove model differences. Therefore, in this analysis, the wood-heat data have been used as a proportional measure of heat output but not as an absolute measure of the stove's contribution to home heating needs.

2.3 Data Analysis

When analyzing a data set this large, one's first instinct is to aggregate the data in almost any way possible. However, it is important not to average away all of the characteristics and anomalies of interest. For that reason, this analysis uses the data at several different levels of aggregation. First, the diversified, or average, load of all 314 customers was calculated for each point in time; this is the mean load of all customers for each 15-minute period, and the resulting load profiles are similar to those used by utility planners. This diversified load was examined on specific days (such as system peak days or other days chosen for comparison), averaged over seasons, and compressed into numerical load measures (maximum load, average load, load factor, etc.).

Second, the average seasonal load profile (one each for weekdays and weekends) for each customer was generated by averaging each 15-minute time period across the days in a season. These customer profiles were used to examine the load characteristics of various user groups by merging them with descriptive project data. The diversified load of each user group was then produced.

Third, the complete unaveraged data set was used to produce several numerical measures of load diversity. This data set was used to calculate the maximum and mean load for each customer for each season. This data set was also used to examine the residential loads at the time of the system and area peaks and on several similar (defined in Section 3.2) days.

3. Weather Normalization

Weather normalization was crucial to the load analysis because no local control group was available for comparison. Weather normalization is commonly performed on some sort of a degree-day basis to evaluate energy savings attributable to conservation programs. However, for this task, load savings are of interest and degree days are useless as a normalization method.

Weather normalization on a 15-minute basis is not commonly found. However, one normalization procedure was found for a single home that included a model of the home's heating, ventilating, and air conditioning (HVAC) system (Kuliasha and Poore 1984). Although it was not feasible to apply this method to every home in the Hood River test, the general approach was of some interest. This method consisted of using linear-regression analysis to model the energy consumption data as a function of various weather parameters. These estimated parameter coefficients were then used in an equation to model the anticipated load under different weather conditions.

Another evaluation of the effect of residential retrofits on electrical load in the Northwest used hourly weather-normalization regressions for each house. Detailed local weather was not available for this study, so the only explanatory variable used was outdoor temperature and lagged averages of this temperature. A similar approach was used by Scientific Systems, Inc., in its analysis of residential end-use load shapes for the Electric Power Research Institute (see Usoro et al. 1985). Again, the regression analysis was applied separately for each household. This study introduced the concept of using Fourier series (sine and cosine) functions to model the non-weather-related household loads.

Another method, more commonly used by utilities, relied on choosing similar days for direct comparison. Because the weather normalization was so important for this analysis, both methods have been used for the wintertime analysis. Only the similar-days method was used for spring, summer, and fall comparisons because (1) the total load is not as closely related to weather during these seasons for a moderate climate like Hood River and (2) winter is the period of prime interest for this analysis because the residential air conditioning load is very small and the system peaks occur during the winter.

The regression method is more difficult to develop and apply but offers the ability to predict savings on peak days when no similar weather period may be available for comparison. The similar-days approach enables closer examination of small subsets of customers, for which the regression method is less successful.

3.1 Regression-Based Models for Weather Normalization

The previously mentioned residential end-use load shape study (Usoro et al. 1985) estimated regression models for individual homes and then used these models to estimate the aggregate load of a large number of customers. Because load savings for individual homes were not examined in this analysis, regression analysis was applied directly to the aggregate load of all the monitored households. If the results had failed to provide the desired accuracy, it would have been necessary to resort to the house-by-house modeling demonstrated in these previous studies.

Several subsets of customers with theoretically similar characteristics were also evaluated to see if the models of such subsets would be more accurate than the model of the whole group. These subsets included all-electric-heated homes (i.e., no woodheat use), homes grouped according to dwelling type (i.e., single-family vs mobile homes or multi-family), and homes grouped according to the results of a spectral (or frequency) analysis. The results of this modeling were mixed. The single-family home and the all-electric-heat homes produced acceptable models, but the other groups showed extremely poor models. Because the purpose of the subset models was to permit comparison between groups (e.g., comparison between single-family homes and mobile homes), these subset models were not developed further.

Preliminary analysis of data from November 1984 tested several different time frames for the regression modeling process. The time frames examined ranged from seasonal (i.e., one model for the whole season) to daily (i.e., one model for each day of the week) to hourly (one model for each hour of the day). In terms of balancing accuracy and ease of application, the most useful regression model was based on four different time periods: weekdays, weeknights, weekend days, and weekend nights. The use of these four models accounts for the difference in energy-use patterns for these different time periods yet avoids the complexity of using hourly models that would also vary between weekdays and weekend days. Holidays were always treated as weekends. Trial application of November models to January weather showed that the models were not likely to be generally applicable to weather in a different season from that of the model's analysis period. This preliminary work also showed that models based on more data, for example, November-February, had significantly higher squared multiple correlation coefficients (R^2) than one-month models.

Early models used the weather variables to model the space heating load. The resulting estimated space heating load, along with water heating load and other non-space-heating load indicators, was then used to model the total load. This two-step modeling process was replaced, however, with a one-step model that explains directly the total load in terms of the weather and behavioral variables. The squared multiple correlation coefficients for this one-step approach were higher, and it was felt that dropping an intermediate estimation step would reduce the errors associated with the final result. Another approach to weather normalization based on hourly regressions for individual houses also found that weather adjustments to total load were just as effective as weather adjustments to space heat load (Perry et al. 1985).

A wide variety of explanatory variables was tested in these models. Some of them, such as outdoor air temperature, indoor air temperature, solar radiation, wind speed, and water heater load, were obvious. Others were less obvious and were chosen after the results of the first models were examined. These include sine and cosine terms based on 8-, 12-, and 24-hour cycles; midday indicators; and other time-of-day indicators (no one equation used all of these time-of-day variables to avoid colinearity problems). Other variables, including barometric pressure, absolute humidity, relative humidity, ground temperatures, and mealtime indicators, were also investigated but with less success.

Lagged variables, the value of a variable at a previous time period, were also significant but not to the extent expected. Some lagged relationships that were tested include indoor temperature, solar radiation, total load, and wind speed. These lag relationships were tested at various time intervals, such as the value 15 minutes before, one hour before, or two hours before.

Test variables were created to look for interactive effects, such as wind speed times air temperature. Other variables tested include wind speed squared, sine and cosine terms squared, sine times cosine, the inverse of the solar radiation, the inverse of a sum of solar and lagged solar radiation values, and the inverse wind speed.

These variables were tested in a wide variety of combinations and over different periods of time. The final weather normalization covers three winter months, December-February, and is applied to the average total load of the 320 load-monitored homes. It is not applicable to individual homes or to subsets of the total sample population.

Four separate models were chosen, one each for weekdays, weeknights, weekend days, and weekend nights. The results of this analysis were evaluated by (1) considering the adjusted R^2, (2) considering the significance of the chosen explanatory variables (as indicated by a t-test at the 95 percent confidence level), (3) considering the magnitude and distribution of residuals, (4) plotting the residuals against the predicted values, and (5) plotting the residuals against date. This last test was used to be sure that the autocorrelated nature of these data did not introduce errors that followed a trend as time progressed. The Durbin-Watson test was also used for each model, and no evidence of temporal autocorrelation was detected. Appendix A contains the results of these tests for each of the models used in this analysis.

Table 3.1. Model constants

Period	A (CONSTANT)	B (LAGTOTAL)	C (DELTEMP)	D (WINDAIR)	E (WATER)	F (INDOOR)	G (LAGINDOOR)	H (COSTERM1)
Monday-Friday nights	2.74	0.674	-0.021	4.1E-4	0.553	0.598	-0.636	-0.258
Monday-Friday days	1.01	0.677	-0.020	0	0.424	0.171	-0.183	-0.127
Saturday-Sunday nights	1.91	0.722	-0.015	2.5E-4	0.541	0.394	-0.420	-0.175
Saturday-Sunday days	5.66	0.685	-0.015	0	0.397	0.385	0.463	0

Period	I (SINCOS)	J (LAG2SOL)	K (COSTERM2)	L (COSTERM3)	M (SOLAR)	N (SINTERM3)	P (MIDDAY)	Q (HOUR)
Monday-Friday nights	-0.117	0	0	0	0	0	0	0
Monday-Friday days	0.098	2.1E-3	-0.207	-0.079	-7.4E-3	0	0	0
Saturday-Sunday nights	-0.089	0	0	0	0	0	0	0
Saturday-Sunday days	0	0	0	0	-7.2E-3	-0.020	-0.051	0.023

A final test of the combination of the four models was based on applying the model to the weather from which it was derived and comparing the result to the actual load during that period. The match was very good. The peak load was correct to within 0.2 percent, or 0.01 kW, and the average load to within 0.1 percent. The load factors matched to within 0.1 percent. The first seven days from each month were plotted to permit visual comparison between the actual load and the artificial load constructed from the model (see Appendix B). Figure 3-1 shows one of these plots for December 5, 1984, for comparison between the actual load and the reconstructed load.

The reconstructed load is, as expected, much smoother than the actual load. However, the reconstruction is very good at matching the peaks, averages, and overall contour of the actual load. The model relies on a lagged value of the load. To start the model, the artificial curve is given an initial value of 3.5 kW, about 1.5 kW higher than the actual load at that time. Within two hours, or eight data points, the modeled load is very close to the actual load and remains close throughout the rest of the winter period.

The actual water heating load is used as an input to the model. Because the water heater load is not directly related to the weather (although it does show seasonal variation), it was not normalized.

The final models chosen are shown in Equation (1) with the coefficients given in Table 3-1. Note that while many variables in this equation appear to be correlated, only a few appear in its application for any one time period.

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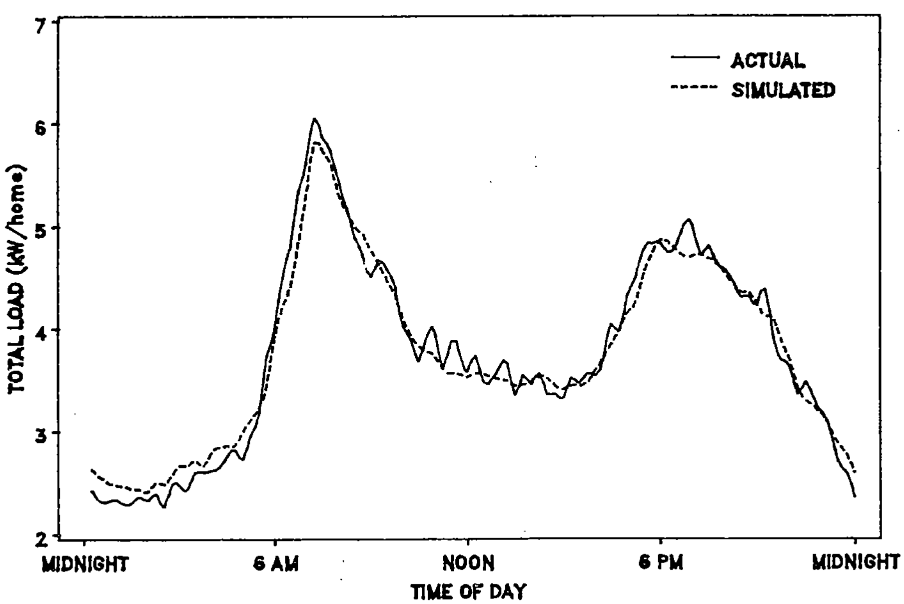

Figure 3-1. Actual load vs load estimated by regression model, December 5, 1984.

$$\begin{aligned} TOTAL = {} & A + B*LAGTOTAL + C*DELTEMP + D*WINDAIR + E*WATER + \\ & F*INDOOR + G*LAGINDOOR + H*COSTERM1 + I*SINCOS + \\ & J*LAG2SOL + K*COSTERM2 + L*COSTERM3 + M*SOLAR + \\ & N*SINTERM3 + P*MIDDAY + Q*HOUR \end{aligned} \quad (1)$$

where:

TOTAL = the total average load per household, kW;
LAGTOTAL = the value of TOTAL 15 minutes previously, kW;
DELTEMP = the outdoor minus the average indoor temperature, °F;
WINDAIR = the wind speed times the outdoor temperature, °F-miles/hour;
WATER = the water heating load, kW;
INDOOR = the average indoor temperature of all the monitored homes, °F;
LAGINDOOR = the value of INDOOR 15 minutes previously, °F;
COSTERM1 = the cosine of 2 pi times the hour of the day / 24 hours;
COSTERM2 = the cosine of 2 pi times the hour of the day / 12 hours;
COSTERM3 = the cosine of 2 pi times the hour of the day / 8 hours;
SINTERM3 = the sine of 2 pi times the hour of the day / 8 hours;
SINCOS = COSTERM1 times SINTERM1;
SINTERM1 = the sine of 2 pi times the hour of the day / 24 hours;
SOLAR = the solar radiation (average of horizontal, direct, and diffuse), Btu/ft^2;
LAG2SOL = the value of SOLAR 30 minutes previously;
MIDDAY = a dummy variable with a value of 1 between noon and 4:00 p.m. and a value of 0 all other times;
HOUR = the hour of the day, ranging from 1 to 24.

Similar models were tested using the feeder load with much less success. Even though the adjusted R^2 of the four models was greater than 96 percent, the peak load was off by almost 10 percent. These poor results are probably caused by the weaker (as compared with the monitored sample) relationship between weather and (1) the non-electrically heated residential load and (2) the commercial load. This method was, therefore, not used for the feeder analysis.

3.2 Similar Days Chosen for Weather Normalization

Similar days were defined as matching the (1) day of the week, (2) average daily outdoor temperature within 5 °F, and (3) minimum (winter, spring, and fall) or maximum (summer) daily outdoor temperature within 5 °F.

To use as much of the data as possible, groups of similar days, as well as a few individual pairs, were chosen for an analysis of each season. The seasons were defined as winter, December-February; spring, March-May; summer, June-August; and autumn, September-November. The period of April 1, 1985-July 25, 1985, was unavailable for analysis because the monitored homes were retrofit with conservation measures during that time. The weather during late November 1985 was extremely cold, breaking several 100-year weather records, and was excluded from any comparison with preconservation energy use.

These groups of similar days were chosen to represent as closely as possible the distribution of outdoor temperatures found throughout each season and to have equal numbers of each day of the week. Note that these seasonal analyses represent the savings during the seasons experienced in 1984-1986 and do not represent any "average" regional weather pattern. Figure 3-2 compares the winter outdoor air temperature distributions between the entire seasons and the chosen groups of comparison days. Table 3-2 lists the chosen winter days and their outdoor temperatures. The other seasons are given in Appendix C. Other weather variables, including wind speed, solar radiation, and humidity, were also plotted to see if the selected periods would be truly comparable. Appendix C contains these plots for all four seasons. Table 3-3 summarizes the average values of these weather variables during the comparison test periods.

The only weather variable that remains significantly different between comparison groups is the wind speed. The average wind speed during the first winter, three mph, was almost twice as large as the average wind speed during the second winter, 1.8 mph. The same was true for the spring comparison periods. The selected groups of days show the same relationship (Figure 3-3). This may introduce some error into the comparison, perhaps overestimating savings. However, the regression relations discussed in Section 3.1 showed that wind speed was not significant in determining daytime loads. Because all of the peaks are daytime peaks, this error should not affect peak-load savings estimates, and the effect on load factor changes should be minimal. (For a difference in wind speed of two mph at an indoor-outdoor temperature difference of 60 ^{0}F, the difference in nighttime predicted total load per household is only about +0.05 kW.)

Installation of conservation retrofits extended into the summer of 1985 until July 25, when about 90 percent of the homes were reported complete. Because the selection of similar days from the postretrofit season was, therefore, restricted to late July and August, the day of the week does not always match for the summer comparison. However, weekdays are always paired with other weekdays and weekend days with other weekend days.

Table 3-2. Winter days chosen for comparison

Period	Date	Day	Average temperature (°F)	Minimum temperature (°F)
Before	Jan. 27, 1985	Sunday	31	29
After	Jan. 26, 1986	Sunday	34	33
Before	Jan. 13, 1985	Sunday	28	27
After	Jan. 5, 1986	Sunday	31	27
Before	Dec. 9, 1984	Sunday	36	35
After	Feb. 16, 1986	Sunday	37	32
Before	Jan. 20, 1985	Sunday	40	32
After	Feb. 2, 1986	Sunday	40	37
Before	Feb. 11, 1985	Monday	37	31
After	Jan. 20, 1986	Monday	39	30
Before	Dec. 10, 1984	Monday	37	30
After	Feb. 10, 1986	Monday	36	31
Before	Dec. 17, 1984	Monday	28	20
After	Dec. 9, 1985	Monday	30	24
Before	Feb. 25, 1985	Monday	41	30
After	Jan. 6, 1986	Monday	42	34
Before	Dec. 11, 1984	Tuesday	31	27
After	Jan. 7, 1986	Tuesday	32	26
Before	Jan. 29, 1985	Tuesday	31	24
After	Jan. 21, 1986	Tuesday	34	28
Before	Feb. 5, 1985	Tuesday	33	28
After	Feb. 11, 1986	Tuesday	33	30
Before	Jan. 22, 1985	Tuesday	35	33
After	Jan. 14, 1986	Tuesday	30	29
Before	Jan. 16, 1985[a]	Wednesday	31	30
After	Jan. 15, 1986[a]	Wednesday	32	29
Before	Jan. 23, 1985	Wednesday	33	32
After	Jan. 22, 1986	Wednesday	33	31
Before	Jan. 2, 1985	Wednesday	24	21
After	Dec. 18, 1985	Wednesday	20	18
Before	Feb. 20, 1985	Wednesday	41	37
After	Feb. 5, 1986	Wednesday	40	33
Before	Jan. 3, 1985	Thursday	24	21
After	Dec. 26, 1985	Thursday	21	20
Before	Feb. 14, 1985	Thursday	35	26
After	Dec. 5, 1985	Thursday	34	27
Before	Dec. 13, 1984	Thursday	40	34
After	Jan. 23, 1986	Thursday	38	32
Before	Jan. 24, 1985	Thursday	33	31
After	Feb. 13, 1986	Thursday	30	28
Before	Jan. 4, 1985	Friday	25	24
After	Dec. 20, 1985	Friday	22	21
Before	Feb. 8, 1985	Friday	31	25
After	Nov. 15, 1985	Friday	30	27
Before	Feb. 15, 1985	Friday	43	33
After	Feb. 28, 1986	Friday	45	35
Before	Jan. 18, 1985	Friday	29	27
After	Feb. 14, 1986	Friday	28	28
Before	Feb. 2, 1985	Saturday	23	20
After	Dec. 21, 1985	Saturday	22	20
Before	Jan. 12, 1985	Saturday	28	26
After	Jan. 4, 1986	Saturday	30	27
Before	Feb. 16, 1985	Saturday	34	24
After	Feb. 8, 1986	Saturday	33	23
Before	Feb. 23, 1985	Saturday	49	44
After	Mar. 1, 1986	Saturday	49	39

[a] Days chosen for cold day comparisons.

Table 3-3. Comparison period weather values

Season	Average temperature (^oF)	Solar radiation (Btu/ft^2)	Wind speed (mph)	Relative humidity (%)	Minimum temperature (^oF)
Prewinter	33	3.4	3.0	86	20
Postwinter	33	3.2	2.1	83	18
Prespring	50	13	5.3	74	32
Postspring	50	11	3.8	73	33
Presummer	68	20	5.4	53	43
Postsummer	67	16	5.8	56	42
Preautumn	52	8.0	2.8	77	32
Postautumn	51	8.7	2.9	74	30

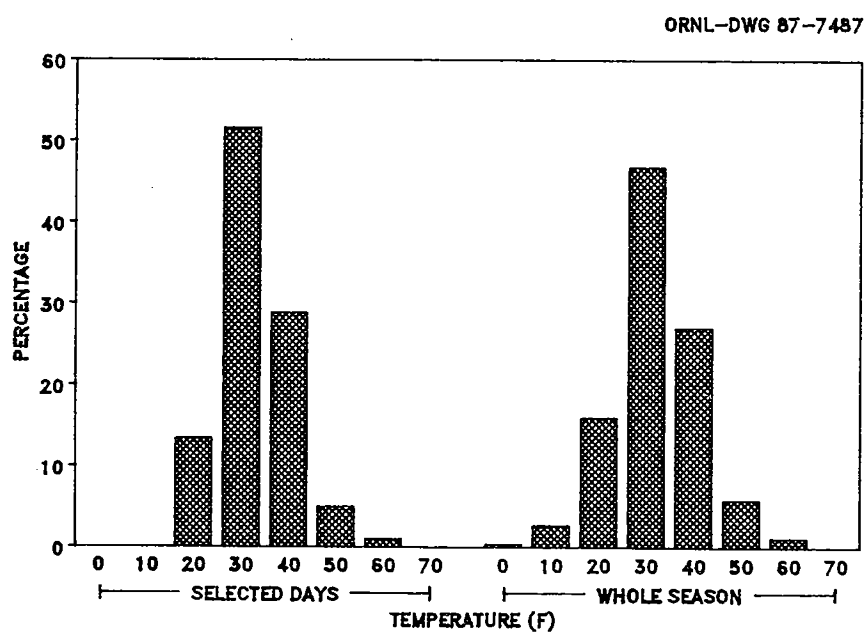

Figure 3-2. Outdoor air temperature distribution comparison, winter selected days.

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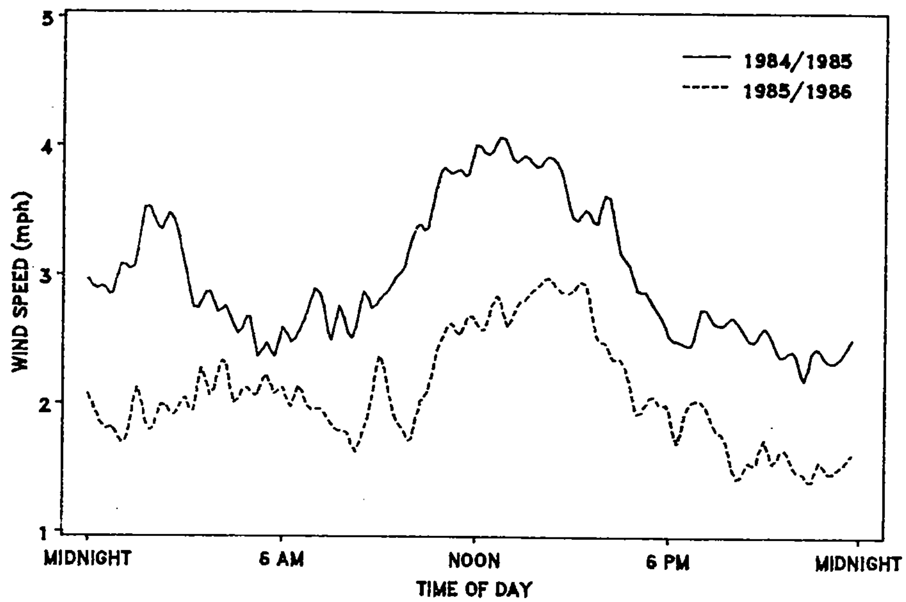

Figure 3-3. **Winter wind speed comparison, selected days.**

A few pairs of closely matching days were chosen to enable a direct comparison of loads without any averaging effects. These days were selected by choosing days with very closely matching average and minimum (or maximum) temperatures. These sets were then examined to find days that were exceptionally hot or cold and that occurred during the week (i.e., Monday-Friday). Other weather variables, including wind speed, solar radiation, and humidity, were then plotted to help select the most closely matching extremely hot and cold days for direct comparison. These weather variable plots are included in Appendix C.

4. Load Savings on the Monitored Feeder

A three-phase feeder line serving mostly residential customers was monitored to help determine whether the impact of the conservation program would be noticeable on a larger portion of the system. A relationship between residential end-use savings (i.e., space or water heat) and system savings was also anticipated, and the measured feeder loads were expected to be useful in exploring this relationship. Once defined, such a relationship could be used to predict the effect of specific retrofit measures, such as those aimed at water heaters, on the system load. However, several implementation problems prevented any meaningful analysis of such relationships or, indeed, any conclusions regarding the effect of the program on the feeder load. Appendix D describes the customer mix served by the feeder, the peak loads served by the feeder, the savings (or lack thereof) attributable to the Project, the feeder loads on system peak days, and the problems affecting this portion of the Project evaluation.

5. Residential Load Savings in the Monitored Sample

5.1 Monitored Sample Composition

The monitored sample was statistically chosen to represent a cross section of the electrically heated portion of the Hood River community. As such, it is made up of 249 single-family dwellings (79%), 55 mobile homes (18%), and 10 multifamily or duplex homes (3%). About 25 percent of the homes have one or more air conditioners, and about 26 percent use one or more portable heaters. Zonal heating systems are installed in 61 percent, and the remainder are equipped with central heating systems. Seventy-two homes (23%) have irrigation pumps on their homes' meters. Although all of these homes are nominally electrically heated, 39 percent claim to use wood or prestologs as their main source of heat. There are only 82 homes that claim to use electricity as their only source of heat (and because a few of these are equipped with wood-stove monitors, even this number is high). Of these 82 homes, only 46 are single-family dwellings.

5.2. Seasonal Comparisons

Load savings for the monitored sample were estimated using both weather-normalization methods for the winter season. Figure 5-1 shows the average diversified weekday load profile before and after retrofit resulting from the regression methodology (the average load profiles for the groups of selected similar days are very similar). A paired t-test shows that these two curves are significantly different at a 95 percent confidence level. The load savings appear to be slightly greater during the morning peak and late afternoon trough periods and slightly less during the early morning and late evening ramp times. Figure 5-2 shows the average space heating and water heating load profiles for weekdays during the winter similar-day period. Examination of this figure shows that most of the savings is due to space heating savings with an average water heater savings of only 0.08 kW.

The overall savings estimates from these two weather-normalization methods are also in close agreement. Table 5-1 gives a summary comparison of the savings estimates for the diversified load of the monitored households. The two methods give identical results of 0.4 kW average load savings per household, corresponding to energy savings of 11 percent. The similar-days method shows a peak-load savings of 0.2 kW/household (or 3%); the regression model shows a peak-load savings of 0.5 kW/household (7%). This difference is not surprising because the regression model normalizes the use of the first season to the weather of the second season, a much more severe winter. The similar-days method normalizes the use from both seasons to the average weather of both winters combined, so the extremely cold days of the second season were not included.

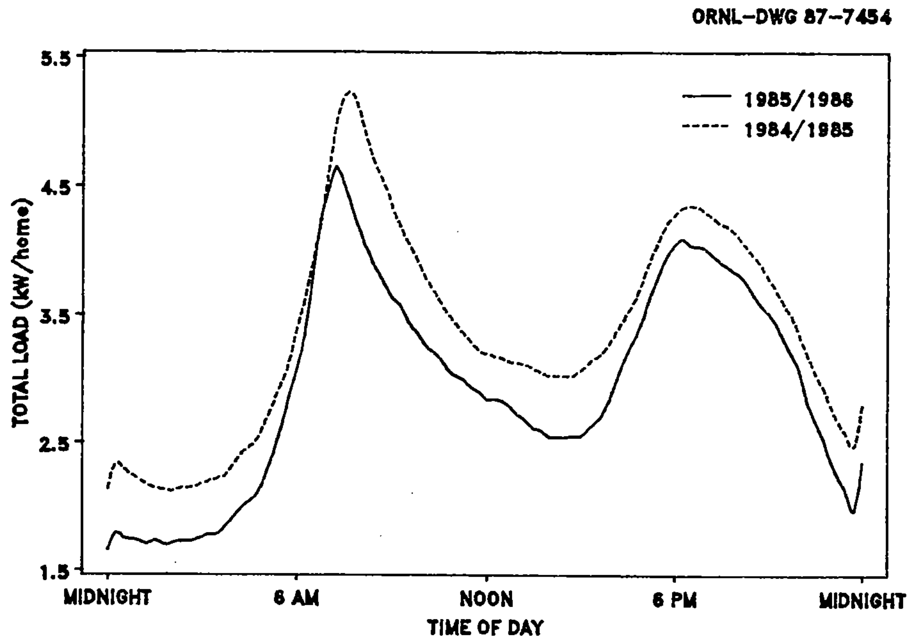

Figure 5-1. Diversified winter-weekday total load profile, comparison based on regression model.

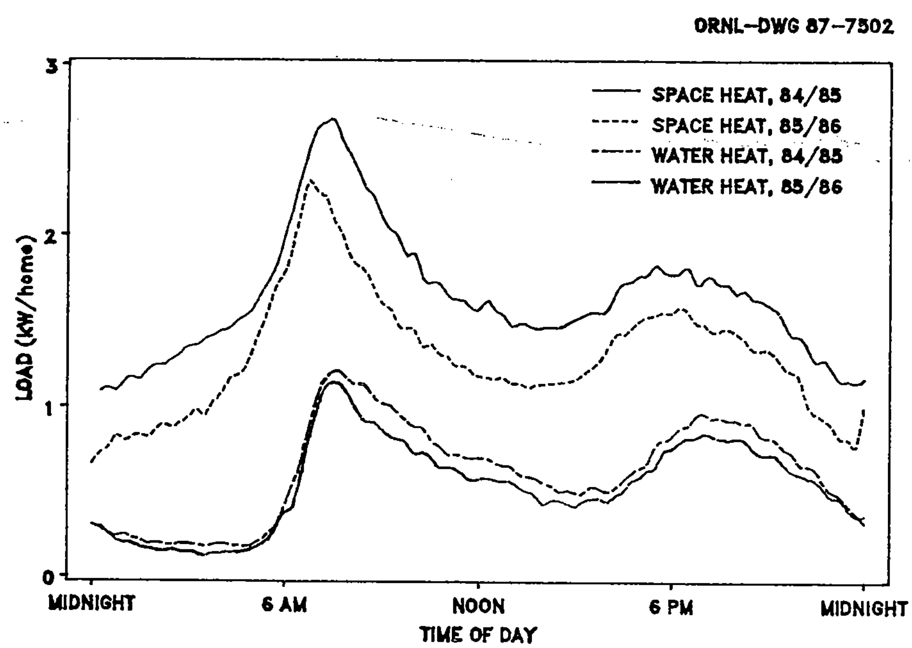

Figure 5-2. Diversified winter-weekday space and water heating load profiles, comparison based on similar days selection.

Table 5-1. Comparison of winter savings estimates

Weather-normalization method	Period	Average total load (kW/household)	Maximum total load (kW/household)	Load factor
Similar days	Before	3.4	6.1	0.55
	After	3.0	5.9	0.50
Regression model	Before	3.4	6.7	0.51
	After	3.0a	6.2a	0.49[a]

[a] These are the actual values resulting from the December 85 -- February 86 period.

A comparison of the diversified load distributions, based on the regression normalization, is shown in Figures 5-3 and 5-4. The number of 15-minute periods with a load level greater than 5.8 kW/household dropped from 80 in the first season to 12 in the second season. A parallel examination of the similar-days distribution also showed a factor of 10 decrease in the duration of these peak loads. The Project, therefore, was successful at achieving capacity, as well as energy, savings. The capacity savings are also larger on colder days, thus decreasing the electric system's sensitivity to extremely cold weather (which is precisely when system demands peak).

The total load both before and after the conservation retrofits was about 0.5 kW/household lower than winter weekday load profiles measured in other conservation programs in the Northwest (Perry et al. 1985). This was likely due to the inclusion of wood-heated, multifamily, and mobile homes in the Project because other conservation programs have typically been restricted to single-family electrically heated homes. The diversified load (from the similar-day method) for the subset of all single-family homes heated mainly with electricity was, therefore, examined. The diversified load of this subset of homes is compared with that of the total monitored population in Table 5-2. Both the magnitude of the single-family electrically heated loads and the savings are comparable to those found in the other programs. The peak savings of 0.8 kW/household for the Hood River single-family electrically heated homes are very close to the measured savings of 0.7 kW/household in these other programs.

The results from both normalization models show that the load factor decreased because peak-load savings, as a proportion of the pre-program peak levels, are less than the average savings, as a proportion of the pre-program average levels. Similar effects on load factor were noted in another evaluation of conservation programs in the Northwest (Perry et al. 1985). Peak loads are defined by the HVAC appliance stock and the load diversity (because furnaces continue to cycle-on simultaneously at the coldest periods of the year). The conservation retrofits in the Project did not include modifications to HVAC systems or appliances. The load diversity was unchanged by the conservation retrofits and is discussed further in Section 6.

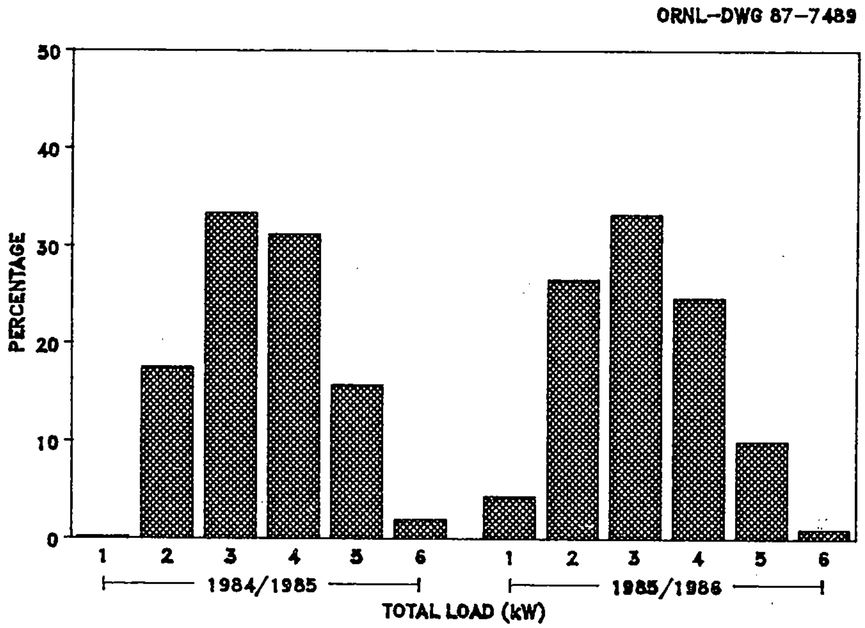

Figure 5-3. Distribution of winter diversified residential loads.

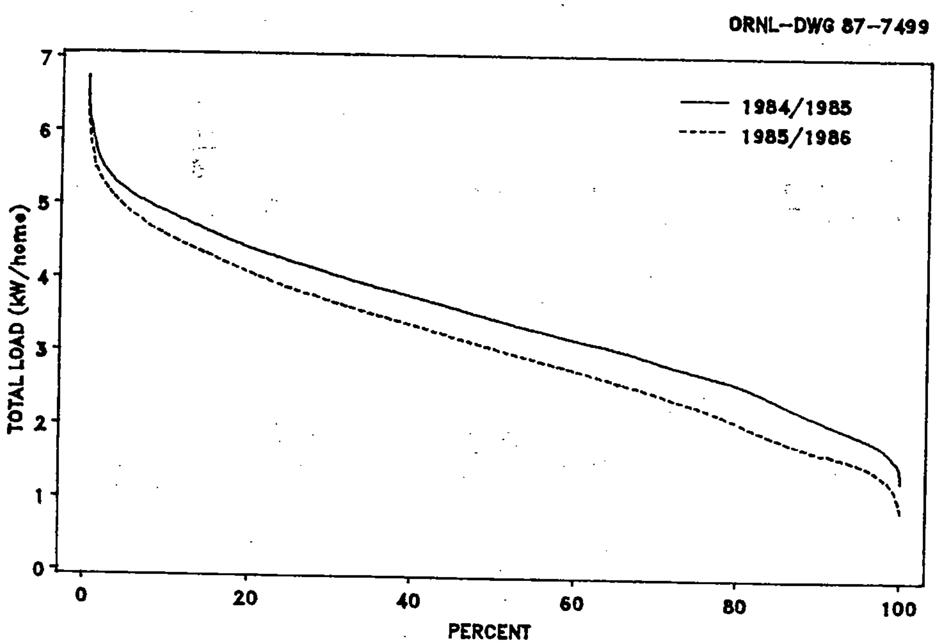

Figure 5-4. Load duration curve for winter diversified residential load.

Table 5.2. Seasonal savings estimates: similar days

Season	Period	Average total load (kW/household)	Energy savings (%)	Maximum total load (kW/household)	Load savings (%)	Average space heating load (kW/household)	Load factor
Spring	Before	2.0		4.6		0.58	0.45
	After	1.9	5	4.1	11	0.47	0.47
Summer	Before	1.4		2.4			0.61
	After	1.4	0	2.2	8		0.64
Autumn	Before	1.9		4.3		0.42	0.44
	After	1.8	5	4.1	5	0.36	0.44
Winter							
	Total monitored sample						
	Before	3.4		6.1		1.6	0.55
	After	3.0	11	5.9	3	1.3	0.50
	Single-family electrically heated homes						
	Before	4.0		6.2		2.2	0.65
	After	3.4	16	5.4	12	1.7	0.61

Although the regression-based weather-normalization method was only applied to the winter months, sets of similar days were selected from all four seasons. Table 5-2 and Figure 5-5 summarize the savings based on the diversified load of the monitored customers during these seasons. As expected for a mild climate such as in Hood River, the spring, summer, and fall savings are much smaller than the winter savings, averaging less than 0.1 kW (5%) in the spring and fall and only 0.05 kW during the summer. The summer peak was decreased by 0.2 kW (8%), which served to increase the seasonal load factor. However, the winter diversified peak is much higher than the summer peak, so the annual load factor would not be improved.

The average diversified total load of the 314 monitored customers was relatively unchanged by the conservation program for the spring, summer, and fall seasons. Figures 5-6 to 5-8 show the weekday diversified load profiles for these seasons. The savings pictured are very small and do not change the shape of the energy-use profile in any of these three seasons. However, paired t-tests showed that even these small differences are significant at a 95 percent confidence level.

The similar-day analysis was also used to examine the programmatic effect on load factor, average total load, and maximum total load distributions among the monitored households. Load factors for individual homes are much lower than the load factor for the diversified load because the individual peak loads are much higher than the diversified peak loads (compare the peak loads shown in Figure 5-9 with the diversified peak load of about six kW/household shown in Table 5-2). The winter change in load factor was the largest of the four seasons, dropping from 0.55 to 0.5 for the diversified load and shifting noticeably from higher to lower values for individual customers (see Figure 5-10). Also note that although the springtime load factors for the diversified load of all 314 homes increased from 0.45 to 0.47, the distribution of load factors for individual homes showed a slight shift toward decreasing load factors in Figure 5-11. During the summer the shift toward increasing load factors for individual customers matched the shift in the load factor for the diversified load. The autumn load factor distribution shifted toward lower values, although the load factor of the diversified load was unchanged at 0.44.

The distribution of household average total loads (shown in Figure 5-12 for winter weekdays) was changed significantly only during the winter season, as would be expected from the low savings noted during the other three seasons. The distribution of maximum loads for each household was relatively unchanged for all four seasons (Figures 5-9 and 5-13 show the winter and summer maximum load distributions). The maximum load is usually defined by the sum of the heating or cooling equipment capacity and appliance ratings more than by a house's need for energy. Because the basic HVAC systems and appliances were unchanged by this conservation program, the unchanged household maximum loads are not surprising.

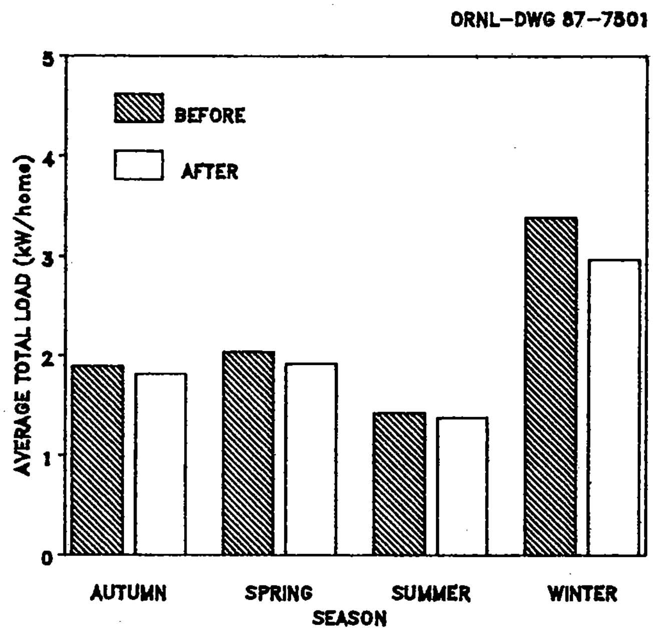

Figure 5-5. Seasonal savings estimates, comparison based on similar days selection.

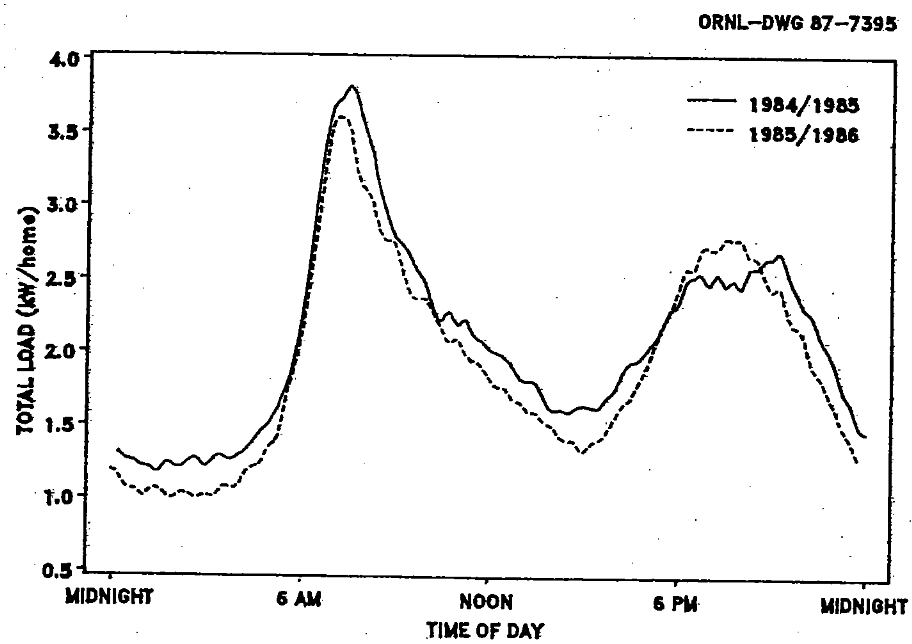

Figure 5-6. Diversified spring-weekday total load profile, comparison based on similar-days selection.

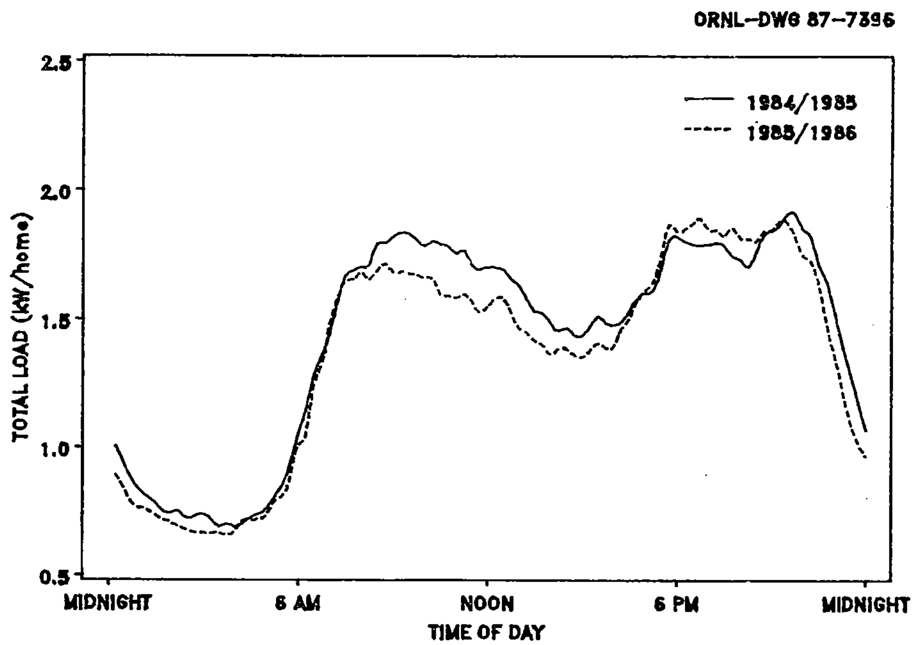

Figure 5-7. Diversified summer-weekday total load profile, comparison based on similar-days selection.

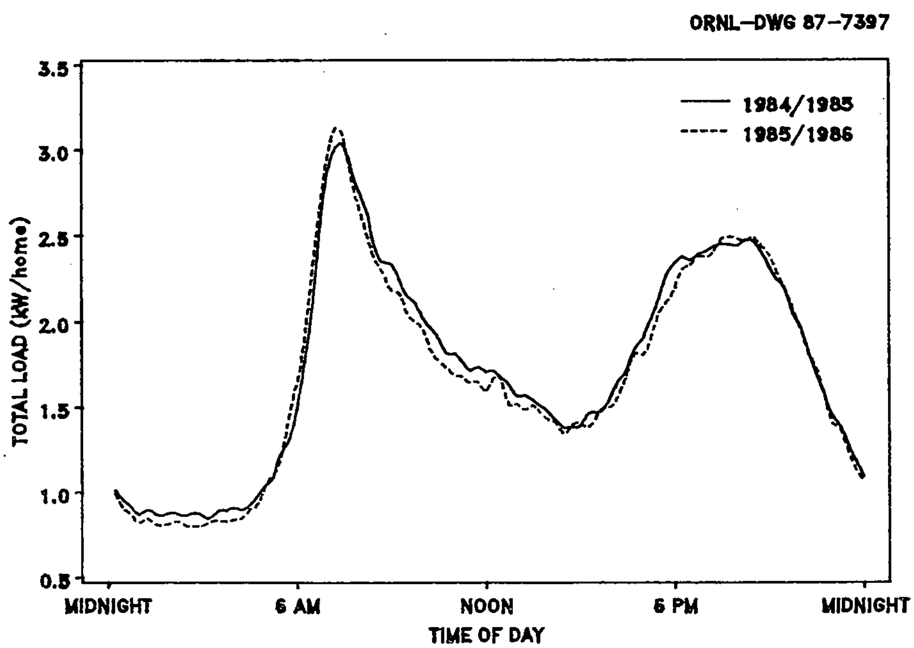

Figure 5-8. Diversified autumn-weekday total load profile, comparison based on similar-days selection.

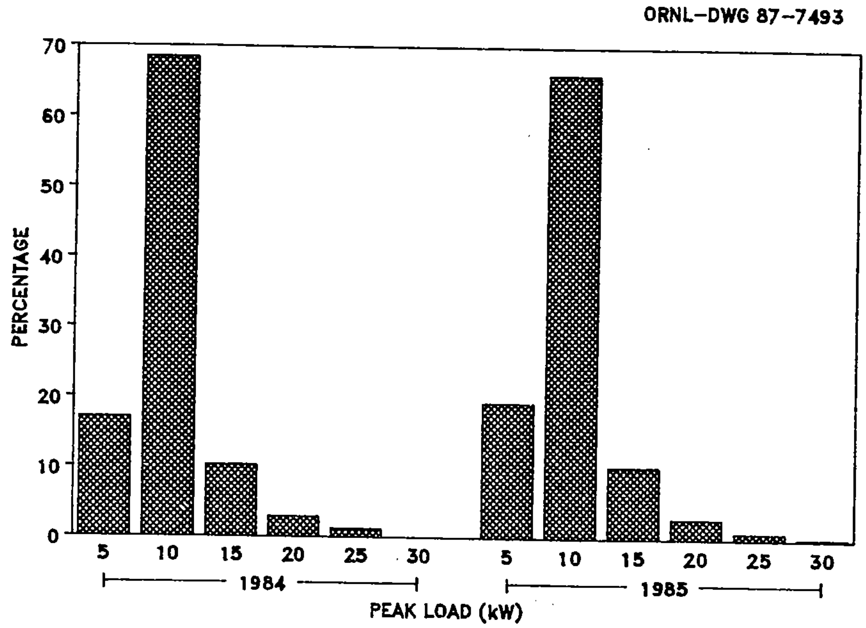

Figure 5-9. Distribution of individual-household winter maximum loads, comparison based on similar-days selection, weekdays only.

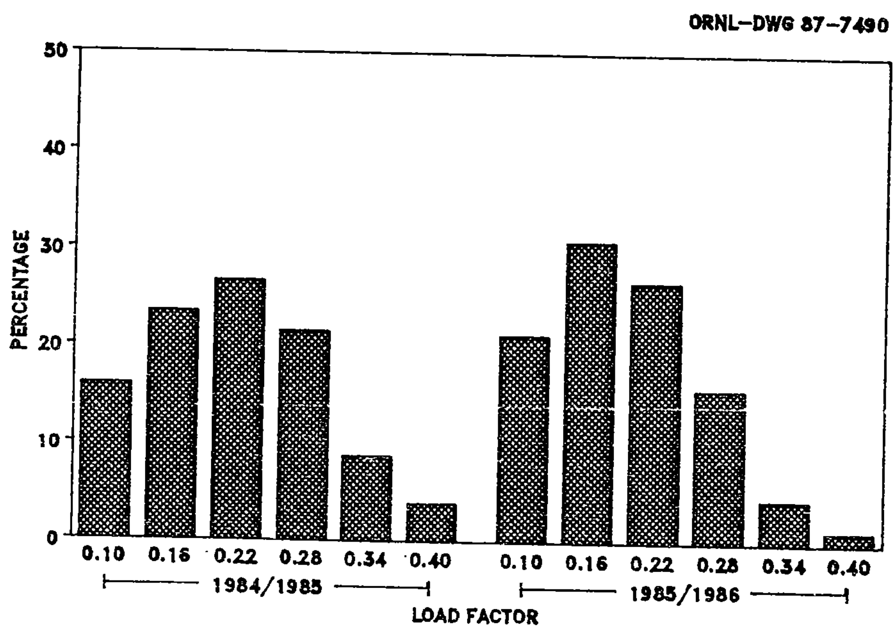

Figure 5-10. Distribution of individual-household winter load factors, comparison based on similar-days selection, weekdays only.

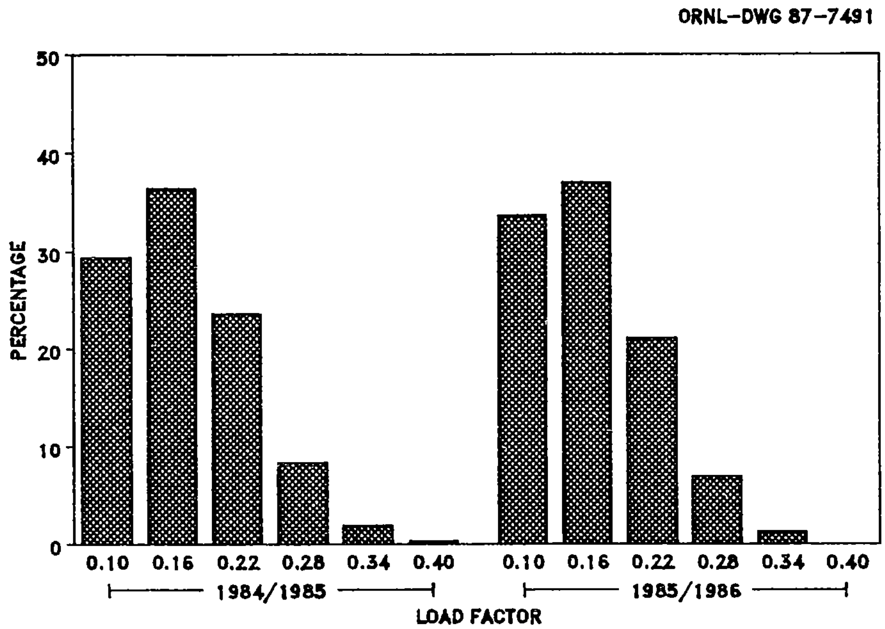

Figure 5-11. Distribution of individual-household spring load factors, comparison based on similar-days selection, weekdays only.

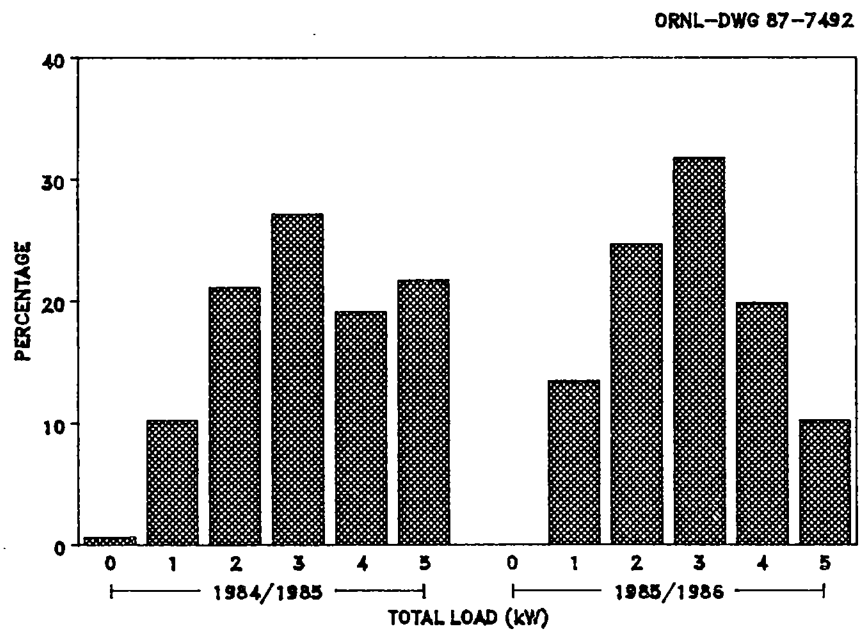

Figure 5-12. Distribution of individual-household winter total loads, comparison based on similar-days selection, weekdays only.

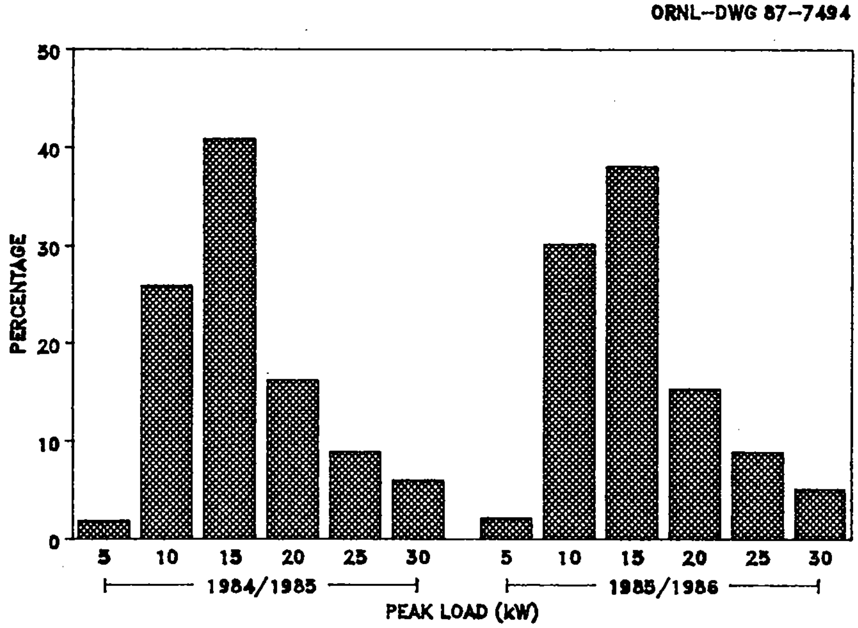

Figure 5-13. Distribution of individual-household summer maximum loads, comparison based on similar-days selection, weekdays only.

5.3 Selected Day Comparisons

Figure 5-14 shows the total diversified load savings between the first and second seasons for the weather that occurred on January 15, 1986 (a cold Wednesday with an average temperature of 31 ^{o}F), when the first season load is estimated using the regression equations discussed in Section 3.1. The average load saving from this comparison is 0.4 kW with a peak savings of 0.5 kW. Figure 5-15 shows the savings achieved when comparing the load on January 15, 1986, with the actual diversified load of January 16, 1985, two days chosen because of their similar weather. The second season average load was lower by 0.5 kW, and the peak was decreased by 0.7 kW. Both of these plots are very similar, showing significant savings throughout the day. These savings were examined in some detail. The difference between the January 16, 1985, load and that of January 15, 1986, were calculated for each 15-minute interval for each customer. These savings were then averaged for each time interval and the standard errors calculated for each value. The results of this examination (Figure 5-16) show that the savings are significantly greater than zero for 92 out of the 96 measured values. These results are summarized in Table 5-3.

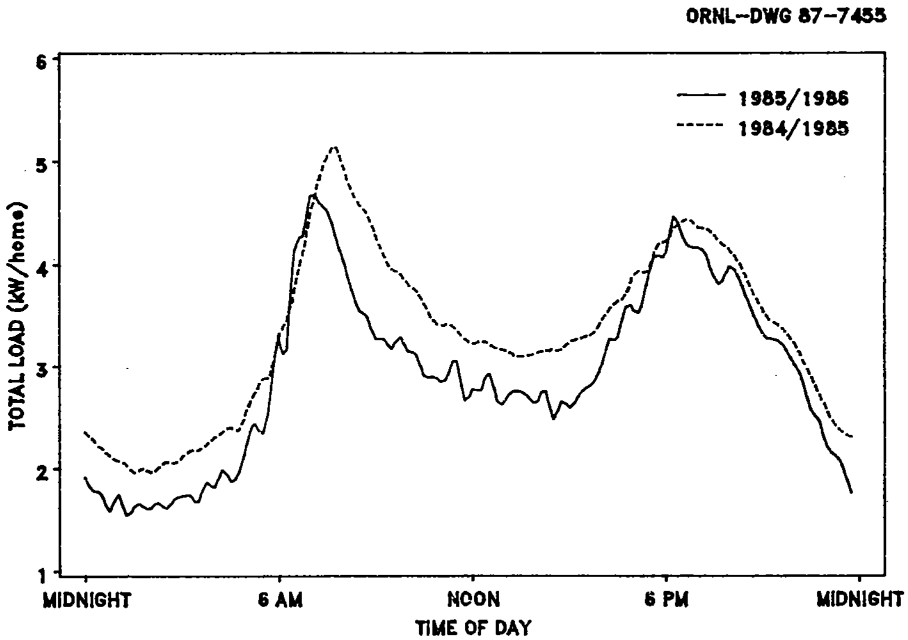

Figure 5-14. Diversified total load for January 15, 1986, comparison based on regression model.

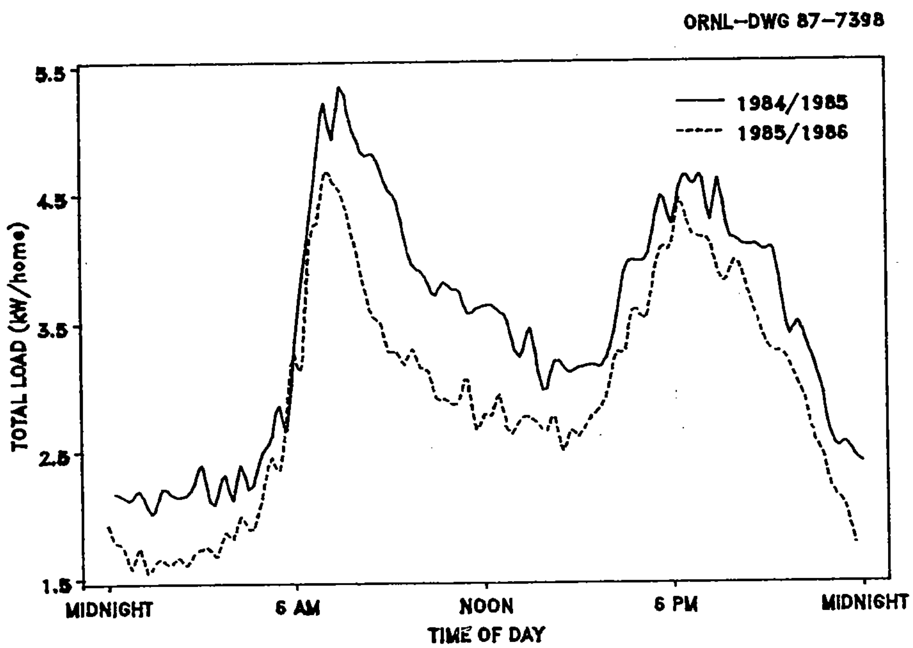

Figure 5-15. Diversified total loads for January 15, 1986, and January 16, 1985, comparison based on two similar cold days.

Table 5-3. Diversified load savings on selected similar days

Weather-normalization method	Average total load (kW/household)	Maximum total diversified load (kW/household)	Average space heating load (kW/household)
	Total monitored sample		
Regression model			
January 15, 1986[a]	3.32	5.15	
January 15, 1986	2.93	4.68	
Savings	0.39	0.47	
Similar days			
January 16, 1985	3.46	5.35	1.76
January 15, 1986	2.93	4.68	1.31
Savings	0.53	0.67	0.45
August 9, 1984	1.55	2.25	
July 26, 1985	1.44	2.07	
Savings	0.11	0.18	
	Single-family, electrically heated homes only		
Similar days			
January 16, 1985	4.23	6.19	2.63
January 15, 1986	3.23	4.80	1.80
Savings	1.00	1.39	0.83

[a] Load estimated using preconservation model from Section 3.1.

Most conservation programs focus on single-family electrically heated homes. This subset of about 150 homes was also examined on these two similar days, and the diversified load is shown in Figure 5-17. The savings portrayed in Figure 5-17 were tested in the same manner as discussed above and are shown in Figure 5-18. These savings are greater than those for the total monitored population.

A comparison of two similar hot summer days (Figure 5-19) shows some late afternoon savings of 0.1 to 0.2 kW, small compared with the wintertime savings.

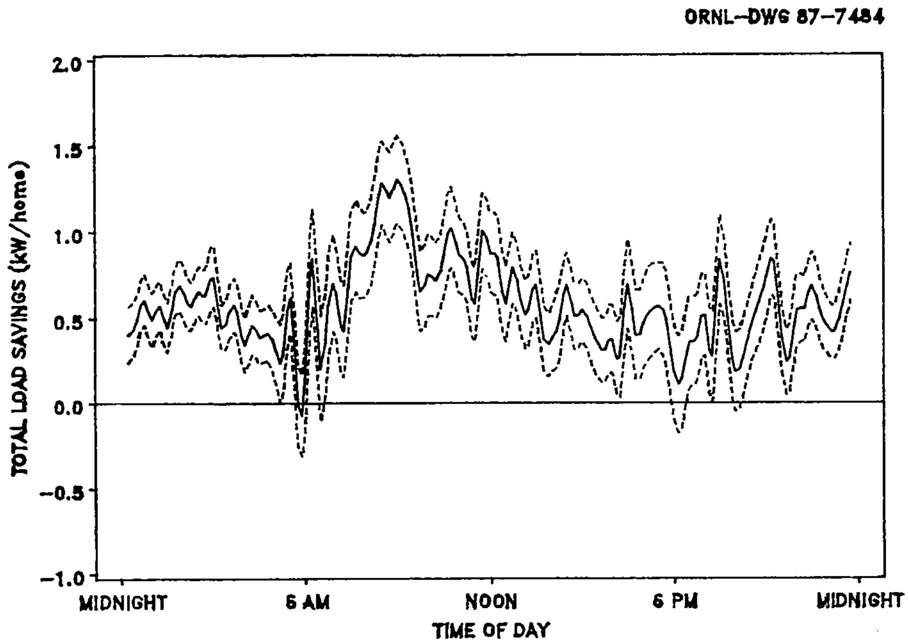

Figure 5-16. Diversified total load savings with standard error bounds for January 15, 1986, and for January 16, 1985, similar cold days.

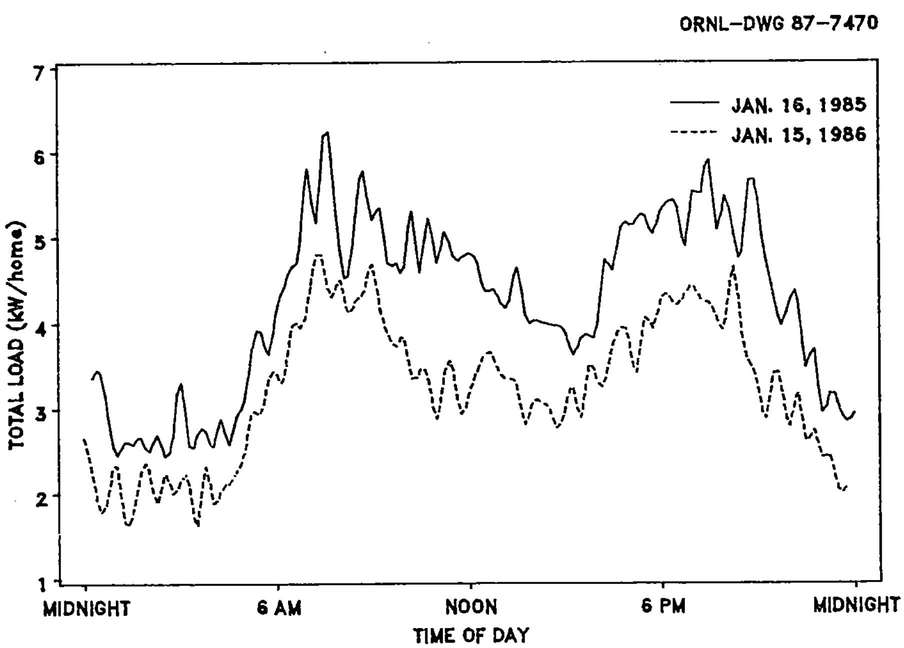

Figure 5-17. Diversified total loads for single-family electrically heated homes on January 16, 1985, and January 15, 1986, two similar cold days.

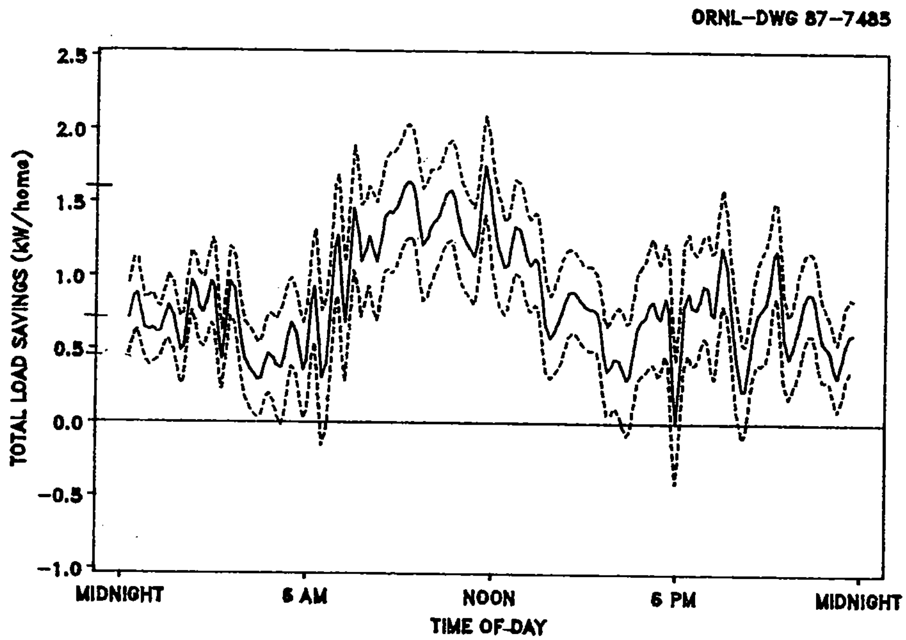

Figure 5-18. Diversified total load savings with standard error bounds for single-family electrically heated homes on January 16, 1985, and January 15, 1986, two similar cold days.

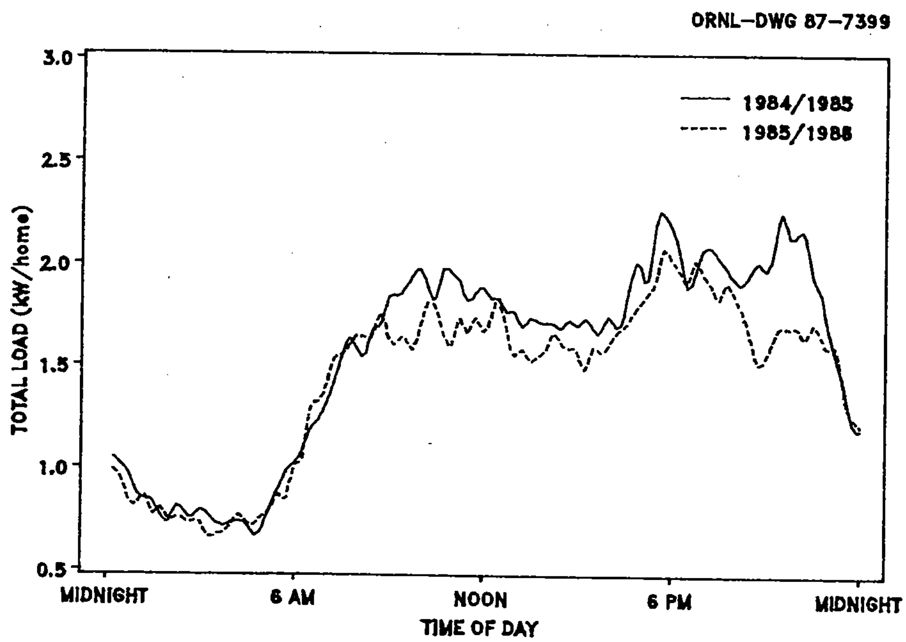

Figure 5-19. Diversified total loads for August 9, 1984, and July 26, 1985, comparison based on selection of similar days.

5.4 Load Profiles for Selected User Groups

The monitored population was examined to identify groups that showed different energy-use characteristics. The major groups chosen for examination were: (1) homes that heat exclusively with electricity vs all other homes, (2) homes that heat mainly with electricity vs homes heated mainly with wood, and (3) manufactured housing vs single-family housing.

Other groups were also examined. Although the energy-use patterns of the duplex and multifamily customers were different from that of single-family homes, there were so few (3%) that meaningful analysis was not possible. Homes that used more than one portable heater had slightly higher (about 0.2 kW/household) morning peaks than homes with less than two heaters. However, the shape of the load and the overall magnitude were very similar. Homes with air conditioners and homes with irrigation pumps had higher summer daytime loads, by about 0.1 to 0.3 kW/household, but these differences were much smaller than the differences (close to 1 kW/household) noted in the groups chosen. Load profiles for all of these comparison groups are included in Appendix E.

Table 5.4 compares the program savings for single-family homes and manufactured homes. The average total load savings for single-family homes (0.48 kW, 14%) were almost twice those of the mobile homes (0.26 kW, 8%). These single-family savings are comparable to those accomplished by the Bonneville Residential Weatherization Pilot Program where first-year savings were about 17 percent (Hirst et al. 1985). The larger single-family savings are due to larger space heating savings, even though the average space heating load of the mobile homes was larger. Single-family homes saved an average of 24 percent of their space heating energy compared with only eight percent for the mobile homes. Figures 5-20 and 5-21 compare the diversified space heating loads on winter weekdays for single-family homes and mobile homes before and after the conservation retrofits. The difficulty in retrofitting mobile homes is underscored by the different investment levels achieved in these homes. The average cost of installed insulation was almost $1,500 more in single-family homes than in mobile homes. Almost $400 more, on the average, was spent on window and door retrofits for single-family homes as well.

Table 5-5 compares the program savings for homes that claim to heat with mostly wood or prestologs with homes that claim to use mainly, but not exclusively, electricity. The savings for the wood-heated homes are less than one-third of the savings in electrically heated homes. As expected, the difference is attributable to differences in savings in space heating use (Figure 5-22). Note that the measured heat output of the wood stoves in these homes also decreased significantly (Figure 5-23), showing that these homes are conserving energy even if not in the form of electricity. A more detailed analysis of wood-heat use and savings can be found in Tonn and White (1985).

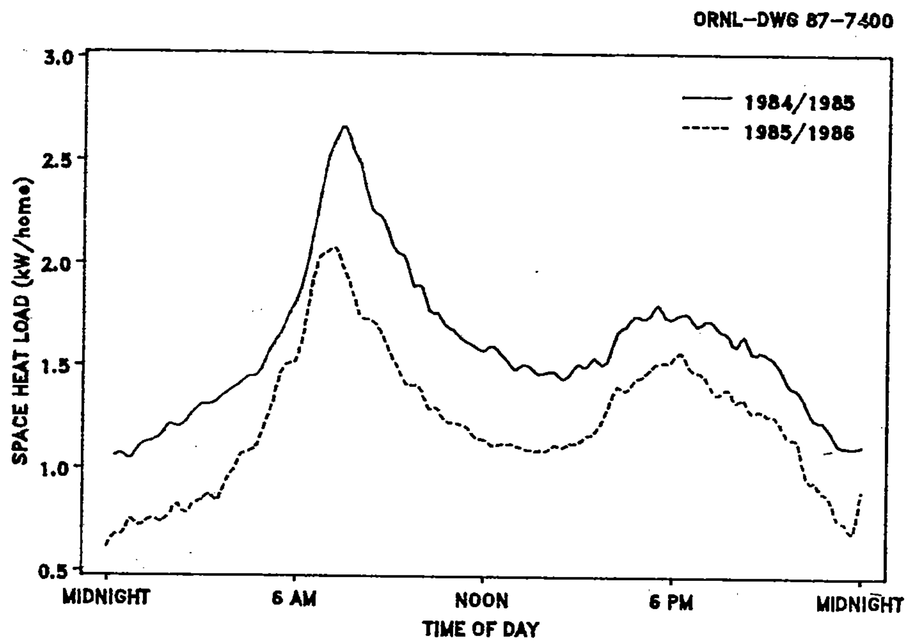

Figure 5-20. Diversified space heating load for single-family homes on winter weekdays, comparison based on similar-days selection.

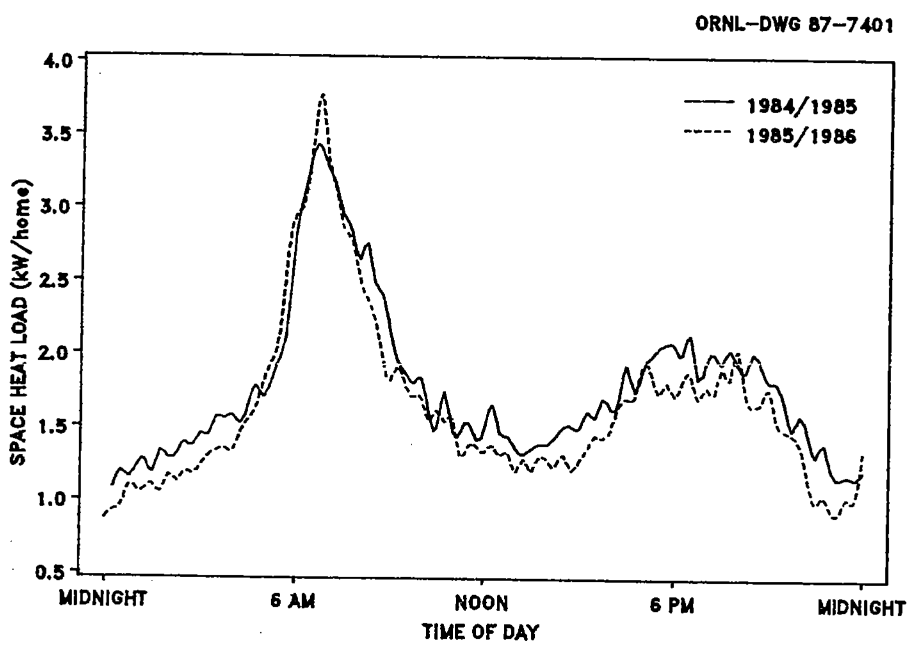

Figure 5-21. Diversified space heating load for mobile homes on winter weekdays, comparison based on similar-days selection.

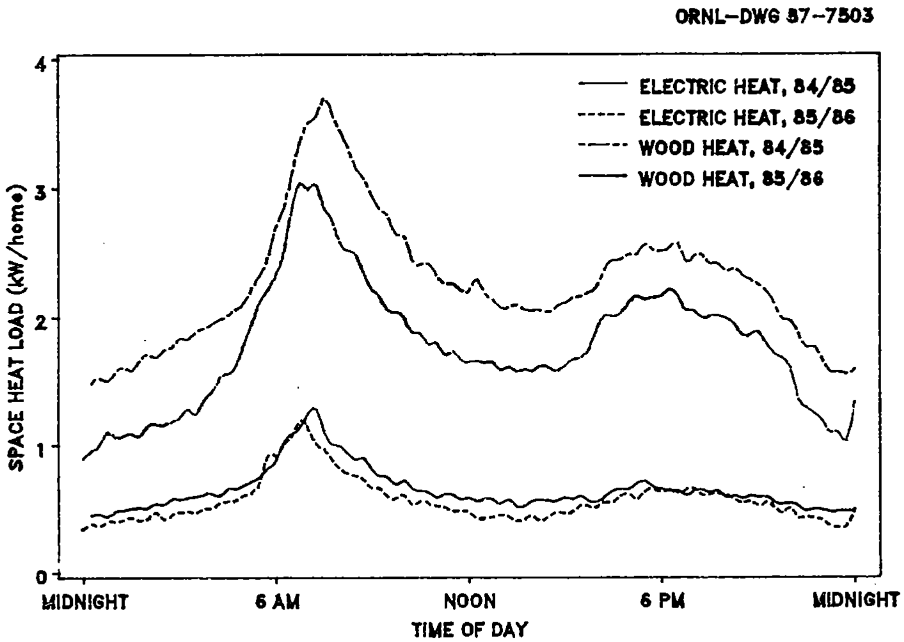

Figure 5-22. Diversified space heating load for homes heated mainly by electricity and homes heated mainly by wood on winter weekdays, comparison based on similar-days selection.

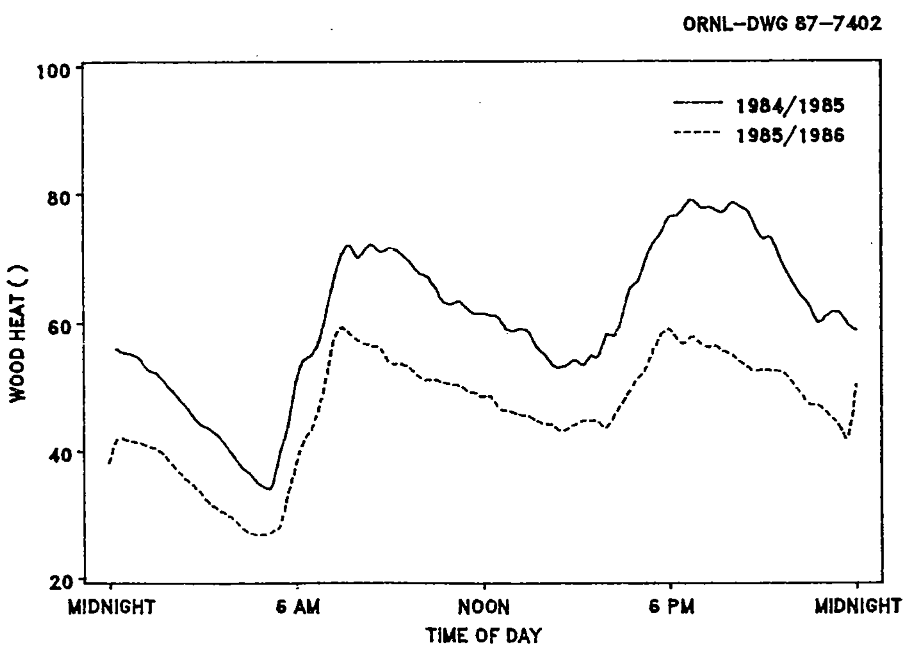

Figure 5-23. Diversified wood heat use for homes heated mainly by wood on winter weekdays, comparison based on similar days selection.

Table 5-4. Average load savings for single-family homes and mobile homes

Average load	Home type (kW/household)			
	Single-family		Mobile	
	Winter	Summer	Winter	Summer
Total before	3.42	1.48	3.32	1.31
Total after	2.94	1.41	3.06	1.27
Total saving	0.48	0.07	0.26	0.04
Space heat before	1.61		1.77	
Space heat after	1.23		1.63	
Space heat saving	0.38		0.14	
Water heating before	0.62	0.49	0.60	0.42
Water heating after	0.56	0.44	0.47	0.38
Water heating saving	0.06	0.05	0.13	0.04

Table 5-5. Average load savings for electrically and wood-heated homes

Average load	Fuel used to heat home (kW/household)			
	Mainly electricity[a]	Mainly wood[a]	Exclusively electricity[b]	Electricity and/or wood[b]
Total before	3.98	2.47	3.94	3.20
Total after	3.36	2.30	3.31	2.82
Total saving	0.62	0.17	0.63	0.38
Space heat before	2.28	0.65	2.48	1.35
Space heat after	1.78	0.56	1.93	1.09
Space heat saving	0.50	0.09	0.55	0.26

[a] This division is based on the customer's response to the question, "Indicate which one of the fuels listed is used most of the time to heat your home."

[b] This division is based on the same question in footnote a, supplemented by the customers' responses to another question: "Do you use any other fuels to heat your home in addition to the fuel you use most of the time?"

Upon examination, Table 5-5 shows that those customers who heat their homes exclusively with electricity do not appear to save any more energy than those customers who claim to use electricity as their main heating fuel with supplementary non-electrical heat (0.63 vs 0.62 kW). However, the group of customers who use some wood is very different from the group who use mainly wood. Occasional wood users save almost twice as much electric energy as primary wood users. It would, therefore, appear that conservation programs aimed at saving electric energy need not rule out all customers with wood stoves but, rather, only those who use the wood stove as their main heating source.

5.5 Residential Loads on System and Area Peak Days

During the first heating season, both the Hood River area and the Pacific system peaks occurred on the same day, February 4, 1985. During the second heating season, the Hood River area peak occurred on November 25, 1985, and the Pacific peak occurred on December 13, 1985. As discussed in Section 4.4, the weather for these days varies from daily minimum temperatures of 0 ^{o}F on February 4 to 8 and 13 ^{o}F on November 25 and December 13, respectively. The regression-based weather-normalization method described in Section 3.1 was, therefore, used to estimate the diversified load that would have occurred before the conservation program for the weather that occurred on November 25 and December 13, 1985. The loads for these days are shown in Figures 5-24 and 5-25. This weather-normalized comparison shows the post-conservation load to be lowered by 0.56 kW/household on the Hood River area peak day and by 0.52 kW/household on the Pacific peak day. The time of the peak appears to advance by 15 to 30 minutes as well.

Figures 5-26 and 5-27 show the difference between single-family homes and mobile homes on February 4, 1985, and December 13, 1985, respectively. On both days, the mobile home diversified load was higher than the single--family home diversified load during the morning peak hours, by about 1.9 kW in February and 1.4 kW in December. In December the mobile home evening load was also higher although it was about the same in February.

The relationship between homes heated mainly by electricity and those heated mainly by wood on peak days also appears unchanged between the two seasons (Figures 5-28 and 5-29). On both peak days, the electrically heated home diversified load peaks are greater than three kW/household higher than the wood-heated home diversified load peaks.

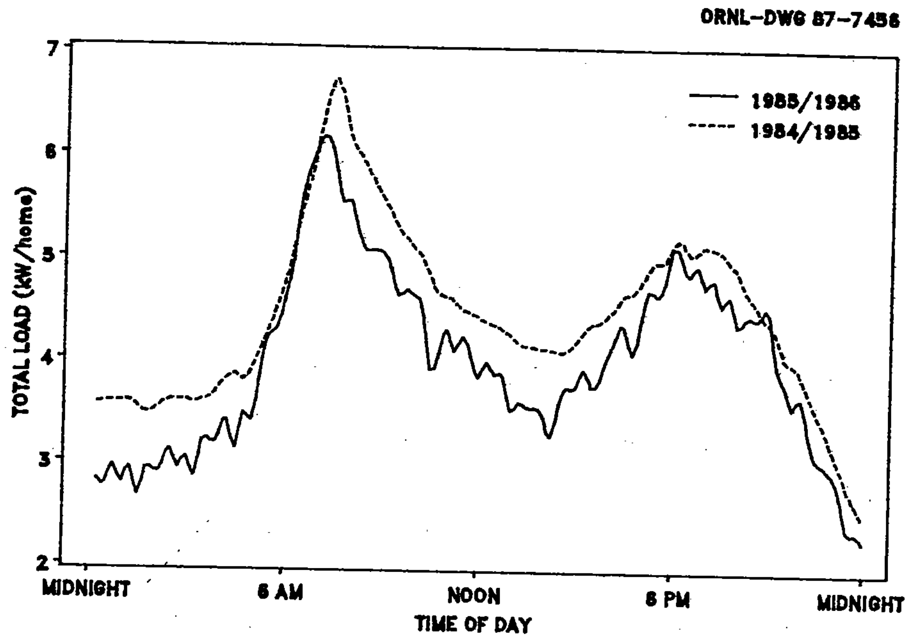

Figure 5-24. Diversified total residential load on Hood River area peak day, November 25, 1985, weather-normalized using regression model.

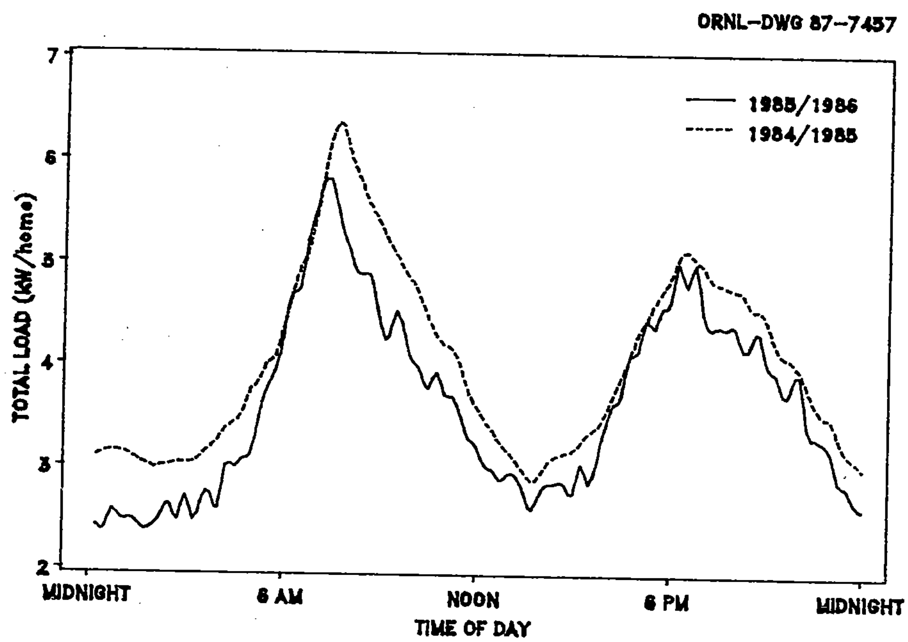

Figure 5-25. Diversified total residential load on Pacific system peak day, December 13, 1985, weather-normalized using regression model.

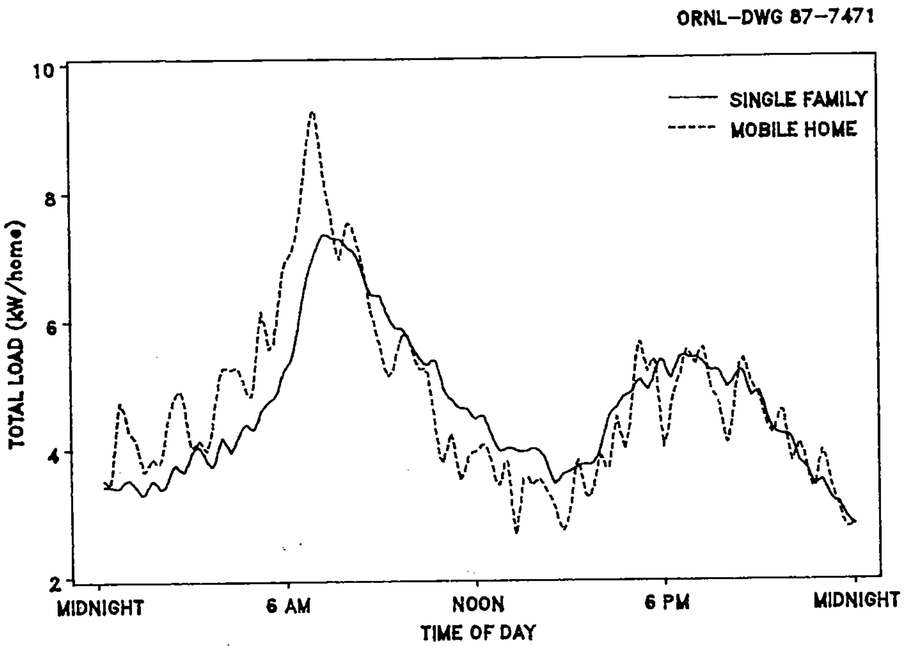

Figure 5-26. Diversified total residential load on February 4, 1985, (Pacific system and Hood River area peak day) for single-family and mobile homes.

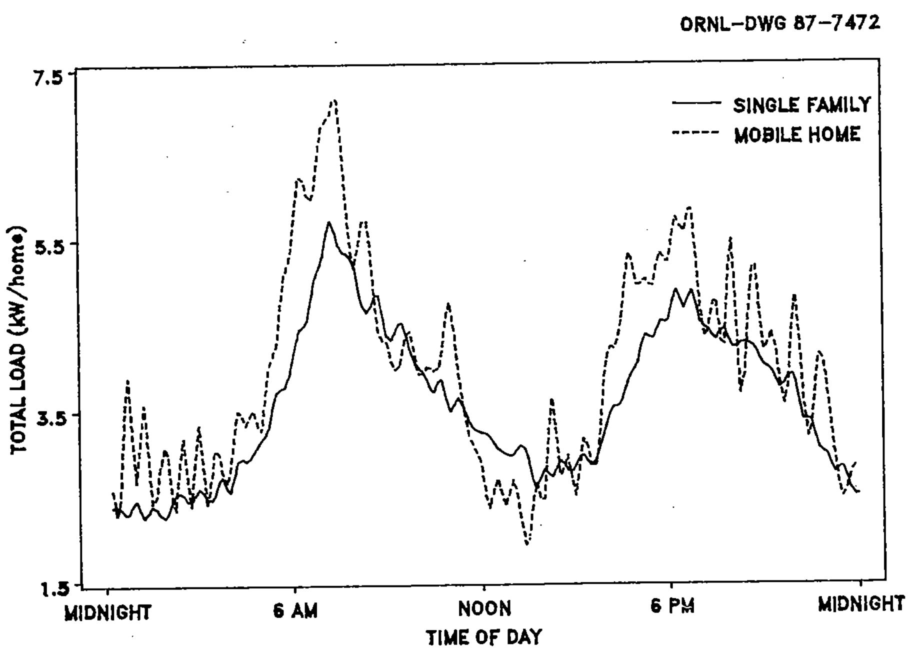

Figure 5-27. Diversified total residential load on December 13, 1985, (Pacific system peak day) for single-family and mobile homes.

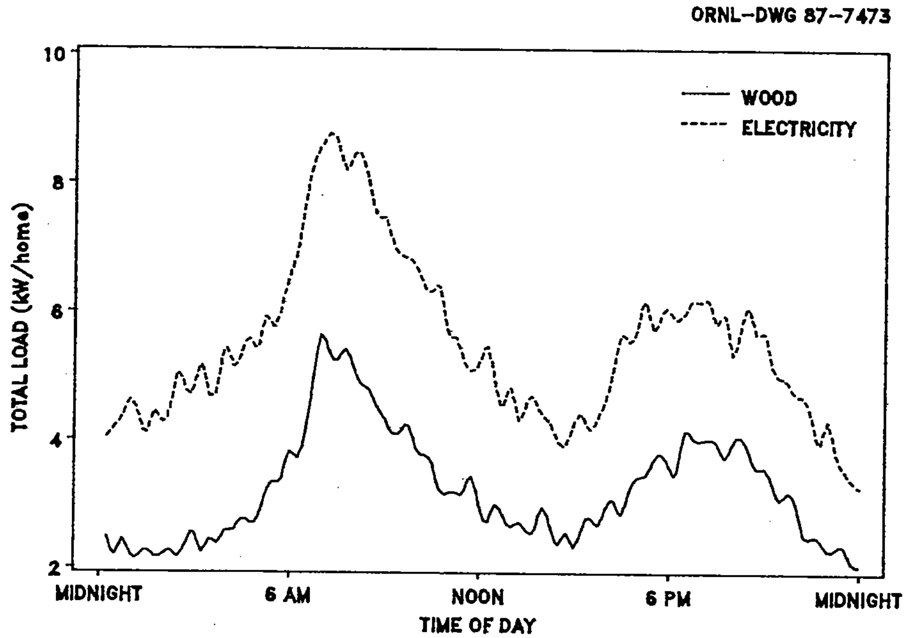

Figure 5-28. Diversified total residential load on February 4, 1985 (Pacific system and Hood River area peak day) for wood-heated and electrically heated homes.

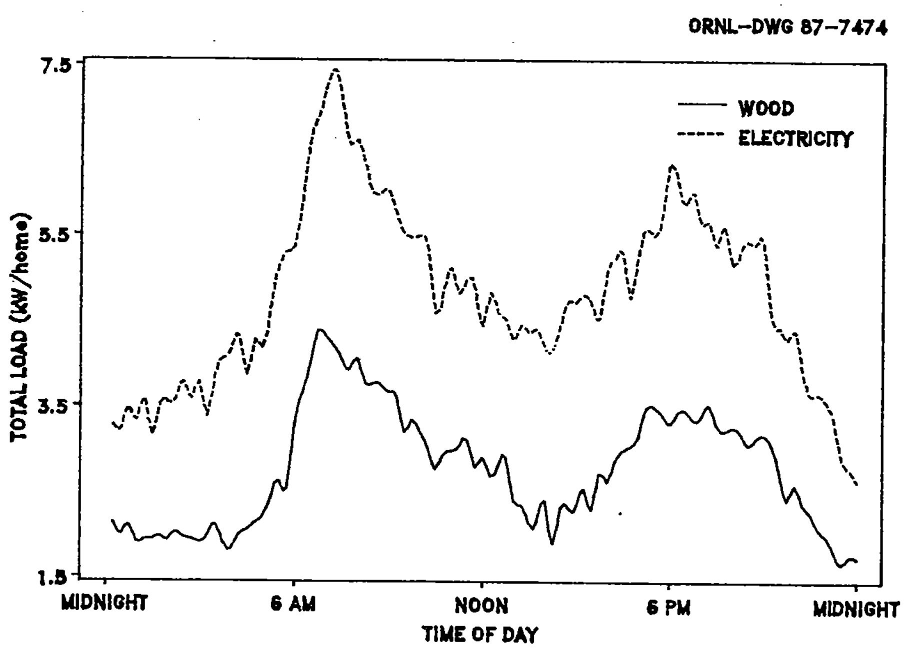

Figure 5-29. Diversified total residential load on November 25, 1985 (Hood River area peak day) for wood-heated and electrically heated homes.

6. Capacity and Diversity Factors

Load diversity occurs when the total connected load is not operated all of the time and customer use patterns vary. There are a number of common measures of load diversity. A diversity factor is the ratio of the sum of the individual maximum demands of various system subdivisions to the maximum demand of the whole system and is always equal to or greater than one. The coincidence factor is the reciprocal of the diversity factor. The peak contribution factor of a subdivision of the system is the demand of that subdivision, at the time of occurrence of the maximum system demand, divided by the maximum system demand. These definitions are illustrated in Figure 6-1. The load factor is the average load divided by the maximum load and can be calculated for any system or system subdivision. Note that all of these definitions produce a single number that depends on the relative maxima of load curves. This dependence reflects the requirement that adequate resources must be available to serve the maximum demand on the system and any of its subdivisions (Kuliasha 1980).

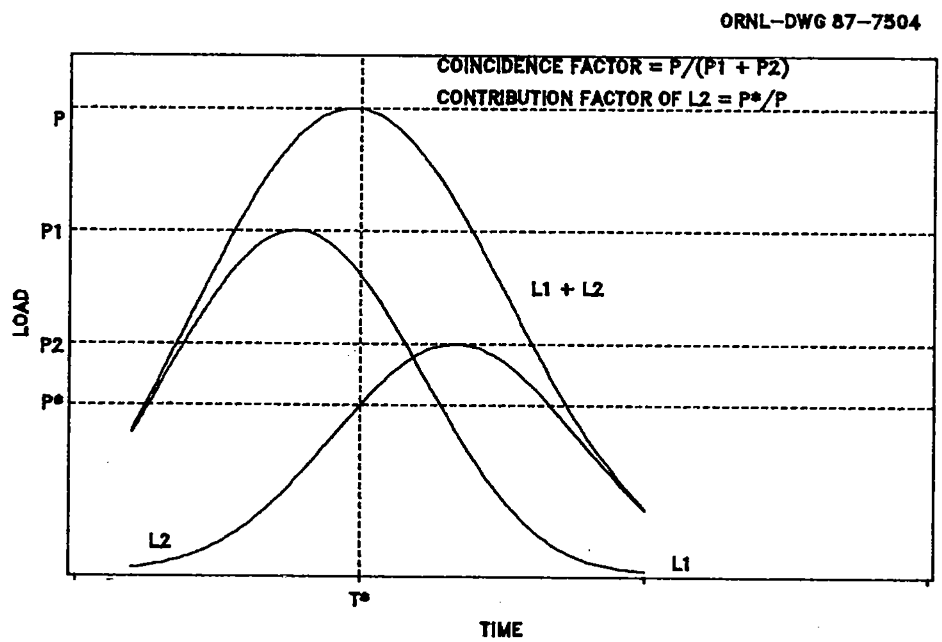

Figure 6-1. Capacity and diversity factor definitions.

Because all of these factors are peak related, they were calculated for the three peak days of interest: February 4, 1985 (preretrofit), when the total Pacific system peaked from 8:00 to 9:00 a.m. and the Hood River area peaked from 9:00 to 10:00 a.m.; November 25, 1985 (post-retrofit), when the Hood River area peaked from 7:00 to 8:00 a.m.; and December 13, 1985, when the Pacific system peaked from 8:00 to 9:00 a.m.

Using the user groups defined in Section 5.4 as load subdivisions, Tables 6-1 to 6-3 summarize these factors for the monitored customers. Table 6-1 shows the coincidence and diversity factors for the monitored customers divided according to dwelling type, main heating fuel, and homes heated exclusively with electricity. All of these factors are very close to 1.0, indicating that the diversified load of each subgroup (e.g., single-family and mobile homes) peaks at about the same time (Figure 5-27). The conservation program apparently had no effect on this high degree of coincidence among the various user groups, a fact demonstrated by comparing Figures 5-26 and 5-27 and Figures 5-28 and 5-29. However, the diversity for each customer treated as an individual load subdivision increased between the peak days of the first and second seasons, with the coincidence factor dropping from 0.56 to 0.51 and 0.48.

Table 6-1. Coincidence and diversity factors for Pacific system and Hood River area peak days

	Preretrofit	Postretrofit Factors	
	Feb. 4, 1985	Nov. 25, 1985	Dec. 13, 1985
	Coincidence factors		
Dwelling[a]	0.97	0.98	0.98
Main heating fuel[b]	0.99	0.99	1.00
Electrically heated[c]	0.98	1.00	0.98
Individual homes[d]	0.56	0.51	0.48
	Diversity factors		
Dwelling[a]	1.03	1.02	1.02
Main heating fuel[b]	1.01	1.01	1.00
Electrically heated[c]	1.02	1.00	1.02
Individual homes[d]	1.79	1.98	2.07

[a] Compares diversified load of single-family dwellings with the diversified load of mobile homes.

[b] Compares diversified load of homes heated mostly by electricity to the diversified load of homes heated mostly by wood.

[c] Compares diversified load of homes heated exclusively by electricity with that of all other homes.

[d] Each customer is treated as a load subdivision.

Table 6-2. Contribution factors for Pacific system and Hood River area peak days

Dwelling type and main fuel	Feb. 4, 1985 9:00 a.m.	Feb. 4, 1985 10:00 a.m.	Nov. 25, 1985 8:00 a.m.	Dec. 13, 1985 9:00 a.m.
	Contribution factors			
Dwelling types[a]				
Single family	0.80	0.80	0.80	0.79
Mobile homes	0.17	0.16	0.17	0.18
Main heating fuel				
Electricity	0.72	0.72	0.73	0.70
Wood	0.27	0.28	0.27	0.30
	Contribution factor/household (x 10,000)			
Dwelling types				
Single family	33	33	33	33
Mobile homes	32	31	33	35
Main heating/fuel				
Electricity	39	39	39	37
Wood	23	23	23	26

[a] Dwelling type factors do not add up to 1.00 because of the small amount of multifamily loads.

Table 6-3. Load factors for Pacific system and Hood River area peak days

Load groups	Feb. 4, 1985	Nov. 25, 1985	Dec. 13, 1985
Total diversified load	0.62	0.65	0.62
Dwelling type			
Single family	0.63	0.65	0.62
Mobile homes	0.51	0.60	0.55
Main heating fuel			
Electricity	0.63	0.65	0.63
Wood	0.57	0.63	0.59
Heating source			
Electricity only	0.65	0.72	0.68
Electricity and/or wood	0.60	0.62	0.58

Contribution factors (given in Table 6-2 for the four peak hours) were calculated to reflect the portion of the monitored residential load attributable to each load subdivision at the time of the system (or area) peak. Single-family homes are seen to contribute about 80 percent of the monitored residential load; mobile homes account for about 17 percent. However, when the contribution factors were divided by the number of households in each group, mobile and single-family homes were seen to be about equal in their contribution to the system peak load. The contribution factors for dwelling type groups were unaffected by the program. Electrically heated homes as a group appeared to contribute about three times as much demand at the time of the peak load as wood-heated homes. However, on a per home basis, the electrically heated home contributions were less than twice as large as those of wood-heated homes. There was a very slight shift in contribution factors during the second season Pacific peak toward increased electricity use in wood-heated homes. This slight increase may reflect the higher electricity savings for the electrically heated homes. However, the change is too small to reach any definitive conclusions.

Load factors for the three peak days for the total diversified load and for various user groups are shown in Table 6-3. A higher load factor indicates a flatter, more-uniform load profile. A lower load factor reflects a load with a high peak but with a lower average load. As expected, those homes heated exclusively with electricity show the best, or highest, load factors. Mobile homes, with low mass for thermal storage, show the lowest load factors. There appears to be a noticeable improvement in the mobile home load factors following the program although, again, the weather differences between the peak days could account for this improvement. Homes heated exclusively with electricity also showed improvement. Other groups were relatively unchanged.

7. A Potential New Approach to Conservation as Load Relief

7.1 Introduction

Conservation is promoted as an alternative to the construction of new power-producing facilities. As discussed elsewhere in this report, one of the main focuses of Project was to quantify the load relief achievable by a vigorous conservation program. The analysis of the load savings in this report has followed the traditional path of examining on system peak days the diversified residential loads before and after conservation retrofits. However, this approach does not adequately address the nature of a conservation resource.

Power-producing facilities may be turned on or off at the utility's direction to meet the needs or demands of the customers composing the total system. Some forms of residential load relief systems are also controlled by the utility (e.g., when air conditioners or water heaters are remotely interrupted at times of system peak loads). Conservation, on the other hand, is nondispatchable and cannot be controlled by the utility. It is based on the individual responses of a large number of small users who may, or may not, elect to use electricity at any level at any time.

Using the diversified load of a large number of customers helps to iron out the variations of individual households. However, there is still the possibility that many customers will raise their thermostats on the coldest day of the year or that homeowners who have burned wood all season may decide that they would rather not venture through the blizzard to the wood pile when they can turn on their baseboard heating systems instead. In other words, this analysis identifies savings achieved during the winter of 1985/86 but cannot say with what degree of assurance this behavior will be repeated in subsequent years.

The rest of this section describes a proposed new, and perhaps more convincing, approach toward evaluating the impact of conservation on utility load forecasting. It is hoped that this proposal will generate discussion and further study of the potential of conservation to provide capacity, as well as energy, savings.

7.2 One Proposed Analysis Method

One way of correcting the load relief estimates to more accurately reflect reality may be to structure them in a probabilistic fashion. Such an approach has been used to estimate the expected value of outages and the consumer interruption costs based on the probability distribution of outages (See National Electric Reliability Study (1981). For this application, the method would need to consider the probability distributions of load savings as a function of time-of-day, outdoor temperature, and day of the week. These functions would then need to be combined with similar functions describing the probable timing of the system peak.

An initial attempt to demonstrate how this method could be applied using the Project data base is shown in Figures 7-1 and 7-2. A distribution of peak times for the diversified residential loads was generated by using the weather-normalized sets of similar days to screen for the peak load on each day (Figure 7-1). This distribution shows that most of the residential peaks occur at about 7:00 a.m. During the second season, however, the late morning peaks were more evenly distributed than in the first season. A distribution relating the time of the peak to the outdoor temperature at that time is shown in Figure 7-2. This distribution, based on a small fraction of the data available, may show a tendency toward later morning peaks on colder days (perhaps caused by longer furnace cycle times).

ORNL-DWG 87-7505

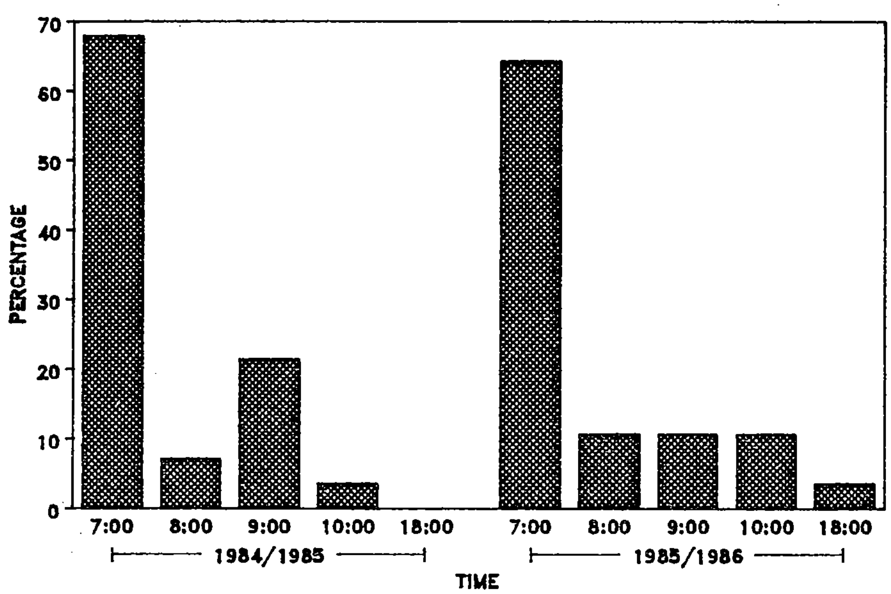

Figure 7-1. Probability distribution of the time of the daily peaks of the diversified residential load.

Further work could develop similar probability distributions for the load savings for different times of day, different seasons, etc. The end result of such an approach would be a more reliable estimate of the load relief achievable at system peak times through conservation efforts.

ORNL-DWG 87-7506

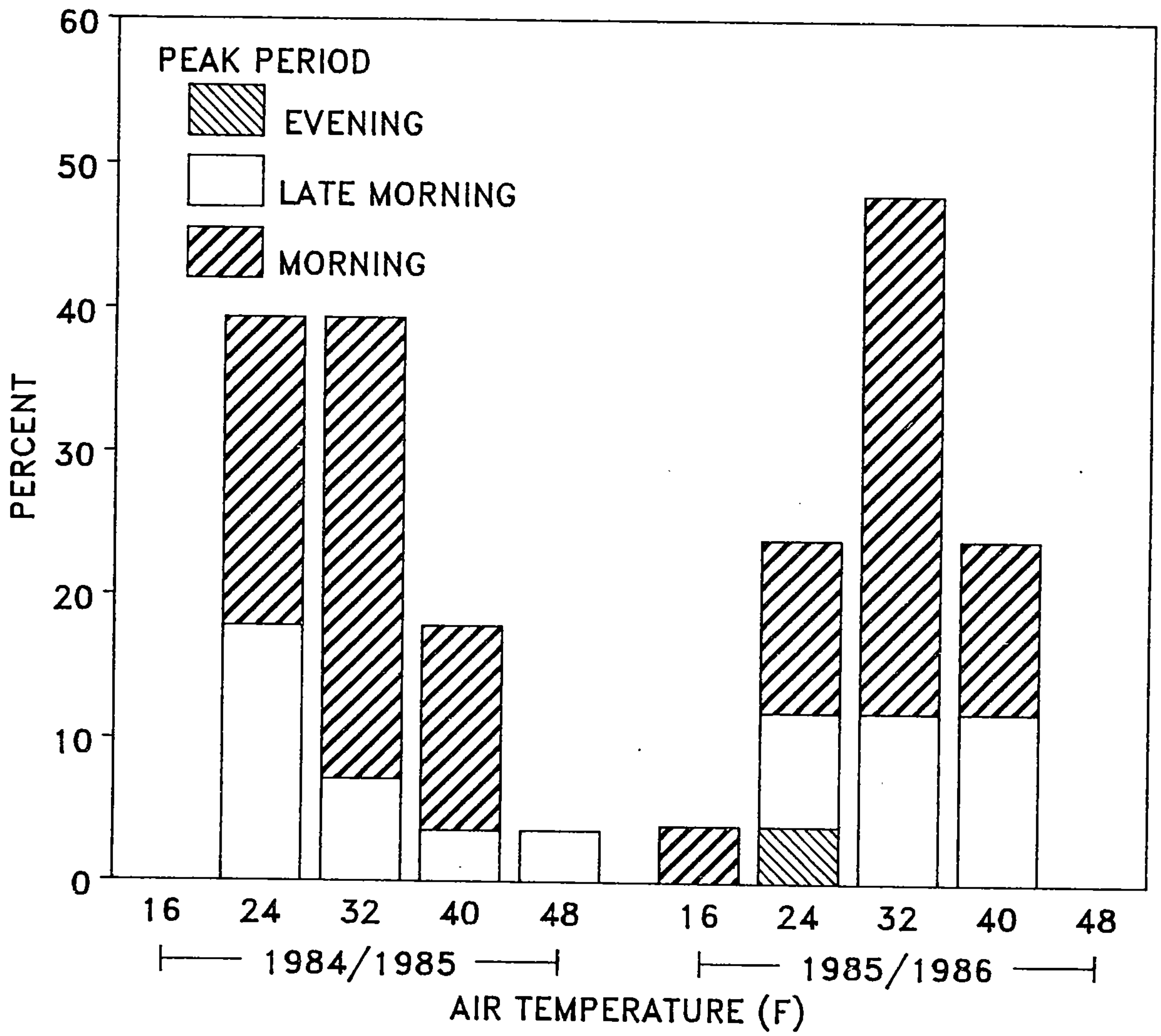

Figure 7-2. Probability distribution of the outside dry-bulb temperature at the time of the daily peak, shown according to the time of the peak.

8. Conclusions and Recommendations

8.1 Conclusions

The weather-normalized diversified residential load saving on the Pacific system and Hood River area peak days was greater than 0.5 kW/household. The load distribution also shows a significant reduction in both peak load levels and in the amount of time spent at higher loads. The average load savings was about 0.4 kW/household throughout the winter season, December-February. The spring, summer, and fall savings were much less, about 0.1 kW/household. Savings for single-family homes heated mainly with electricity were higher, averaging 0.6 kW/household in the winter season.

The load factor of the diversified residential load decreased following the conservation retrofits because of peak-load savings that are proportionally less than the average load savings. To avoid this effect, a conservation program may need to include HVAC equipment and appliance improvements in addition to the weatherization retrofits used in Project. Such equipment improvements would be likely to reduce the maximum demand per household, which was relatively unaffected by the Project weatherization improvements.

Examination of these load data suggests that load reductions attributable to the Project retrofits increase with decreasing ambient temperature. Thus, the project reduced the electric system's sensitivity to cold weather.

Single-family home savings were almost twice as large as those achieved in mobile homes, although the pre-program electrical loads are comparable. Single-family homes saved an average of 24 percent of their space heating energy compared with only eight percent for the mobile homes. This reflects the inherent difficulty in applying weatherization retrofits to mobile homes (also shown by the lower investment levels). Research in new conservation methods or building standards for mobile homes would appear to be warranted.

The load savings for homes heated mainly by wood (as indicated in homeowner questionnaires) are less than one-third of the savings for electrically heated homes. Therefore, these wood-heated homes should be excluded from any program where the objective is saving electricity. However, savings in homes where the electric heat may be supplemented with wood heat are not significantly less than savings in homes heated exclusively with electricity (0.62 vs 0.63 kW), and these homes should not be excluded. Woodstove heat output was also reduced by the program so that improved air quality may be a side product of the conservation program although air quality was not measured. Also, the peak-load contribution of wood-heated homes would nearly double if the occupants chose to return to the use of electric heat. Inclusion of such homes in conservation programs may, therefore, serve as a form of insurance against sudden large residential load increases in the future.

Programmatic savings measurements on the monitored feeder were hampered by several confounding factors. Overall, the feeder loads decreased by a very small amount during the fall and winter and increased during the spring and summer. Relationships between decreases in feeder load and residential end-use savings could not be ascertained because of the small size of the change in feeder load, the unmeasured commercial loads, and the timing of the residential retrofits.

8.2 Future Research Directions

The huge amounts of information collected for this load study could be used to provide much more knowledge about conservation mechanisms than has been available before. This evaluation focused on the results achievable from the Project approach of maximum market penetration to every home with installed electric space heating equipment. Therefore, although some disaggregation according to housing type was included in this analysis, much more is possible and should be pursued. More study of electrically heated single-family homes would certainly be useful. These homes are most frequently targeted by conservation programs because their savings potential is usually larger than that of other homes. For example, the regression-based weather normalization could be optimized for this group of houses, permitting a closer examination of their behavior on system peak days. A more detailed examination of "occasional" wood users could yield useful application guidelines for utilities to use when targeting programs for maximum conservation results. Further disaggregation may permit estimates of potential savings on distribution transformers.

Commercial loads and many non-electrically heated homes supplied by the monitored feeder were monitored beginning in February 1986. A careful combination of this load data (once a full winter's data have been collected) with past billing histories may permit further investigation of the effect of Project on feeder-level loads. A more detailed examination of the residential customers on the feeder, for example, determining what portion of them uses significant amounts of wood heat, might also be useful in explaining why the changes between seasons were so small.

A possible new approach has been introduced to help quantify conservation-based load relief for utility load planners. This treatment recognizes the uncontrolled nature of conservation resources and treats them in a realistic manner that may improve the reliability and acceptability of forecasts based on the use of conservation for load relief. This concept has been only sketchily introduced in this analysis and is worthy of further development. The Hood River data base is large enough to provide a basis for this development.

The water heater data should be examined to determine which of the two water heater savings measures, the water heater wrap or the low-flow shower heads, is the most effective. This could be done by examining the time distribution of the water heater savings (i.e., comparing the savings during and immediately following the high-use periods to the savings that are more constant throughout the day).

Acknowledgements

Many people have contributed to the Hood River Project and to this load analysis in particular. Terry Oliver and Ken Keating of the Bonneville Power Administration and Gil Peach of Pacific Power & Light provided valuable program guidance. The Pacific staff -- in particular, Karen Schoch, Greg Paetzhold, and Doug McAllister -- worked extensively to clean and prepare the data for this analysis. Mike Kuliasha and Eric Hirst of Oak Ridge National Laboratory (ORNL) helped to plan this project and reviewed its progress. Rick Goeltz of ORNL was an enormous help in accessing the project data base and monthly billing records for the feeder customers.

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Appendix A: Weather Normalization, Regression Test Results

Four models, all based on the results of multivariate linear regressions and discussed in Section 3.1, were developed for weather-normalization purposes. All four models were tested for autocorrelation by using the Durbin-Watson test, and no evidence of autocorrelation was detected.

The model for weekday nights had an adjusted R^2 of 0.985. All of the independent variables were significant above the 99.9 percent level as judged by the t-test. The model for weekday days had an adjusted R^2 of 0.971, and all of the variables were significant above the 99.9 percent level except for the 30-minute lagged solar variable, which was significant at the 98.2 percent level. The model for weekend nights had an adjusted R^2 of 0.978, and all of the variables were significant above the 99.9 percent level. The model for weekend days had an adjusted R^2 of 0.962, and all of the variables were significant at the 99.9 percent level except for the dummy midday variable at 99.5 percent and the SIN3 term at 85 percent.

The residuals are plotted against the predicted values for these four models in Figures A-1 to A-4. They are plotted against date-time in Figures A-5 to A-8.

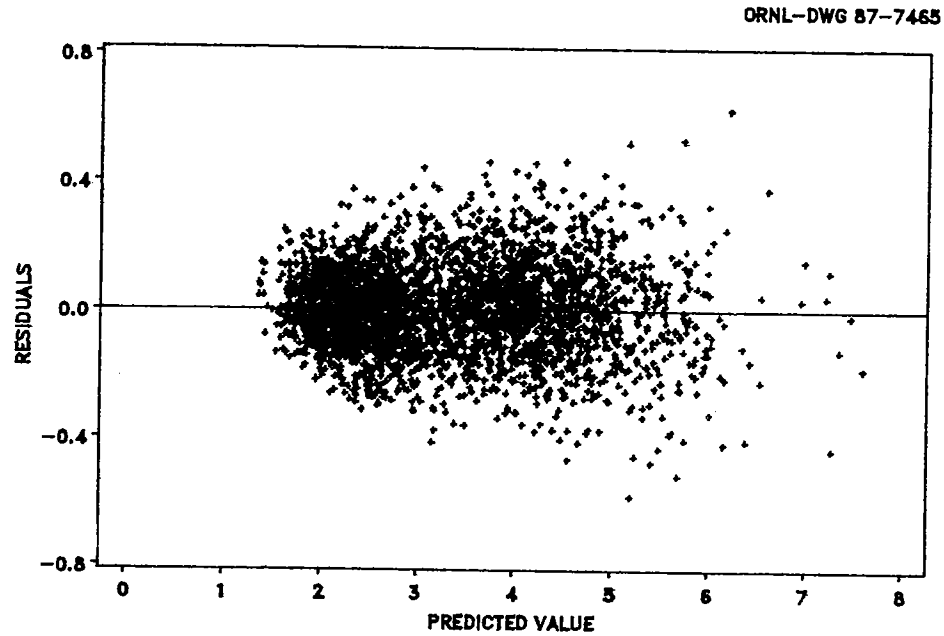

Figure A-1. Model 19, weekday nights, residuals vs predicted values.

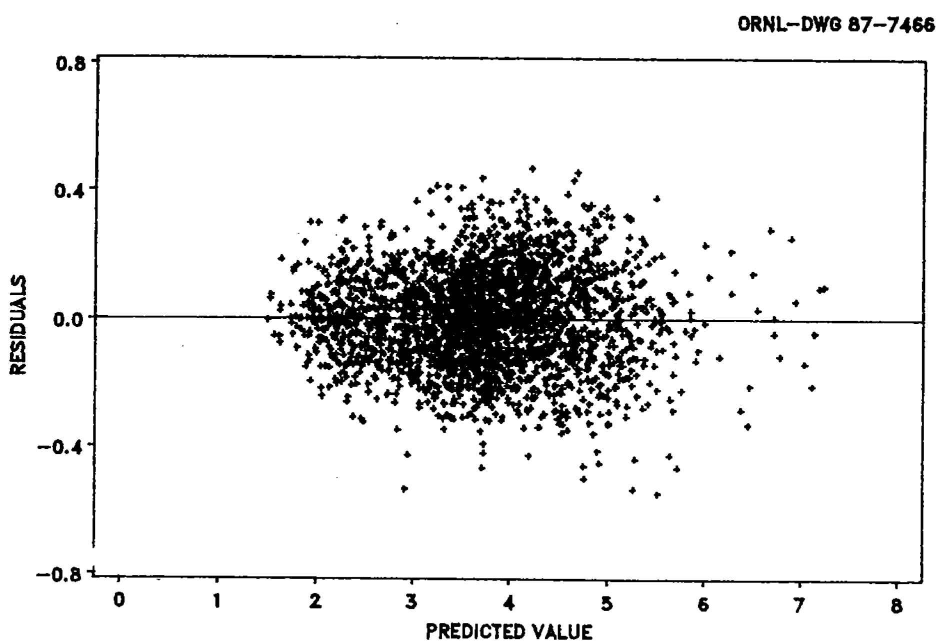

Figure A-2. Model 27, weekday days, residuals vs predicted values.

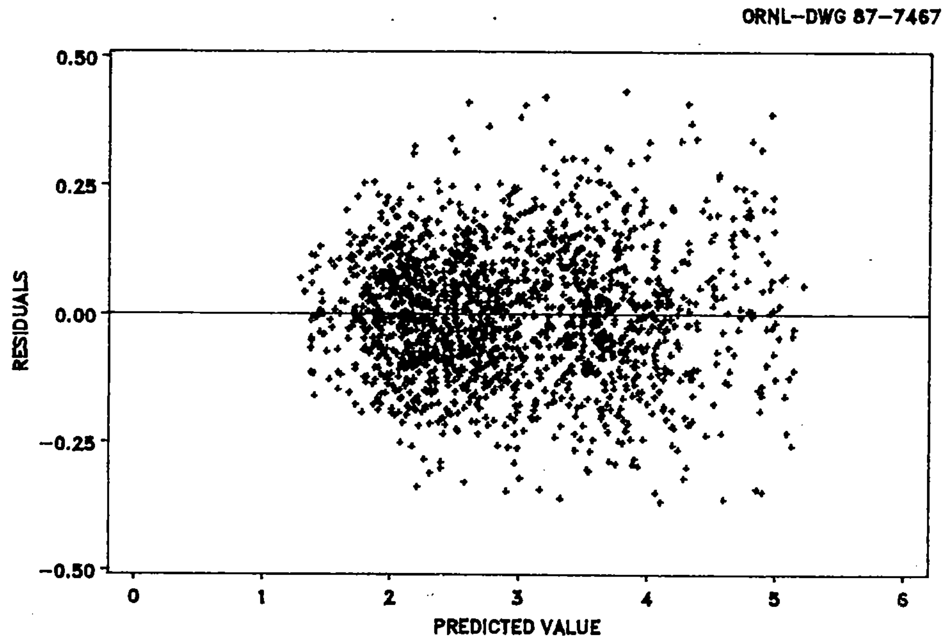

Figure A-3. Model 38, weekend nights, residuals vs predicted values.

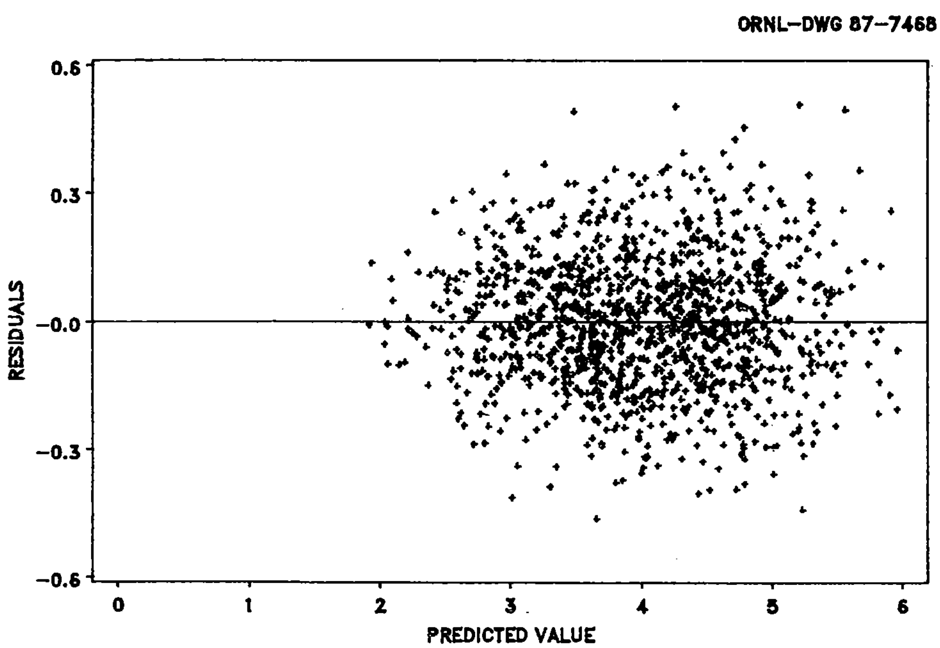

Figure A-4. Model 29, weekend days, residuals vs predicted values.

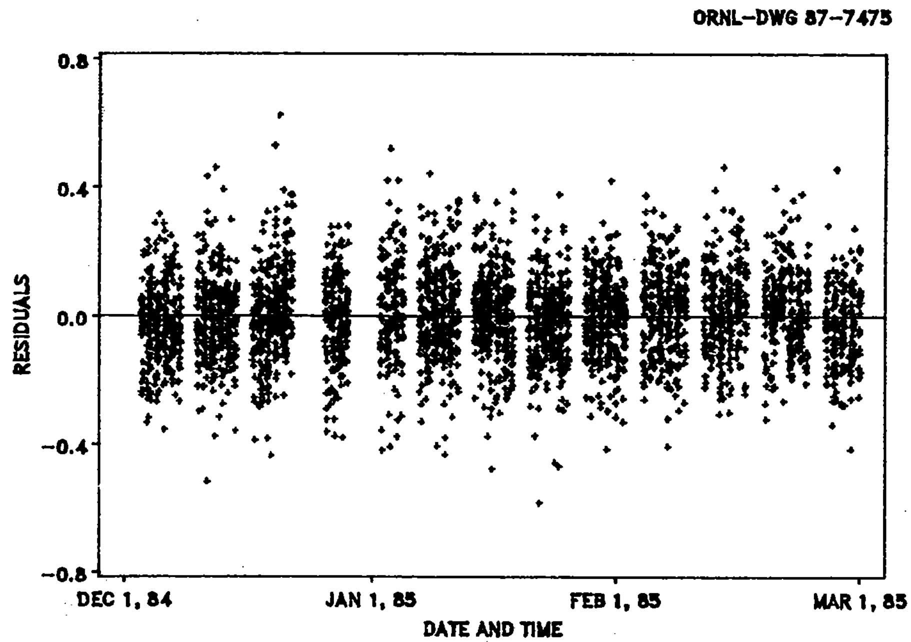

Figure A-5. Model 19, weekday nights, residuals vs date-time.

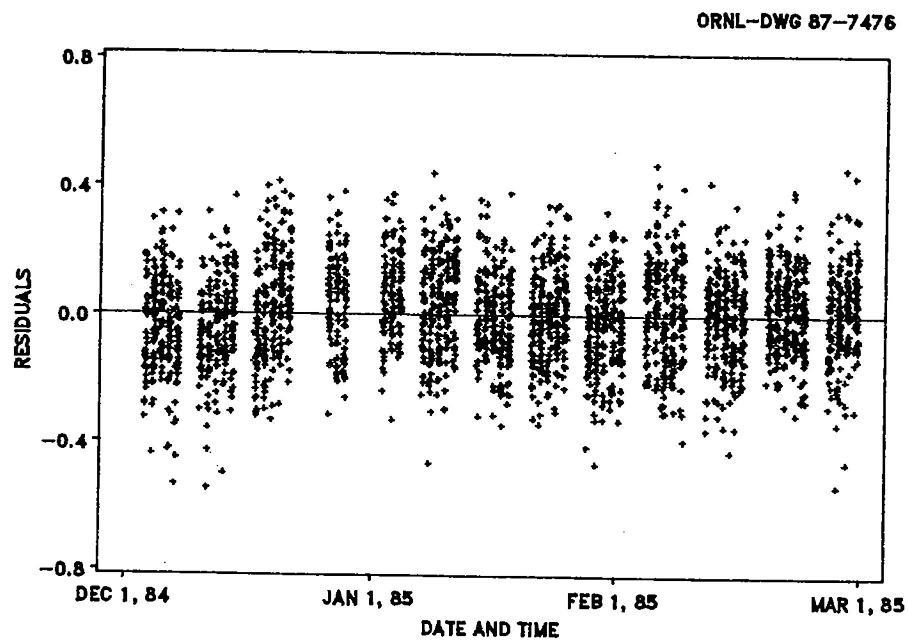

Figure A-6. Model 27, weekday days, residuals vs date-time.

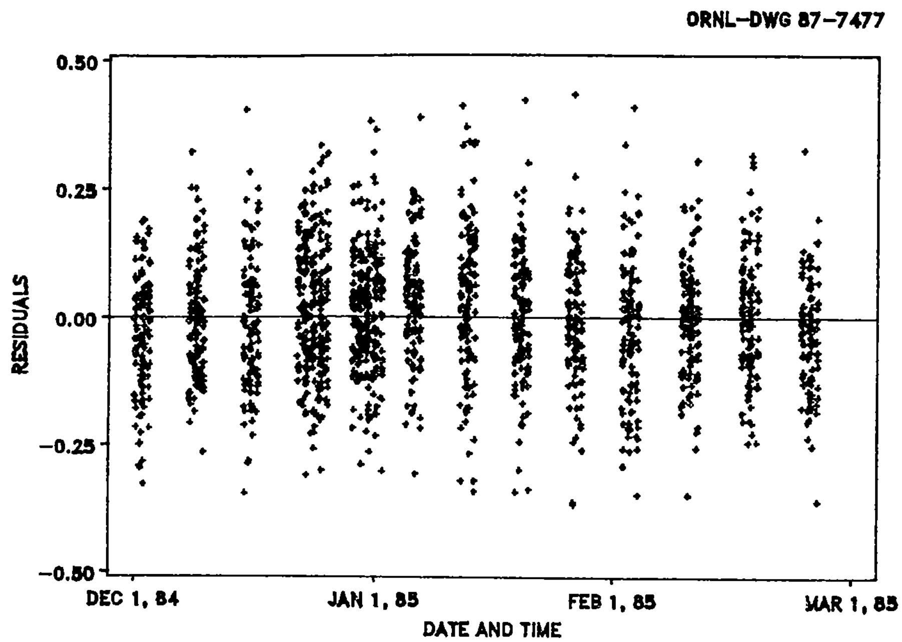

Figure A-7. Model 38, weekend nights, residuals vs date-time.

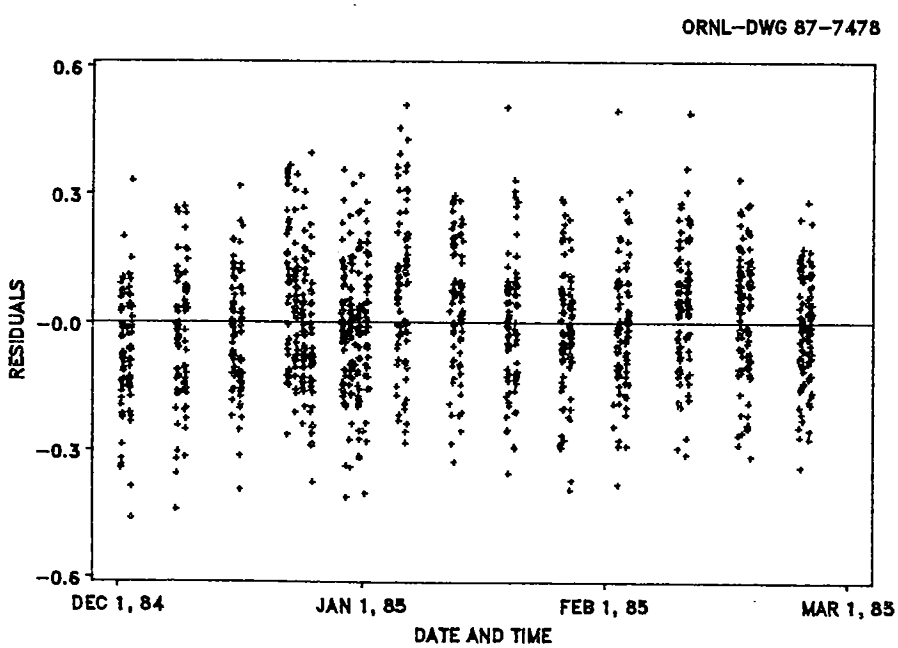

Figure A-8. Model 29, weekday days, residuals vs date-time.

Appendix B: Weather Normalization, Regression-Plot Examples

Figures B-1 to B-7 compare one week (the first week in February 1985) of the diversified load generated by using the regression model to the actual diversified load for that period.

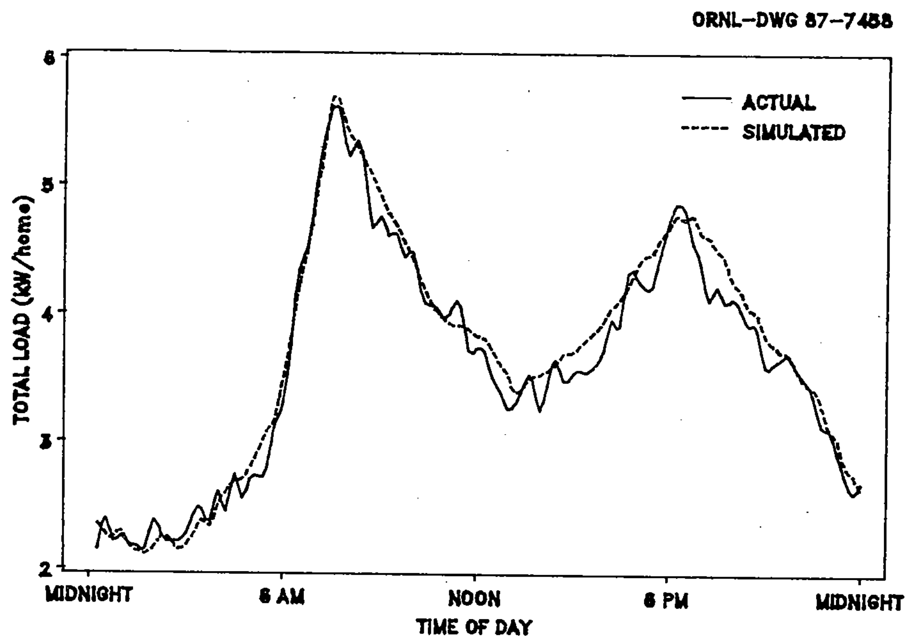

Figure B-1. Actual load vs load estimated by regression model, Friday, February 1, 1985.

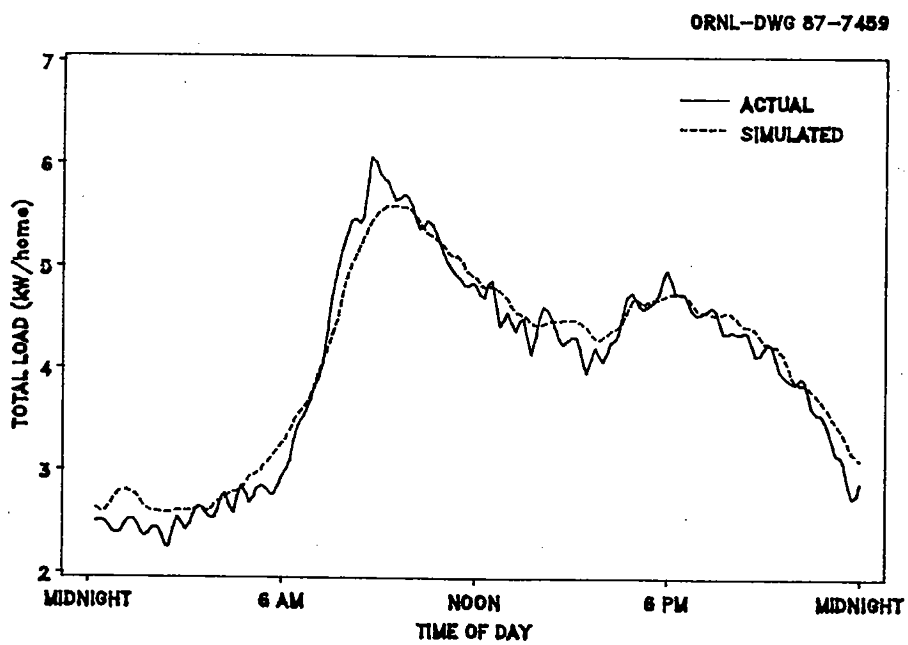

Figure B-2. Actual load vs load estimated by regression model, Saturday, February 2, 1985.

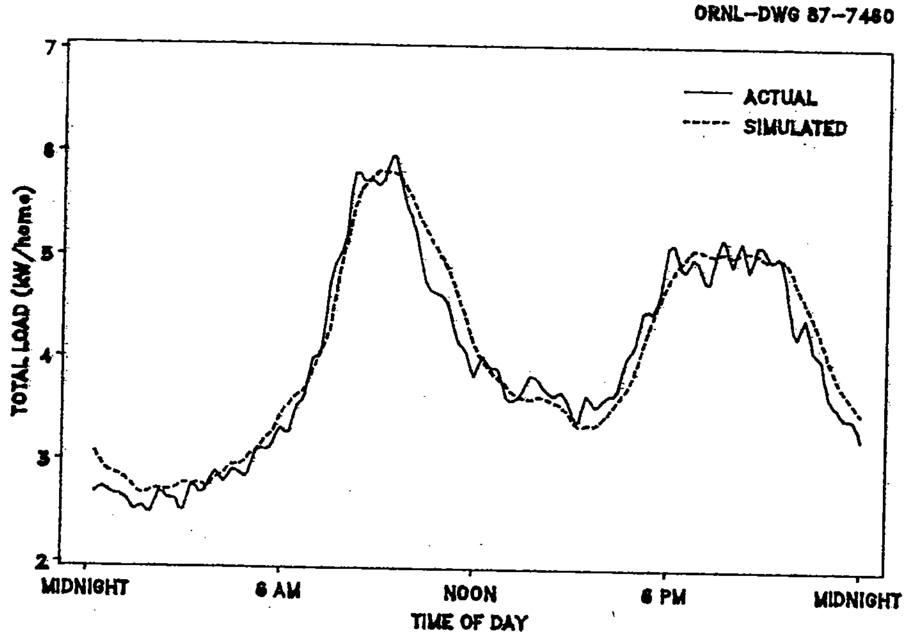

Figure B-3. Actual load vs load estimated by regression model, Sunday, February 3, 1985.

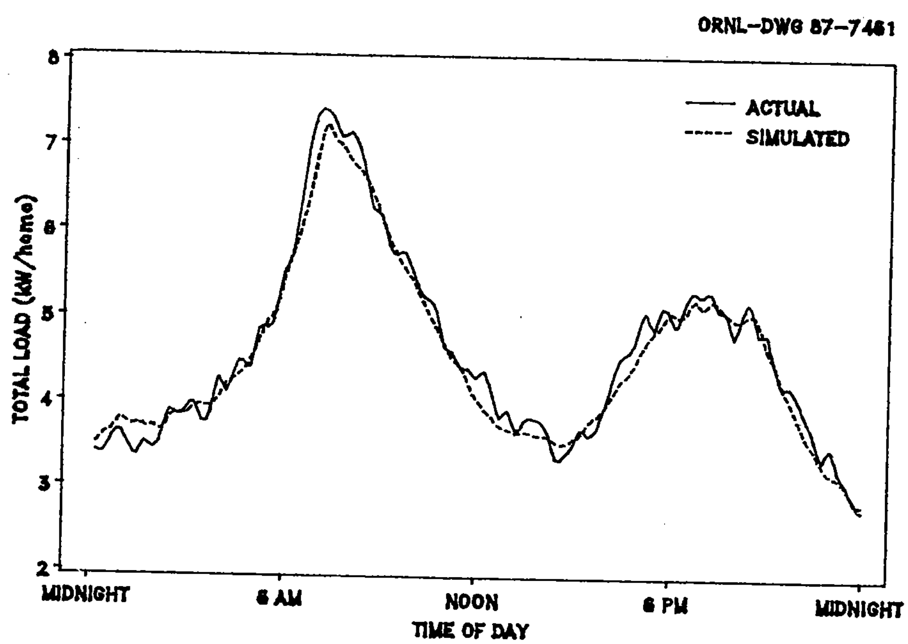

Figure B-4. Actual load vs load estimated by regression model, Monday, February 4, 1985.

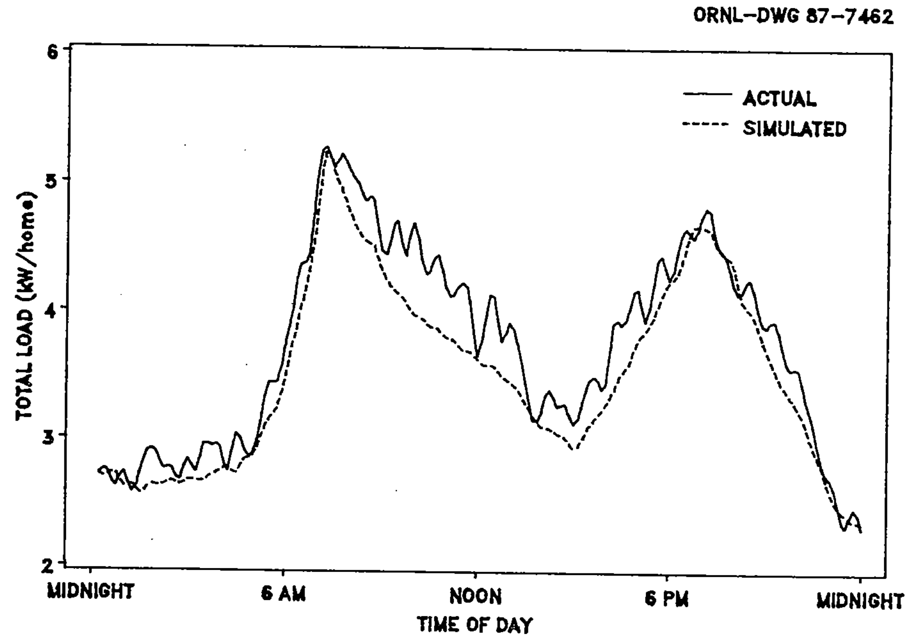

Figure B-5. Actual load vs load estimated by regression model, Tuesday, February 5, 1985.

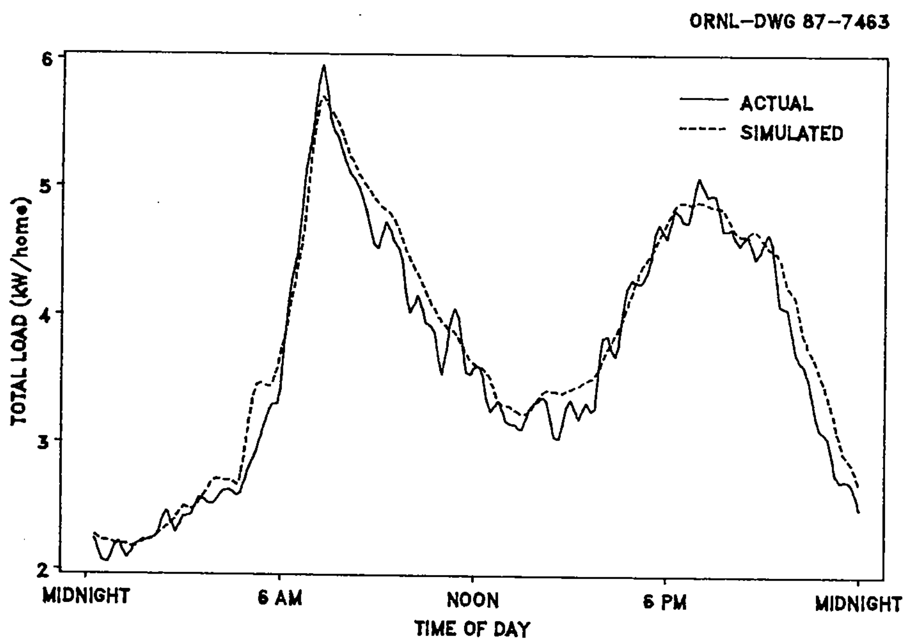

Figure B-6. Actual load vs load estimated by regression model, Wednesday, February 6, 1985.

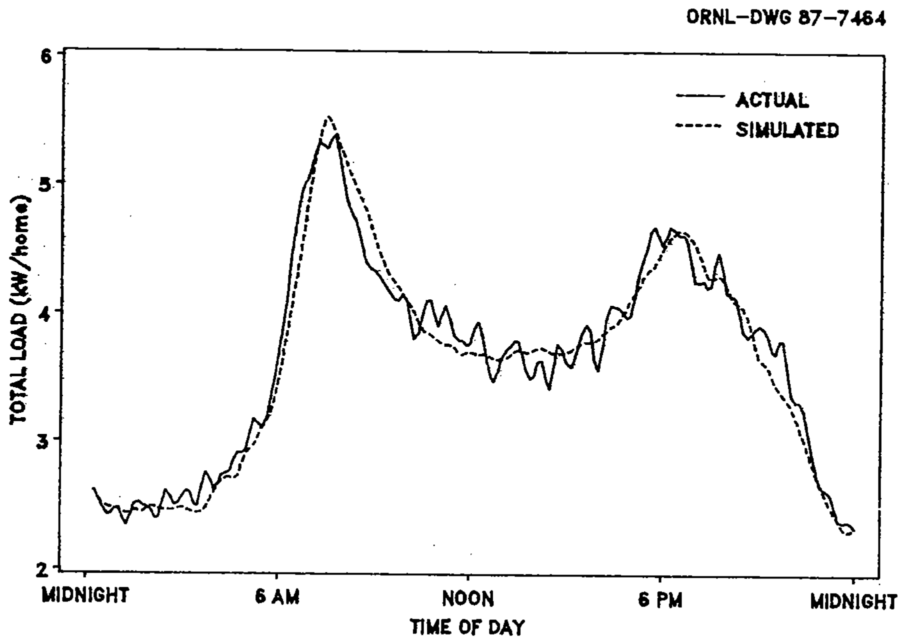

Figure B-7. Actual load vs load estimated by regression model, Thursday, February 7, 1985.

Appendix C: Weather Normalization, Similar-Days Comparisons

The similar-day selection process was described in Section 3.2. This appendix includes plots for weather variables considered when choosing these groups of similar days. The similar days chosen to represent the spring, summer, and autumn seasons are listed in Tables C-1 to C-3. Figures C-1 to C-7 show all weather variables tested for the winter similar-day groups. Figures C-8 to C-15 show this same information for the spring similar-day groups, Figures C-16 to C-23 for fall, and Figures C-24 to C-31 for summer.

Two similar cold days, January 16, 1985, and January 15, 1986, and two similar hot days, August 9, 1984, and July 26, 1985, were also chosen for comparison. Plots for these days are also included (Figures C-32 to C-44).

Figures C-45 to C-47 compare the outdoor air temperature distributions for the selected days with those of the whole periods for autumn, spring, and summer.

Table C-1. Spring days chosen for comparison

Period	Date	Day	Average temperature (°F)	Minimum temperature (°F)
Before	May 6, 1984	Sunday	48	38
After	Mar. 2, 1986	Sunday	48	33
Before	May 21, 1984	Monday	49	36
After	Mar. 10, 1986	Monday	48	42
Before	Mar. 12, 1985	Tuesday	42	32
After	Mar. 25, 1986	Tuesday	44	35
Before	May 1, 1984	Tuesday	49	43
After	Mar. 18, 1986	Tuesday	49	44
Before	May 2, 1984	Wednesday	47	41
After	Mar. 12, 1986	Wednesday	45	38
Before	May 31, 1984	Thursday	51	40
After	Mar. 30, 1986	Thursday	51	37
Before	May 11, 1984	Friday	55	47
After	Mar. 28, 1986	Friday	55	44
Before	May 19, 1984	Saturday	55	47
After	Mar. 29, 1986	Saturday	56	43

Table C-2. Summer days chosen for comparison

Period	Date	Day	Average temperature (°F)	Maximum temperature (°F)
Before	July 15, 1984	Sunday	76	100
After	July 28, 1985	Sunday	77	100
Before	June 25, 1984	Monday	71	86
After	July 29, 1985	Monday	76	84
Before	July 2, 1984	Monday	67	78
After	Aug. 5, 1985	Monday	67	79
Before	June 26, 1984	Tuesday	64	69
After	July 30, 1985	Tuesday	62	66
Before	Aug. 28, 1984	Tuesday	62	76
After	Aug. 27, 1985	Tuesday	64	74
Before	July 4, 1984	Wednesday	73	87
After	Aug. 14, 1985	Wednesday	69	89
Before	June 13, 1984	Wednesday	60	72
After	Aug. 21, 1985	Wednesday	59	70
Before	June 14, 1984	Thursday	65	79
After	Aug. 29, 1985	Thursday	62	78
Before	June 28, 1984	Thursday	68	78
After	July 31, 1985	Wednesday	63	79
Before	July 20, 1984	Friday	64	76
After	Aug. 2, 1985	Friday	66	73
Before	July 27, 1984	Friday	68	76
After	Aug. 1, 1985	Thursday	63	72
Before	July 14, 1984	Saturday	70	94
After	Aug. 17, 1985	Saturday	71	90
Before	June 30, 1984	Saturday	60	74
After	Aug. 31, 1985	Saturday	60	75
Before	Aug. 9, 1984[a]	Thursday	76	91
After	July 26, 1985[a]	Friday	78	94

[a] These days were chosen for a hot-day comparison.

Table C-3. Autumn days chosen for comparison

Period	Date	Day	Average temperature (°F)	Minimum temperature (°F)
Before	Oct. 21, 1984	Sunday	37	32
After	Nov. 17, 1985	Sunday	36	33
Before	Sept. 24, 1984	Monday	48	32
After	Sept. 30, 1985	Monday	49	30
Before	Nov. 12, 1984	Monday	46	42
After	Nov. 4, 1985	Monday	46	40
Before	Sept. 11, 1984	Tuesday	55	47
After	Sept. 10, 1985	Tuesday	52	47
Before	Sept. 5, 1984	Wednesday	59	49
After	Sept. 25, 1985	Wednesday	59	44
Before	Oct. 3, 1984	Wednesday	58	41
After	Sept. 11, 1985	Wednesday	54	44
Before	Oct. 4, 1984	Thursday	57	49
After	Oct. 24, 1985	Thursday	53	49
Before	Sept. 14, 1984	Friday	58	40
After	Sept. 27, 1985	Friday	59	42
Before	Nov. 10, 1984	Saturday	39	34
After	Oct. 26, 1985	Saturday	43	35
Before	Sept. 1, 1984	Saturday	60	49
After	Sept. 21, 1985	Saturday	60	50

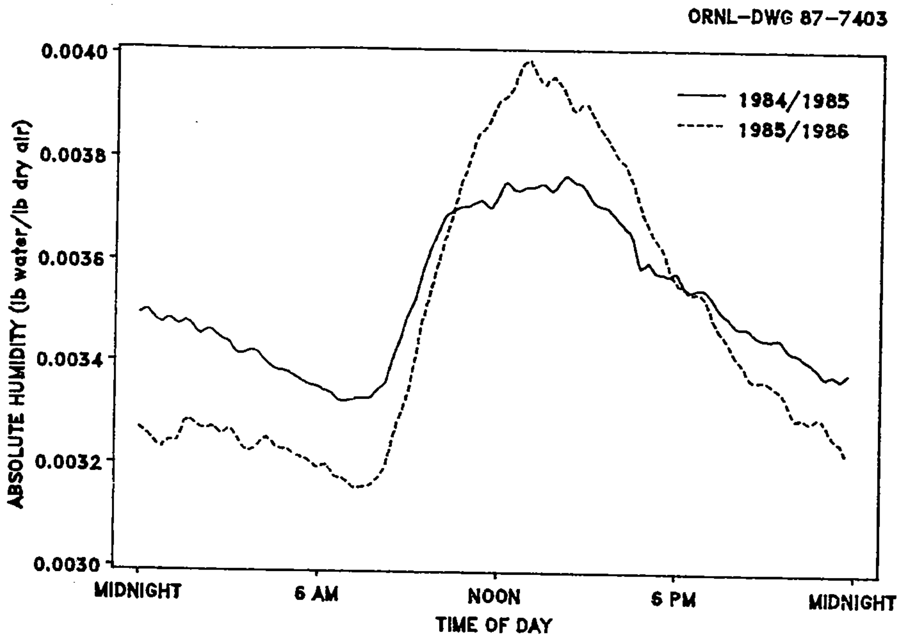

Figure C-1. Winter comparison of similar-day periods, absolute humidity.

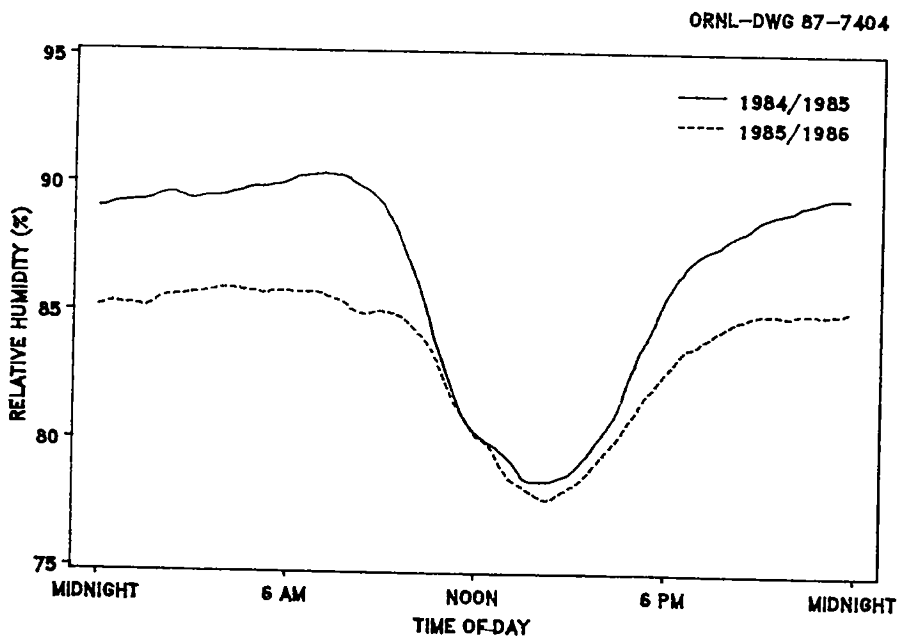

Figure C-2. Winter comparison of similar-day periods, relative humidity.

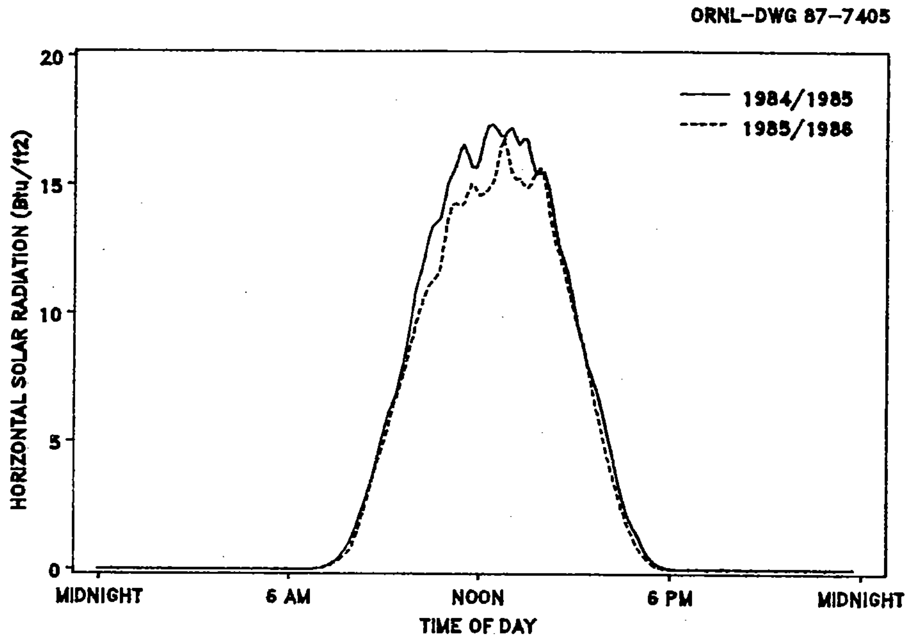

Figure C-3. Winter comparison of similar-day periods, horizontal solar radiation.

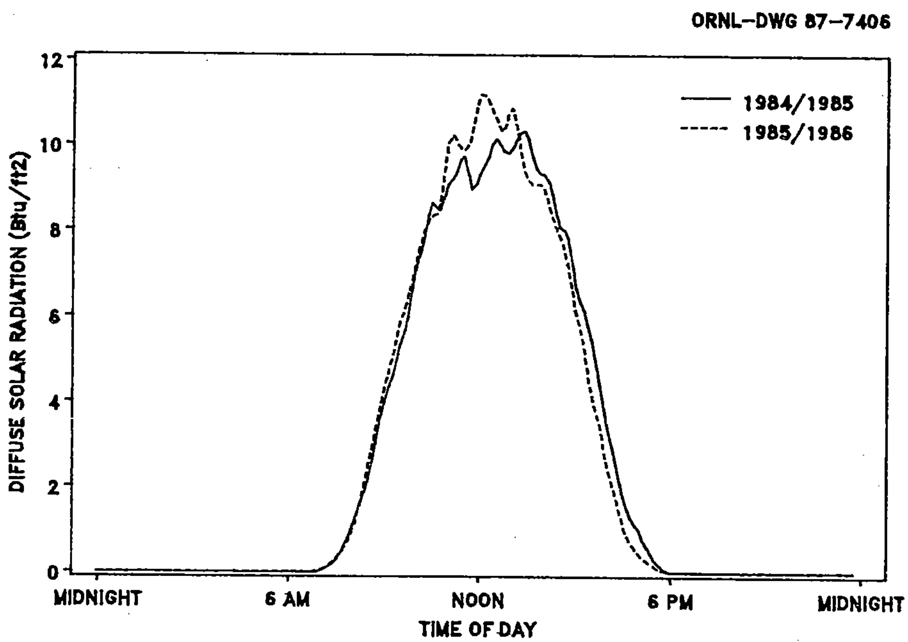

Figure C-4. Winter comparison of similar-day periods, diffuse solar radiation.

ORNL-DWG 87-7407

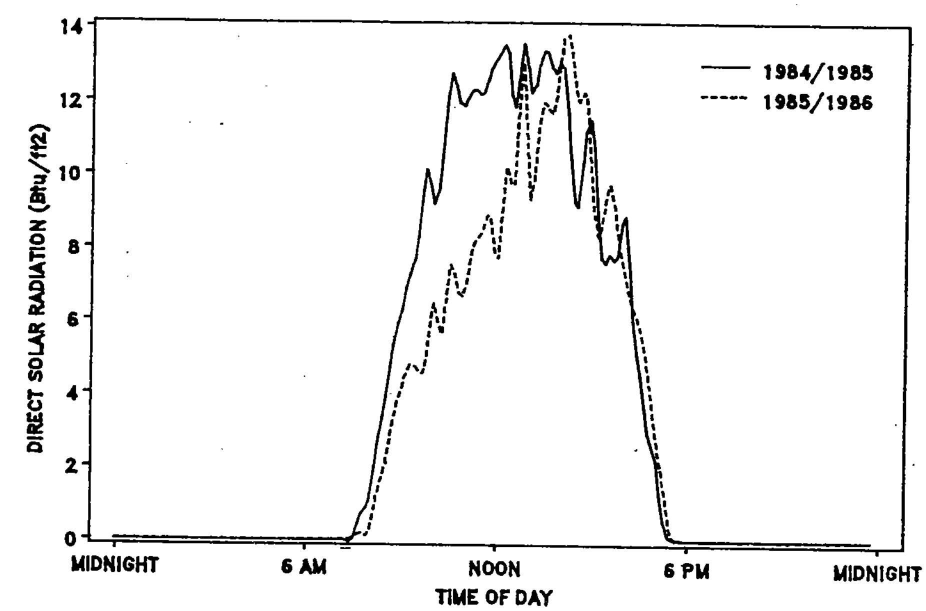

Figure C-5. Winter comparison of similar-day periods, direct solar radiation.

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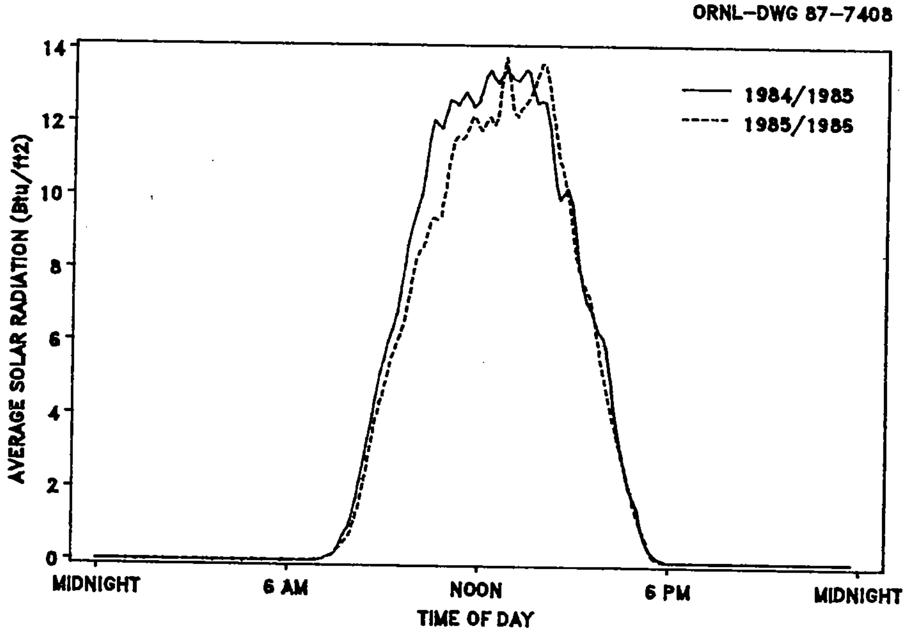

Figure C-6. Winter comparison of similar-day periods, average of horizontal, diffuse, and direct solar radiation.

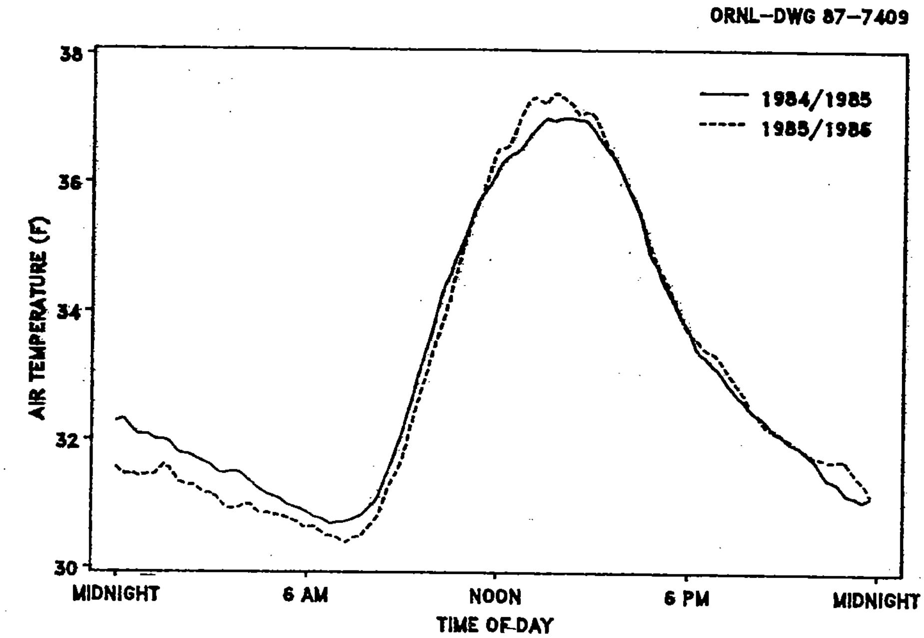

Figure C-7. Winter comparison of similar-day periods, air temperature.

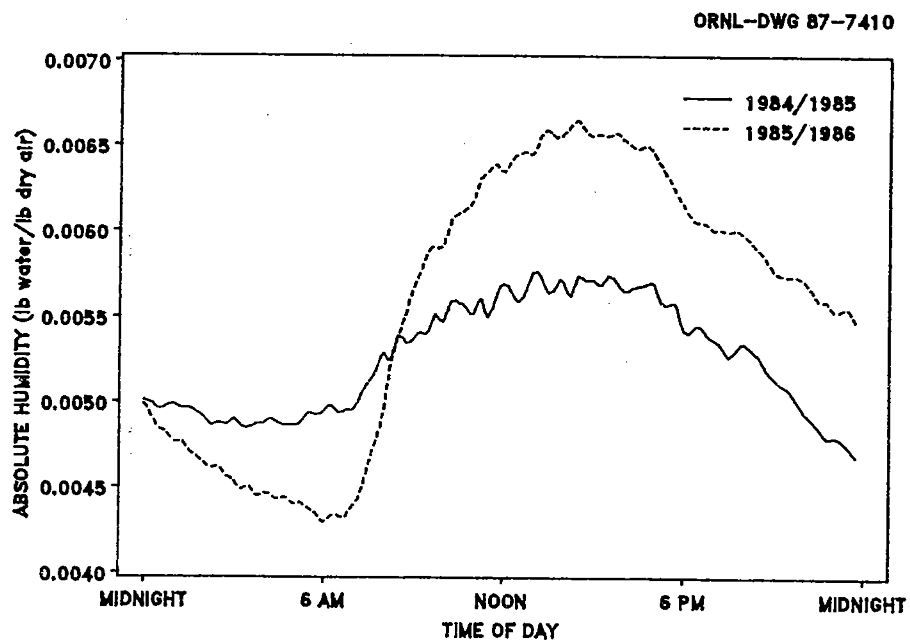

Figure C-8. Spring comparison of similar-day periods, absolute humidity.

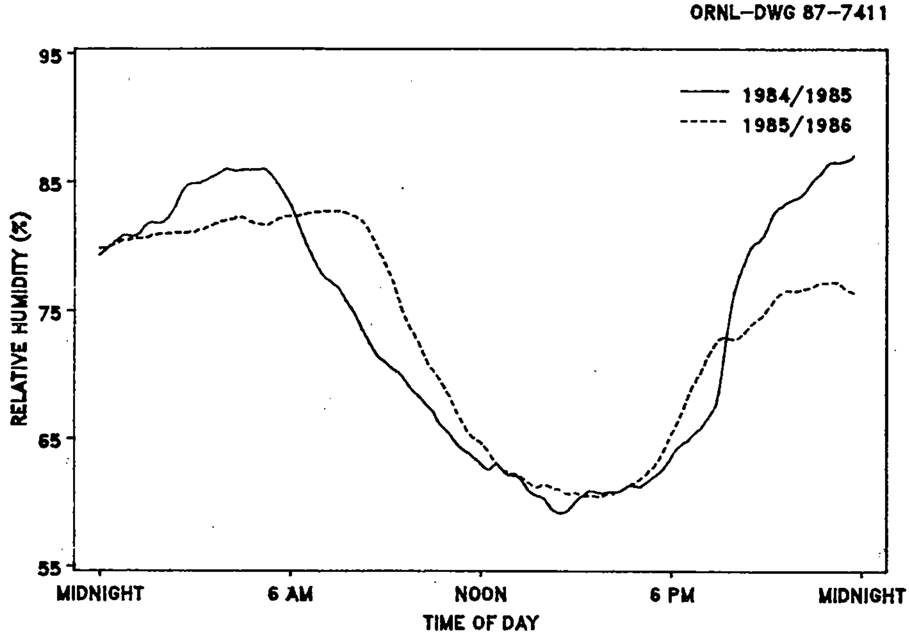

Figure C-9. Spring comparison of similar-day periods, relative humidity.

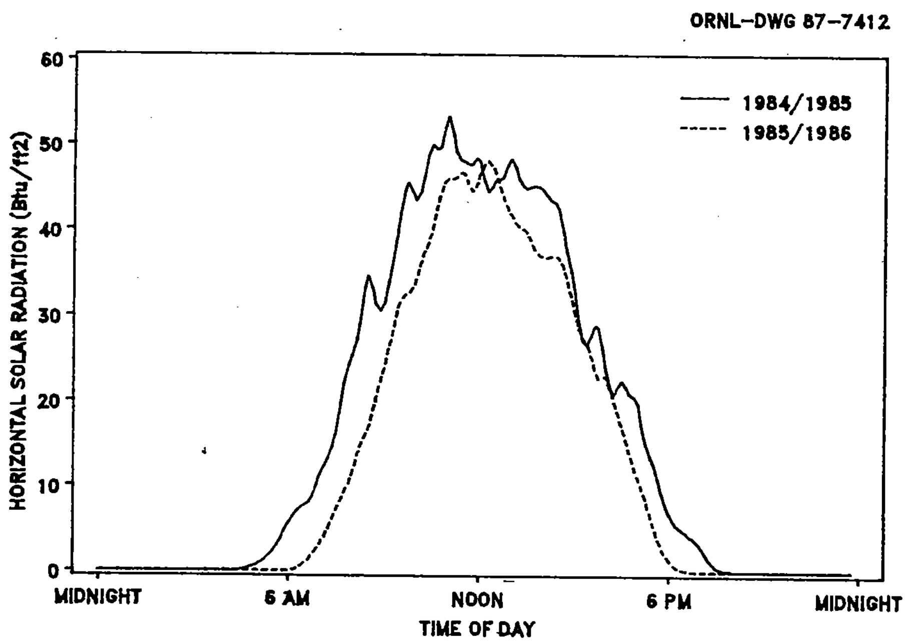

Figure C-10. Spring comparison of similar-day periods, horizontal solar radiation.

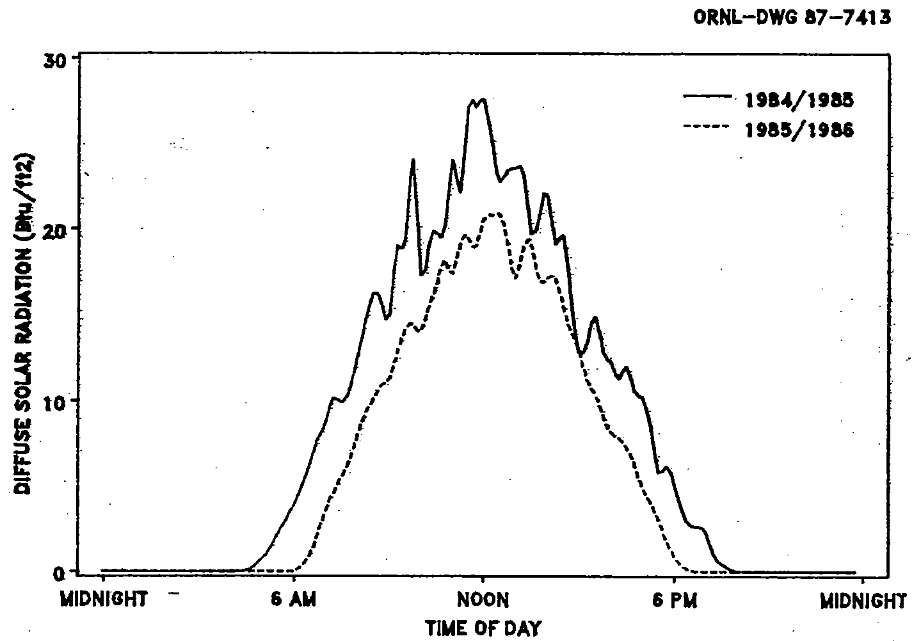

Figure C-11. Spring comparison of similar-day periods, diffuse solar radiation.

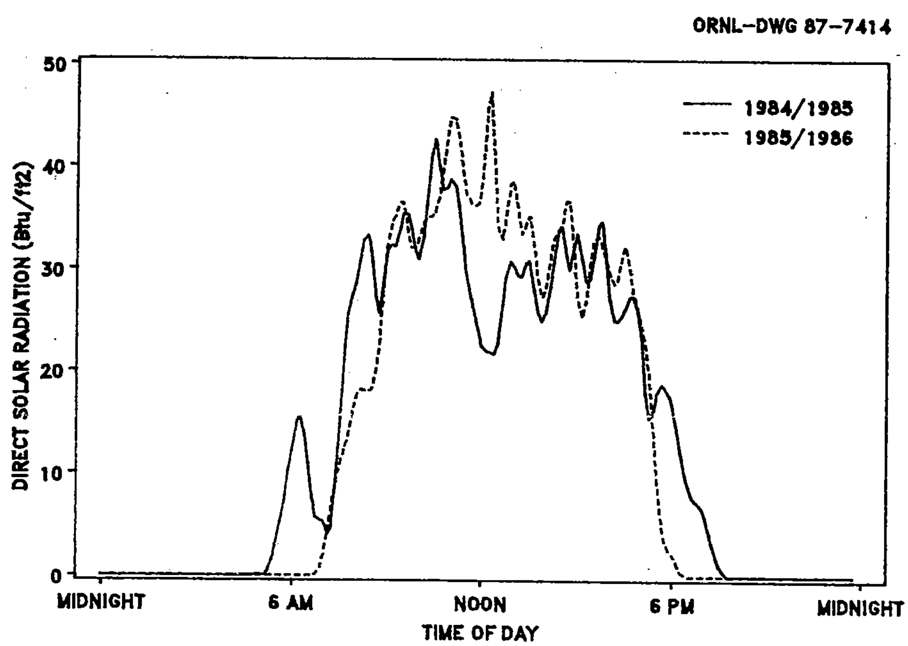

Figure C-12. Spring comparison of similar-day periods, direct solar radiation.

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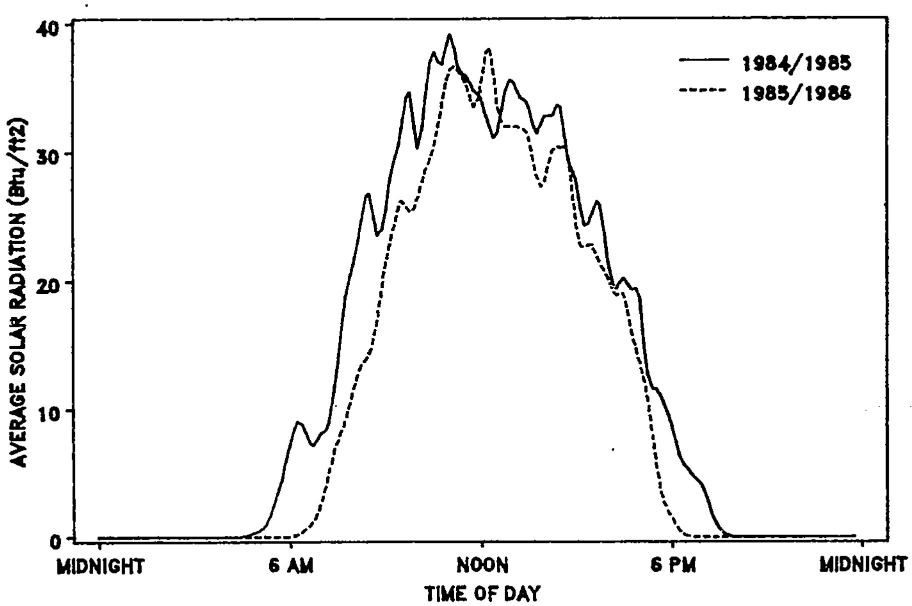

Figure C-13. Spring comparison of similar-day periods, average of horizontal, diffuse, and direct solar radiation.

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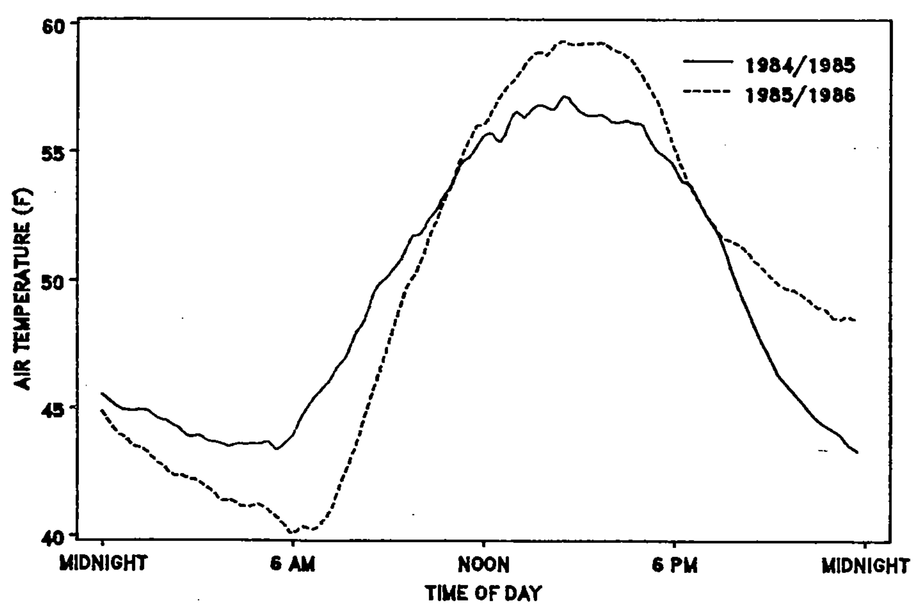

Figure C-14. Spring comparison of similar-day periods, air temperature.

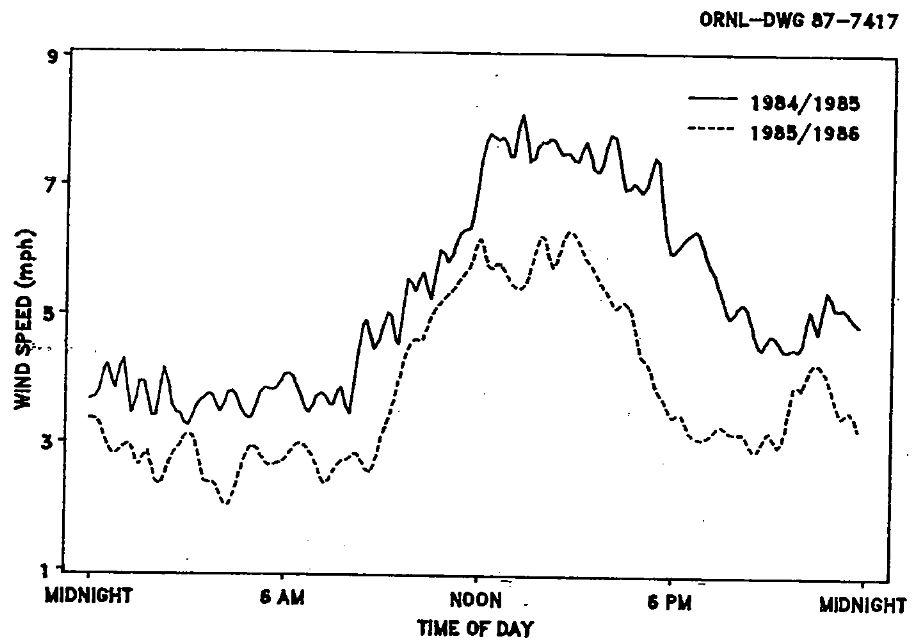

Figure C-15. Spring comparison of similar day periods, wind speed.

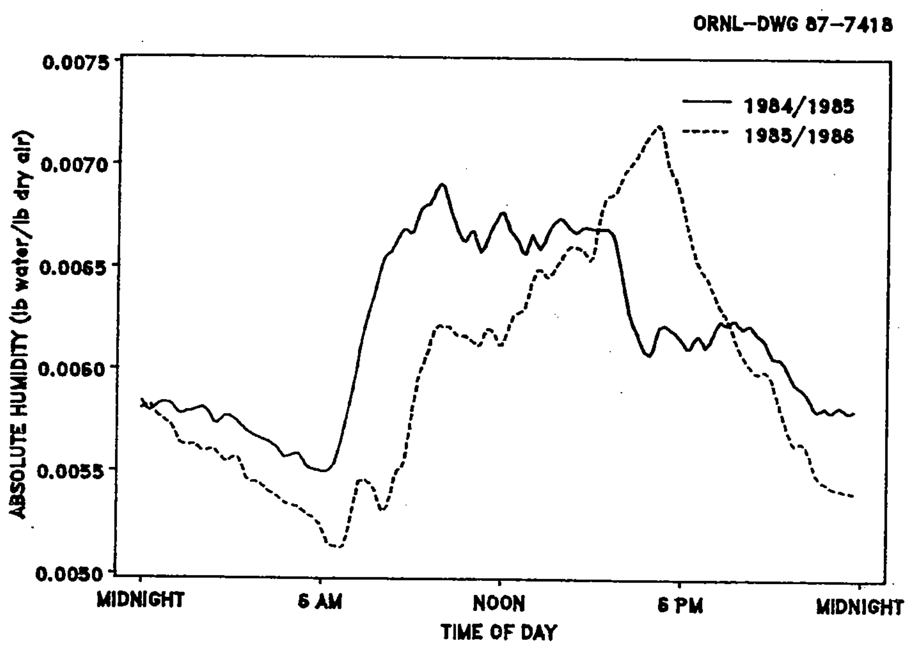

Figure C-16. Autumn comparison of similar-day periods, absolute humidity.

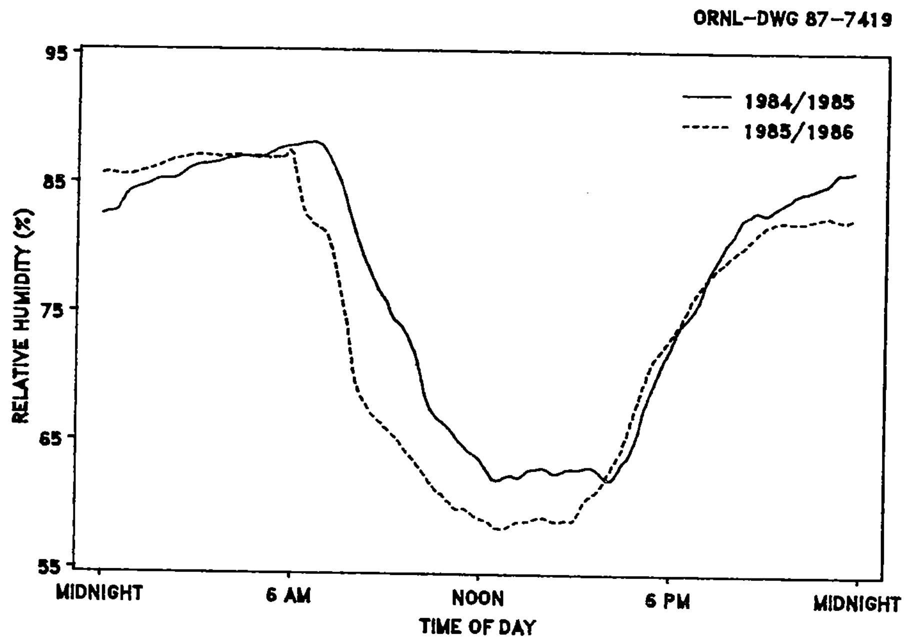

Figure C-17. Autumn comparison of similar-day periods, relative humidity.

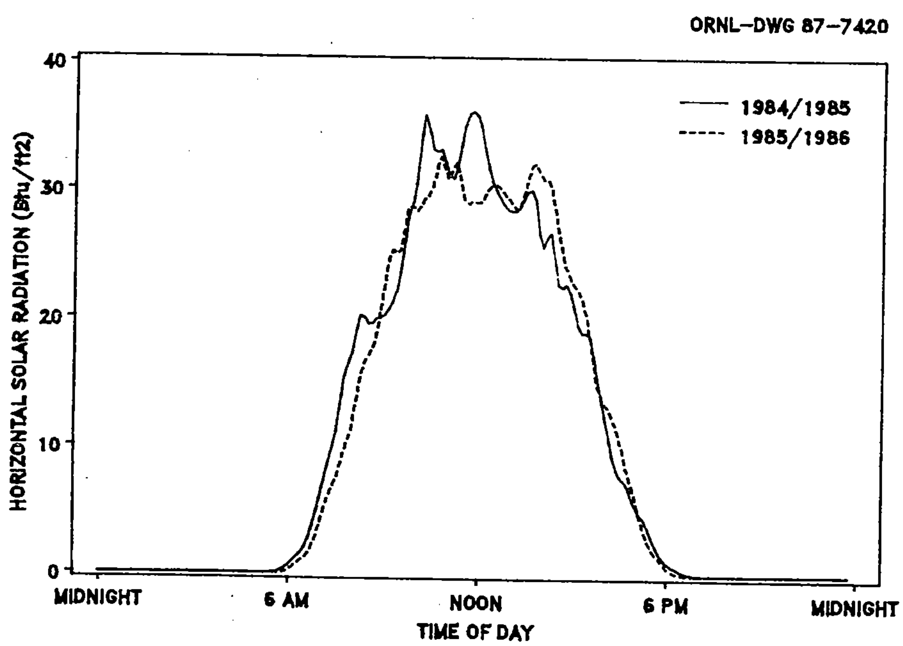

Figure C-18. Autumn comparison of similar-day periods, horizontal solar radiation.

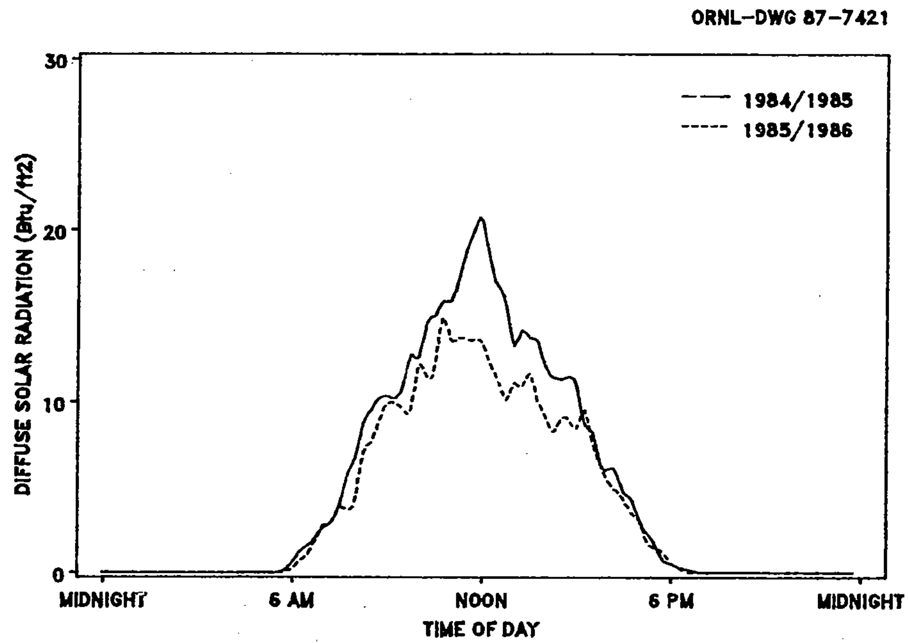

Figure C-19. Autumn comparison of similar-day periods, diffuse solar radiation.

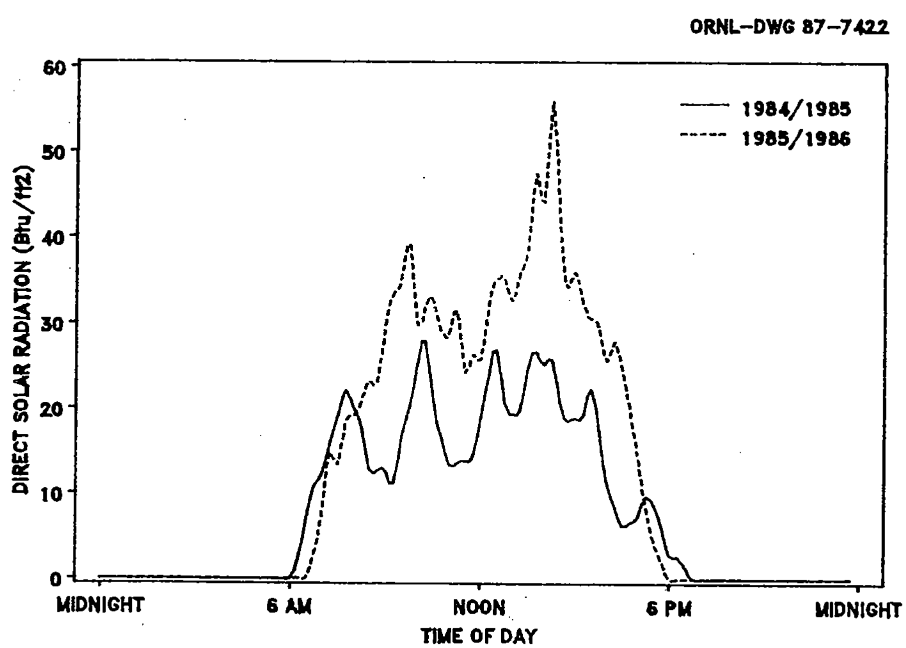

Figure C-20. Autumn comparison of similar-day periods, direct solar radiation.

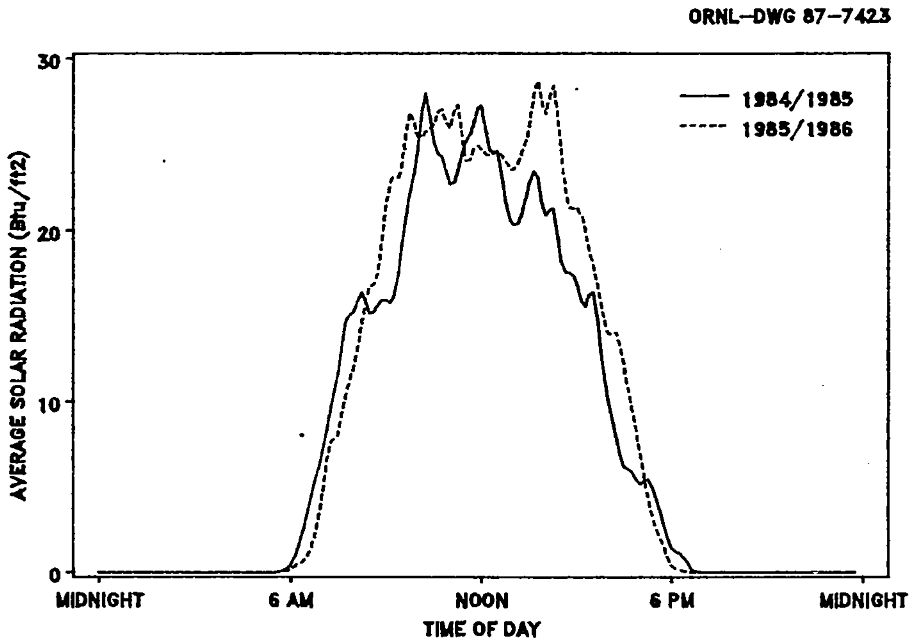

Figure C-21. Autumn comparison of similar-day periods, average of horizontal, diffuse, and direct solar radiation.

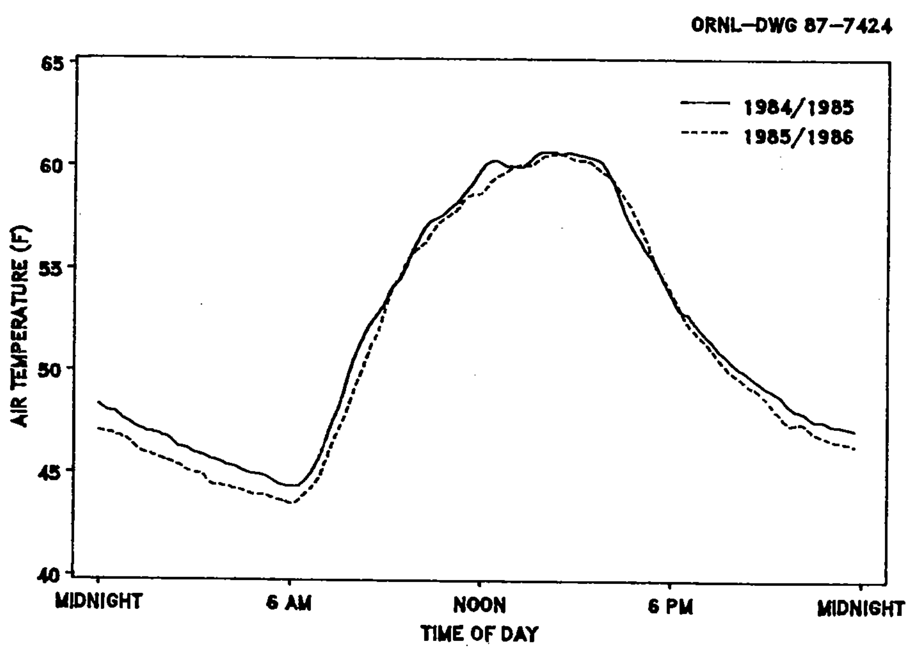

Figure C-22. Autumn comparison of similar-day periods, air temperature.

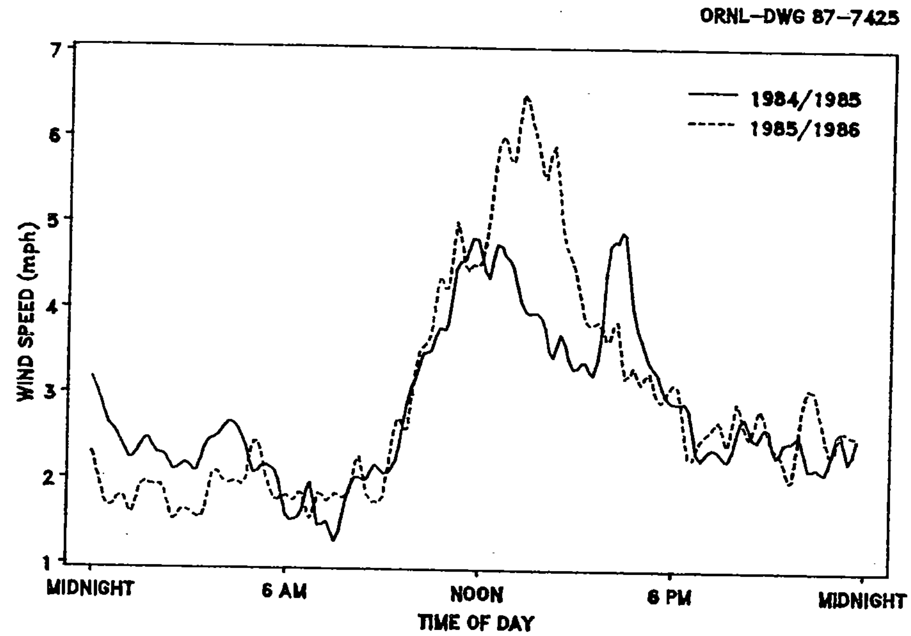

Figure C-23. Autumn comparison of similar-day periods, wind speed.

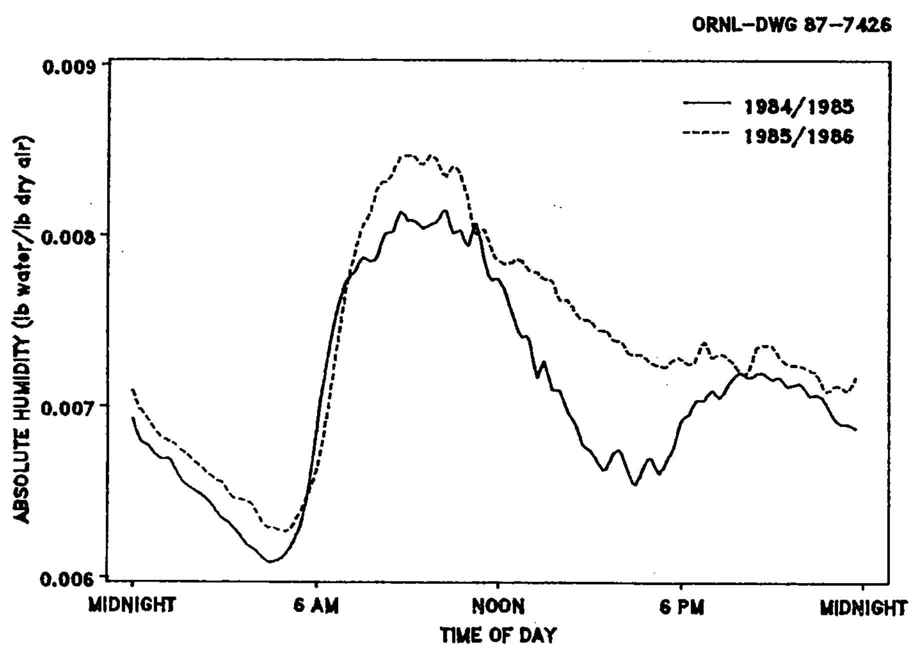

Figure C-24. Summer comparison of similar-day periods, absolute humidity.

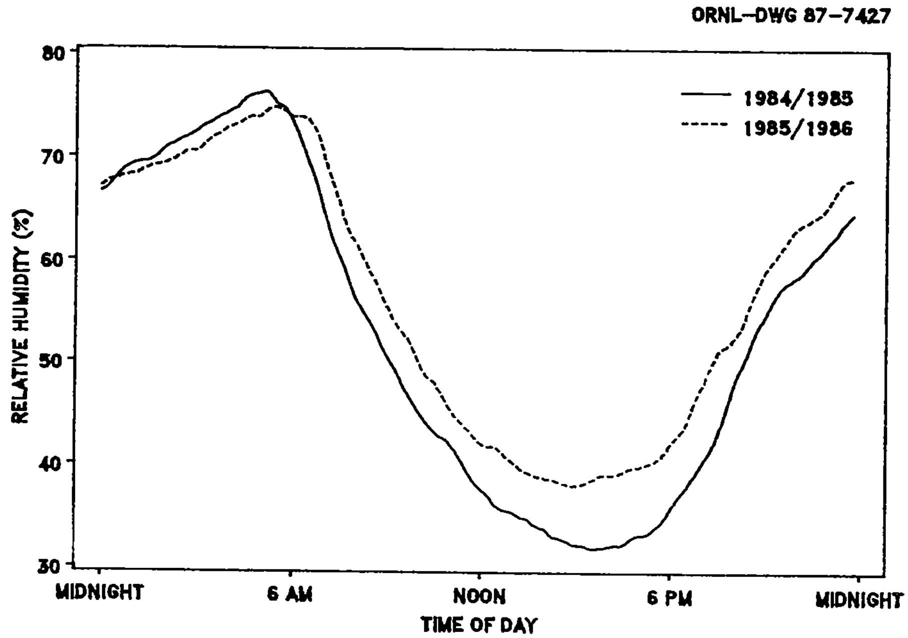

Figure C-25. Summer comparison of similar-day periods, relative humidity.

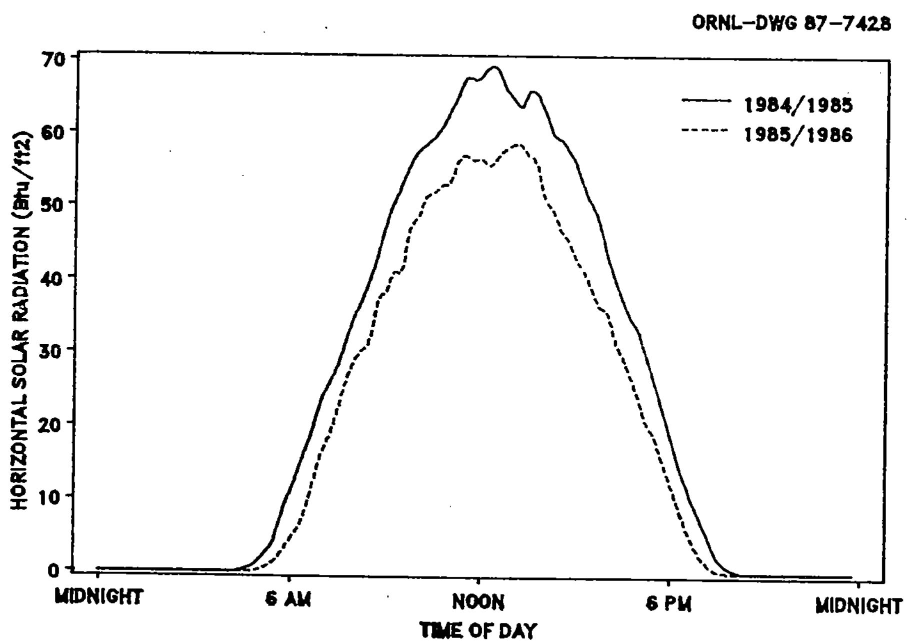

Figure C-26. Summer comparison of similar-day periods, horizontal solar radiation.

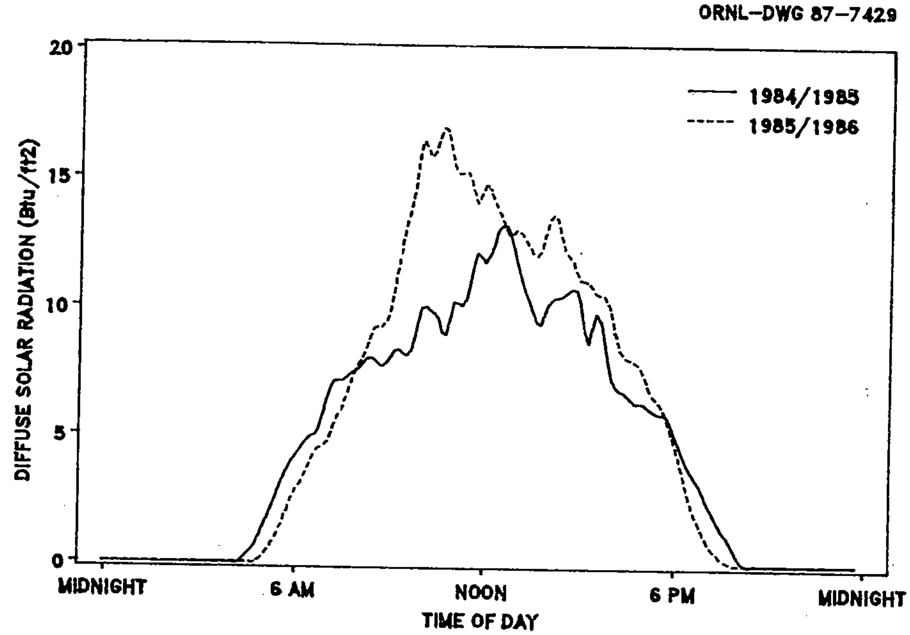

Figure C-27. Summer comparison of similar-day periods, diffuse solar radiation.

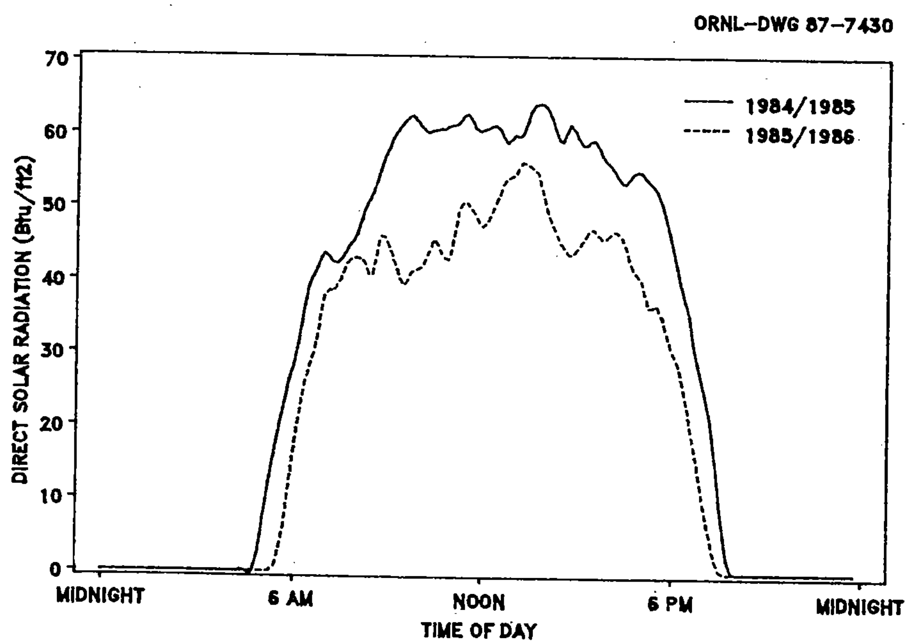

Figure C-28. Summer comparison of similar-day periods, direct solar radiation.

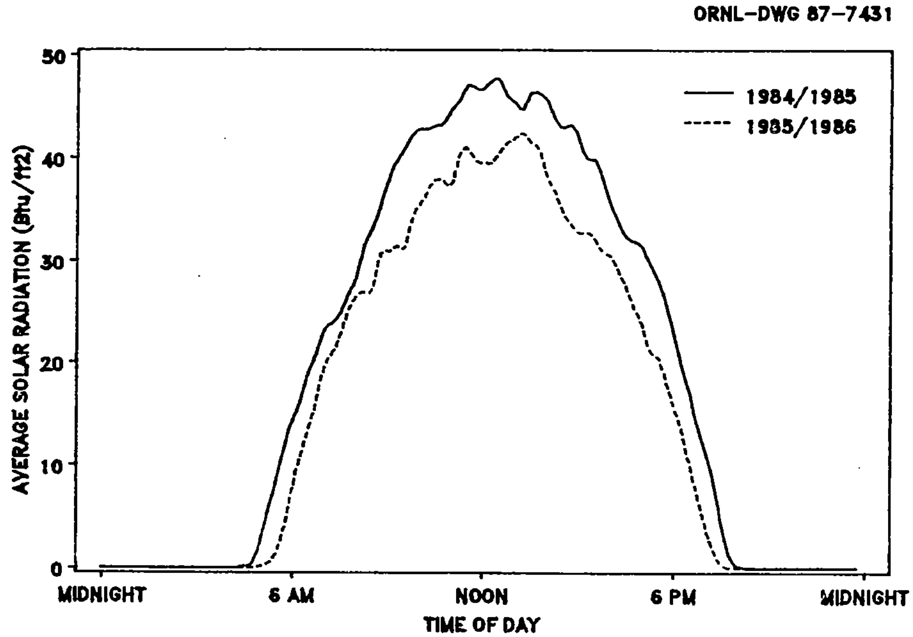

Figure C-29. Summer comparison of similar-day periods, average of horizontal, diffuse, and direct solar radiation.

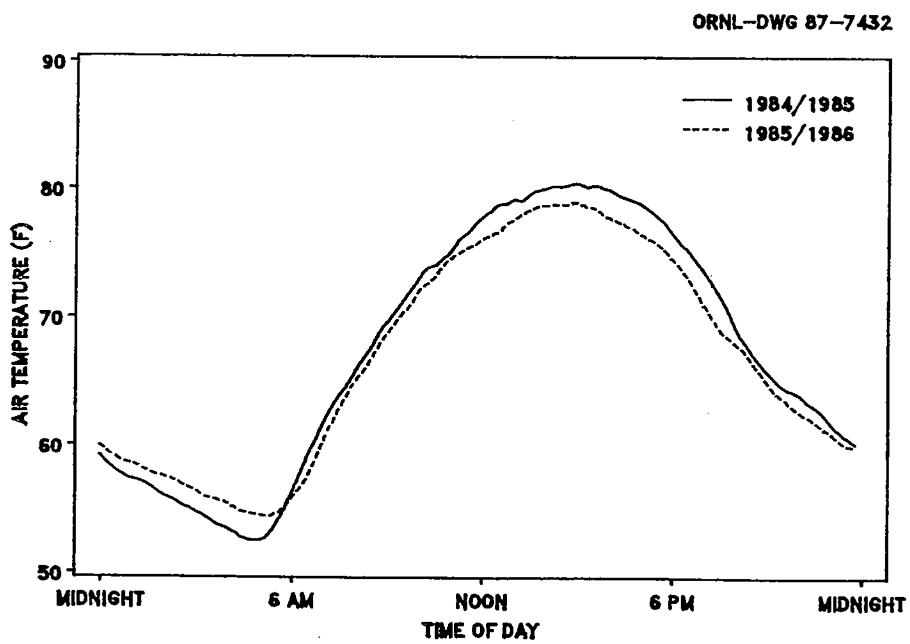

Figure C-30. Summer comparison of similar-day periods, air temperature.

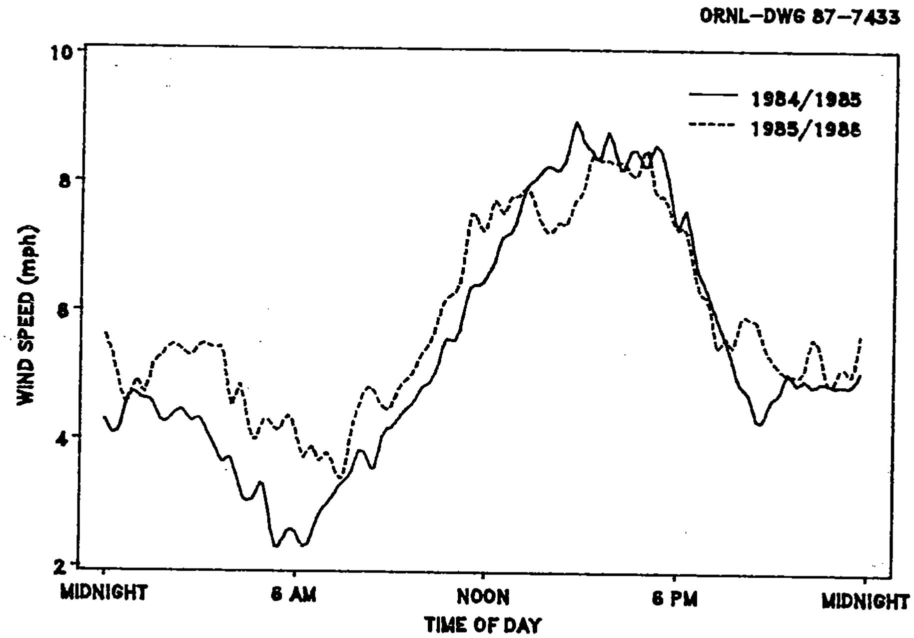

Figure C-31. Summer comparison of similar-day periods, wind speed.

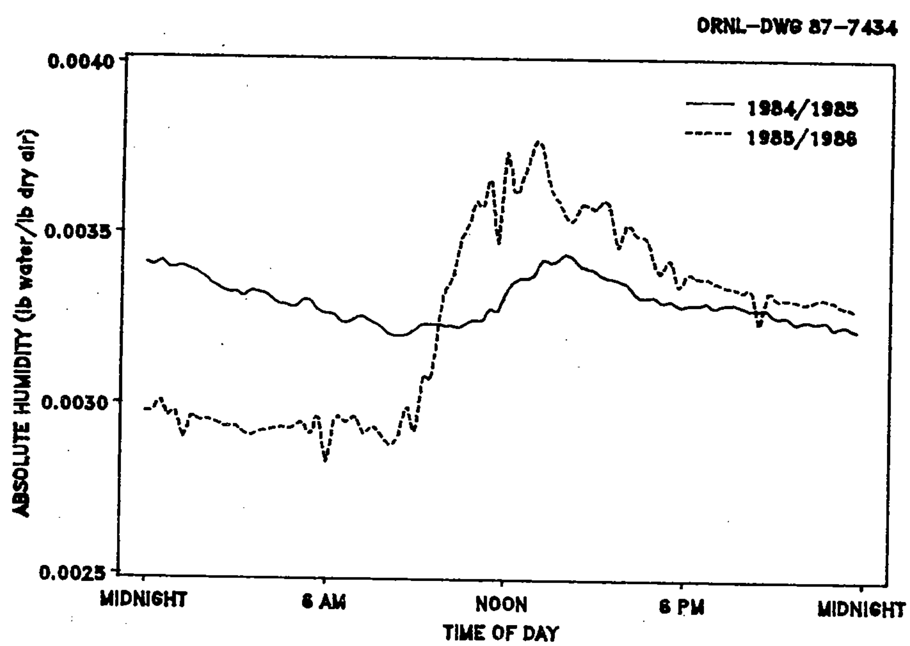

Figure C-32. Comparison of two similar cold days, absolute humidity.

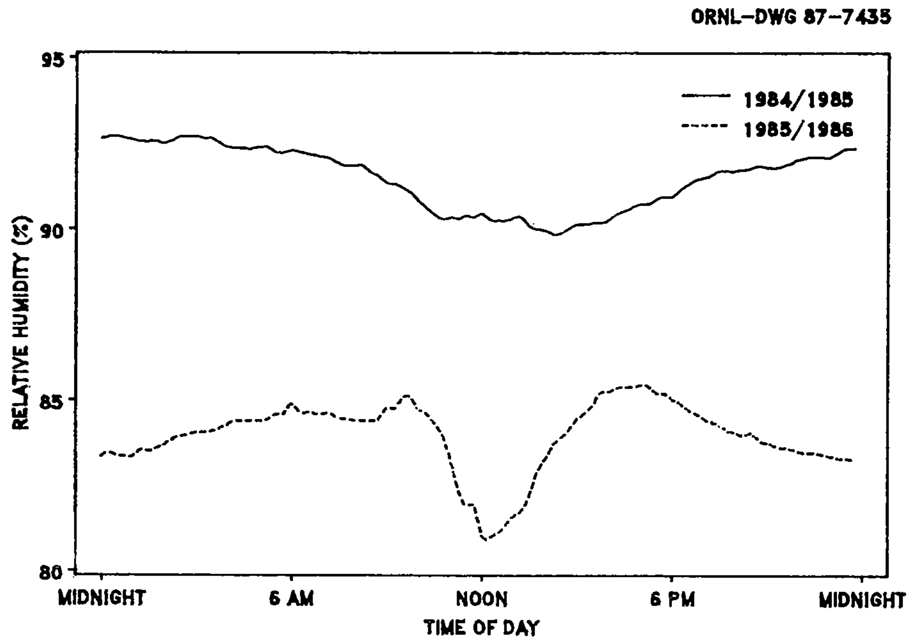

Figure C-33. Comparison of two similar cold days, relative humidity.

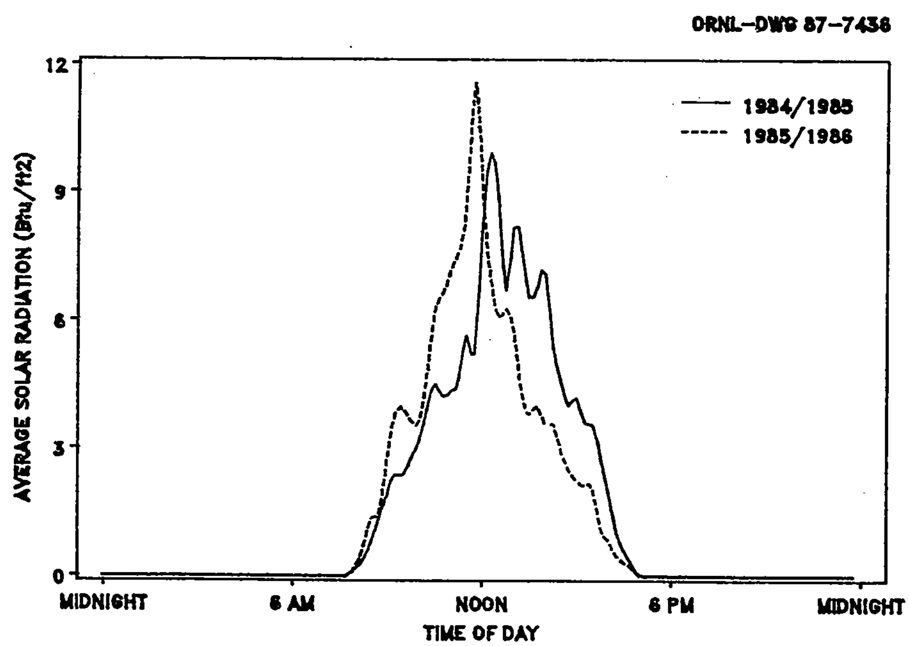

Figure C-34. Comparison of two similar cold days, average of horizontal, diffuse, and direct solar radiation.

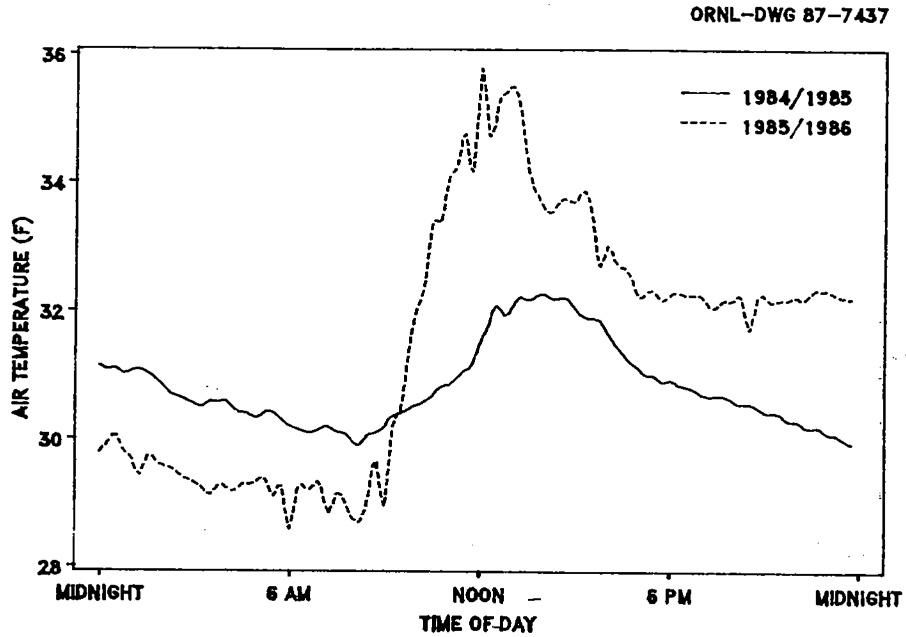

Figure C-35. Comparison of two similar cold days, air temperature.

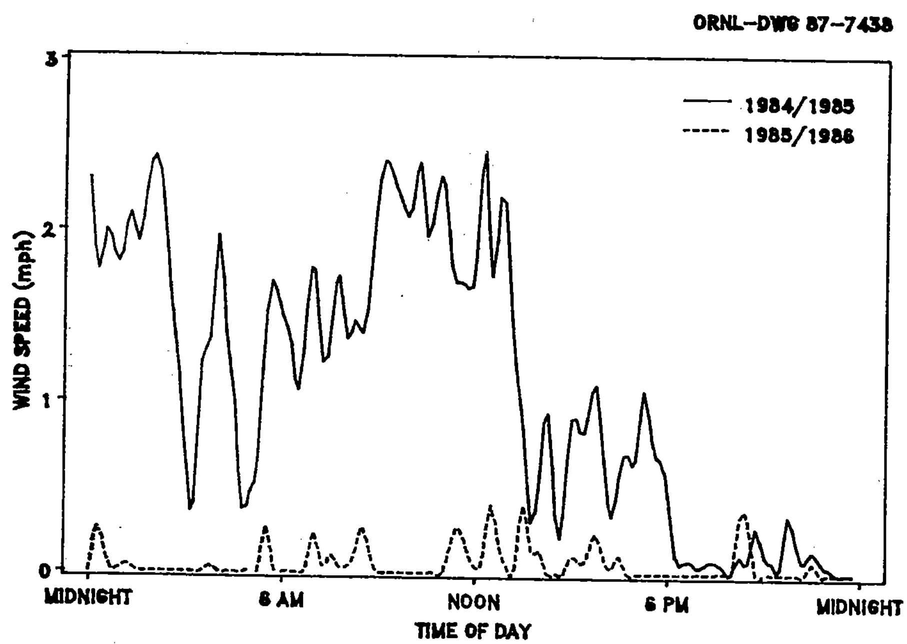

Figure C-36. Comparison of two similar cold days, wind speed.

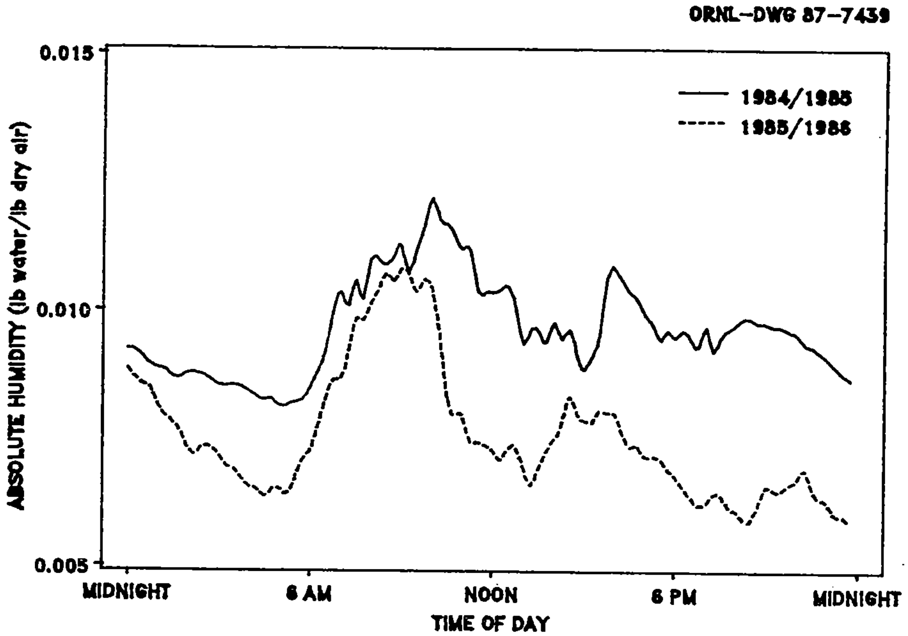

Figure C-37. Comparison of two similar hot days, absolute humidity.

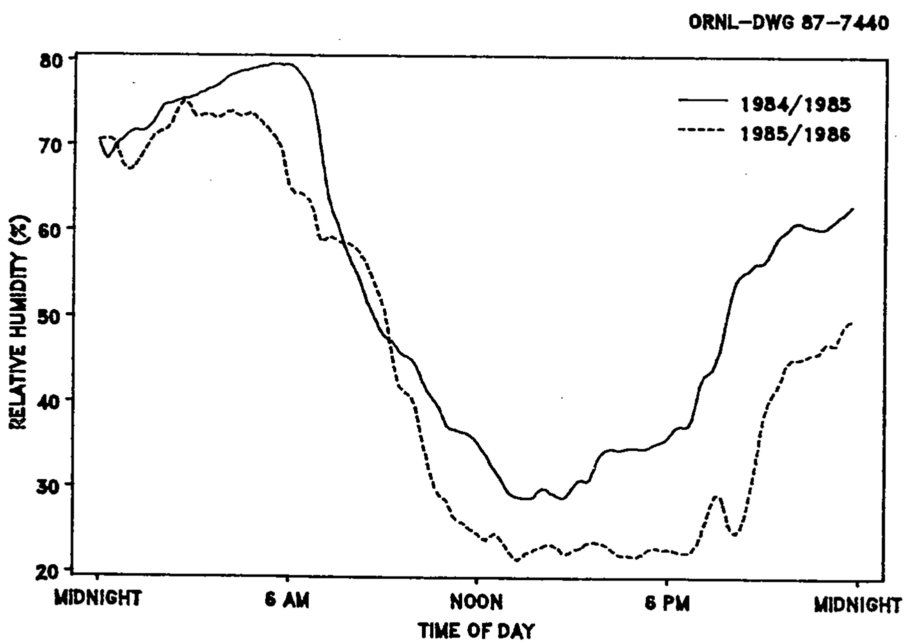

Figure C-38. Comparison of two similar hot days, relative humidity.

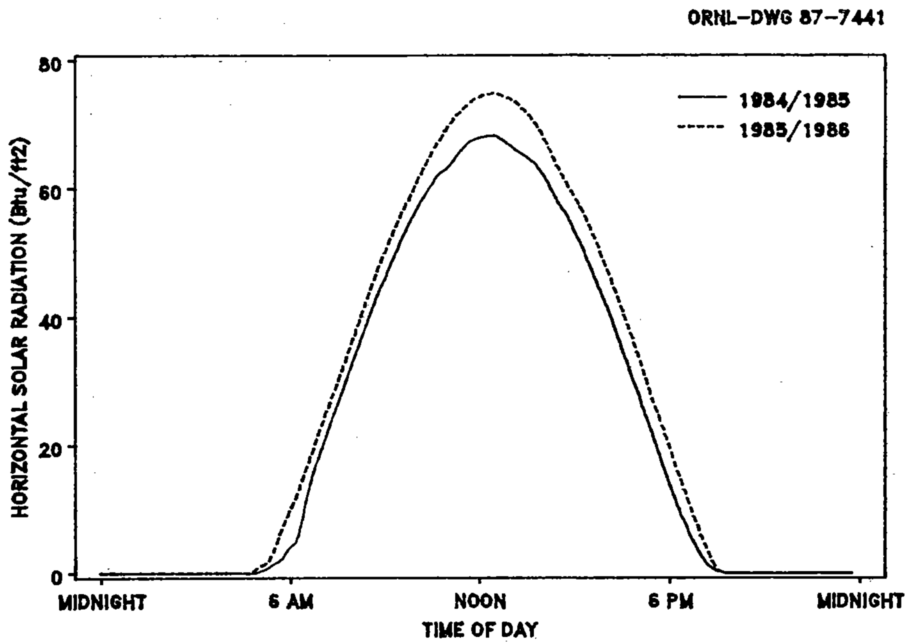

Figure C-39. Comparison of two similar hot days, horizontal solar radiation.

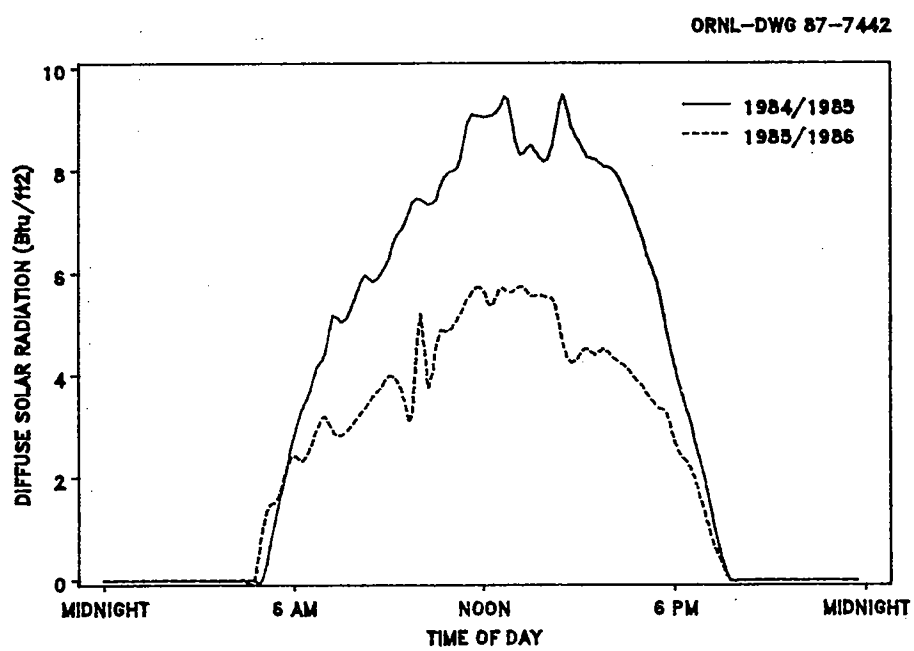

Figure C-40. Comparison of two similar hot days, diffuse solar radiation.

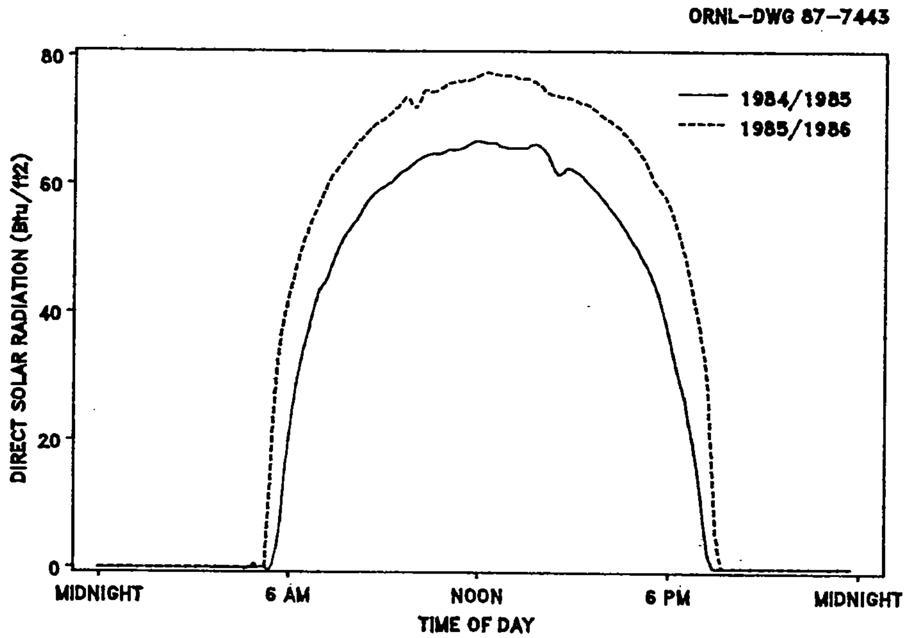

Figure C-41. Comparison of two similar hot days, direct solar radiation.

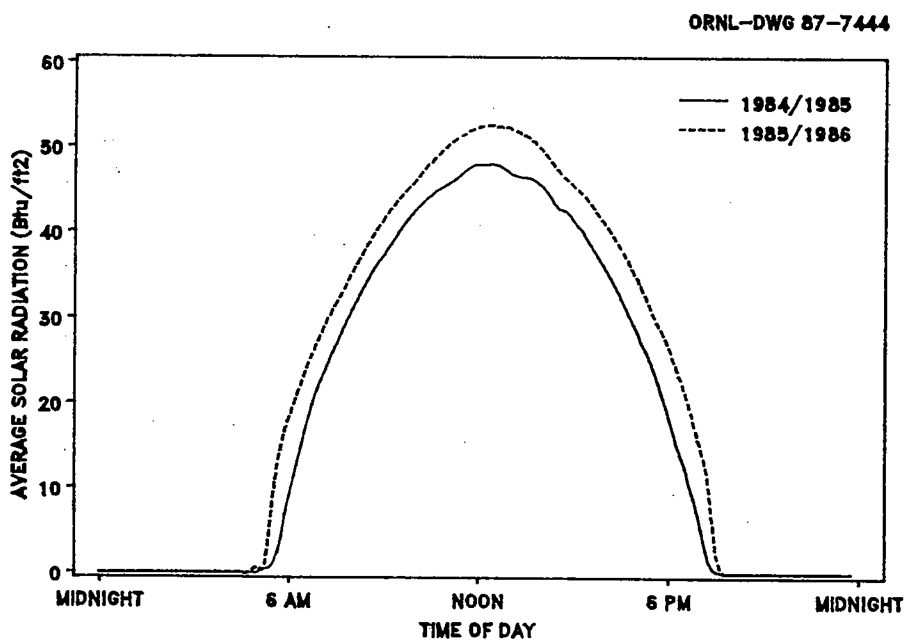

Figure C-42. Comparison of two similar hot days, average of horizontal, diffuse, and direct solar radiation.

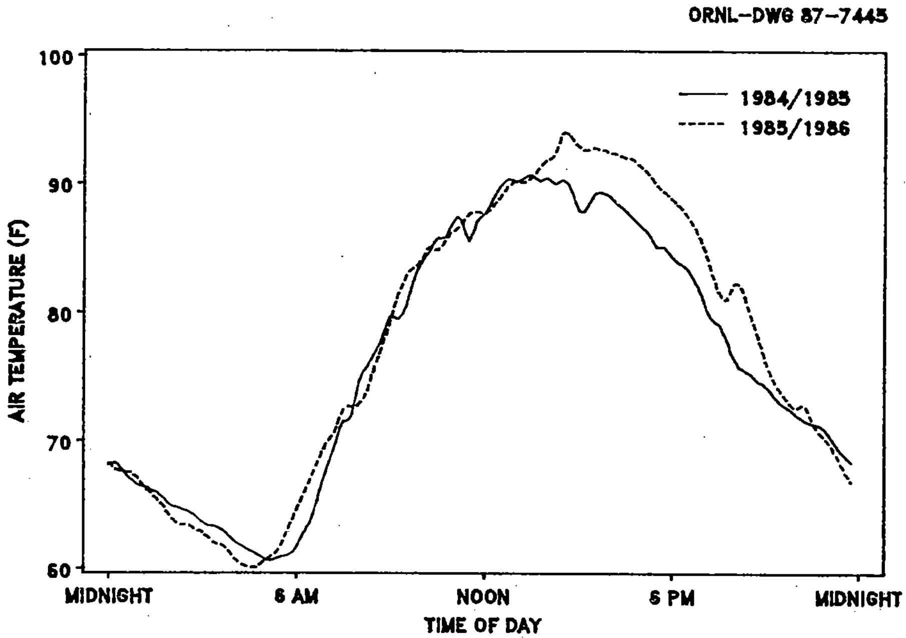

Figure C-43. Comparison of two similar hot days, air temperature.

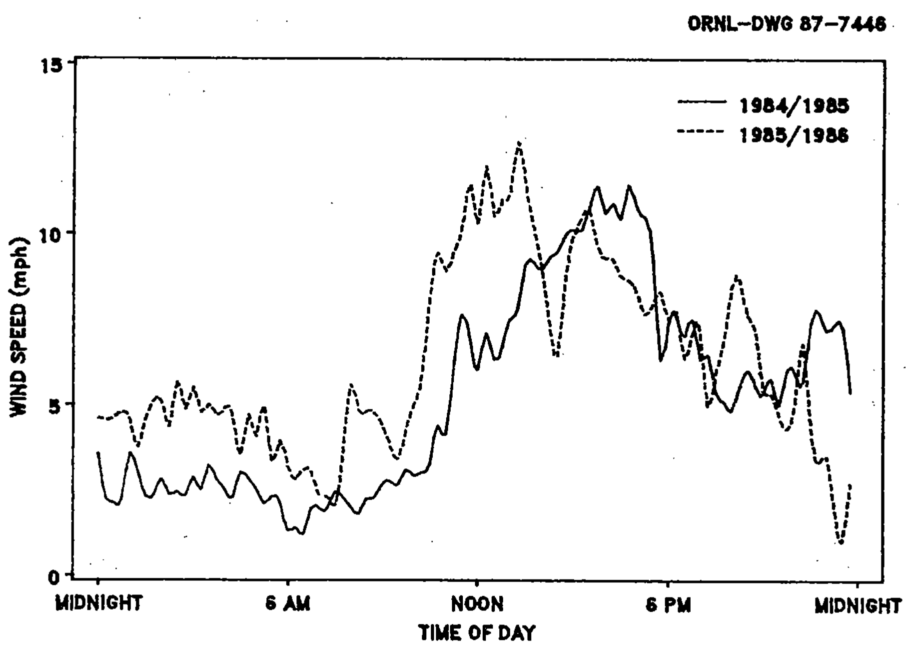

Figure C-44. Comparison of two similar hot days, wind speed.

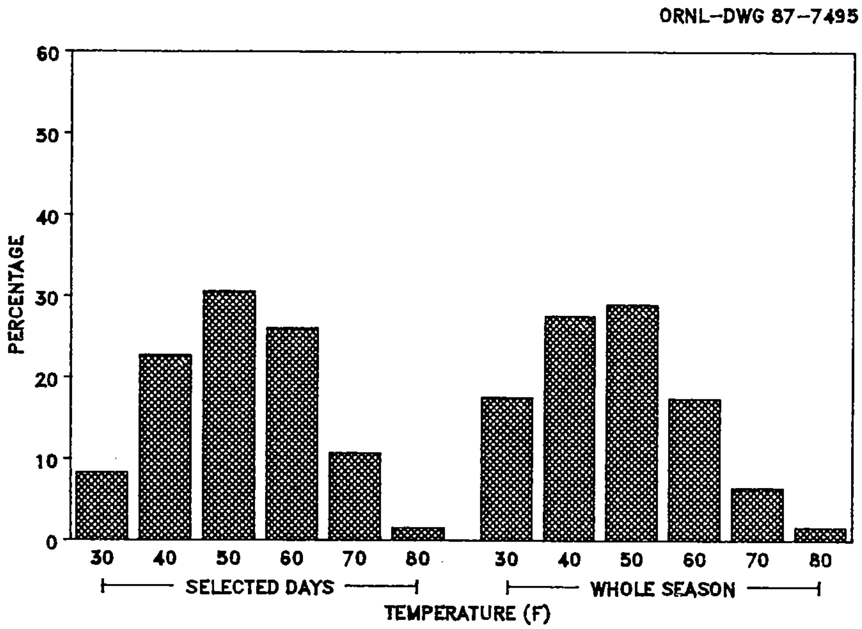

Figure C-45. Outdoor air temperature distribution comparison, autumn selected days.

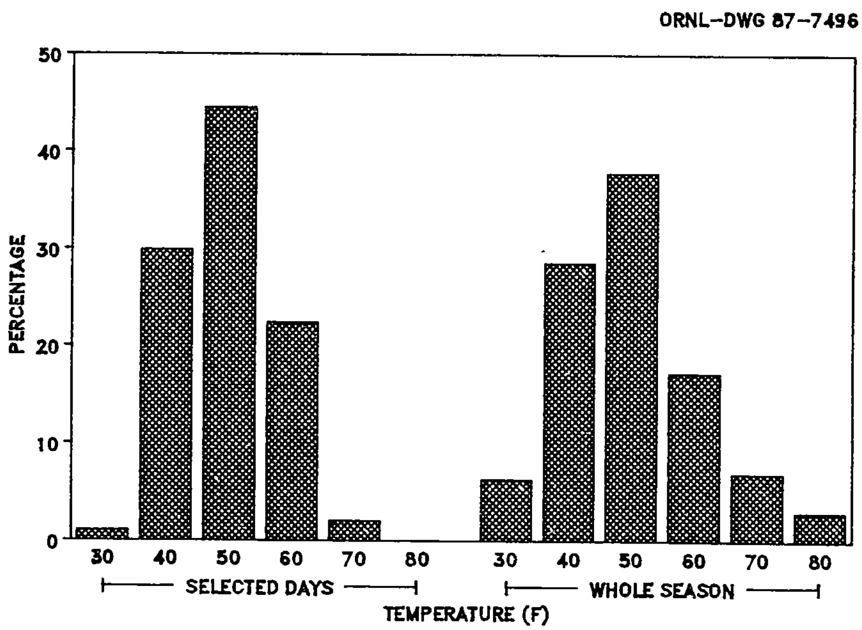

Figure C-46. Outdoor air temperature distribution comparison, spring selected days.

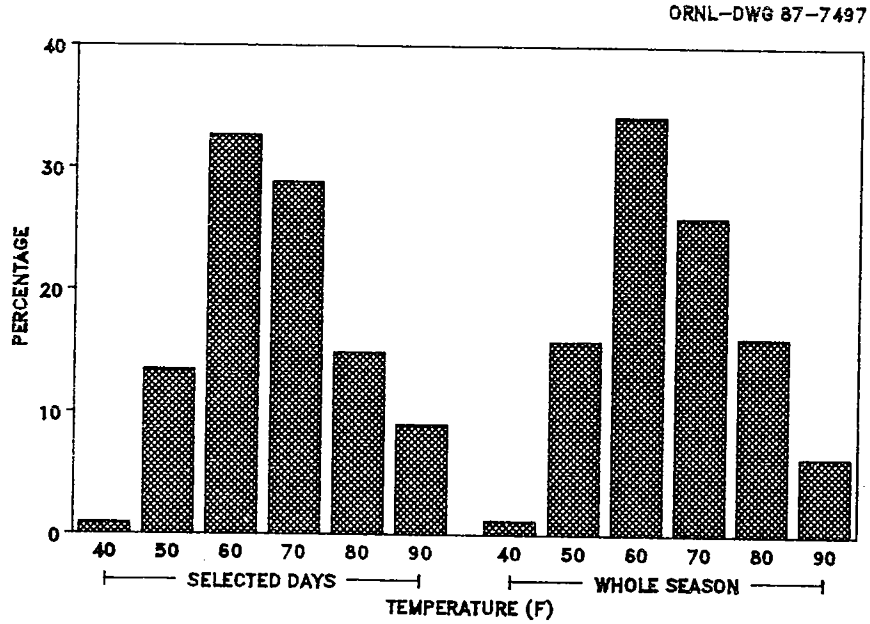

Figure C-47. Outdoor air temperature distribution comparison, summer selected days.

Appendix D: An Examination of the Monitored Feeder

The monitored feeder supplies about 42 small commercial customers and about 40 irrigation pumps, along with about 400 residential customers. A sawmill was monitored separately beginning in November 1984, and its load has been subtracted from the total feeder load wherever possible. Other small commercial loads, including churches, schools, and a radio station, however, remain within the measured loads. Examination of monthly billing data for commercial customers shows their loads to be relatively constant from month to month with little seasonal variation. Figure D-1 shows the relative magnitude of the monthly commercial energy use (including the pump loads) to the monthly residential energy use. The commercial energy use represented about 15 percent of the total feeder energy use during the summer months but only about 10 percent during the winter months because of fluctuating residential consumption, not fluctuating commercial energy use. The pumping loads contributed about five percent of the total feeder energy use during the summer and nothing during the winter.

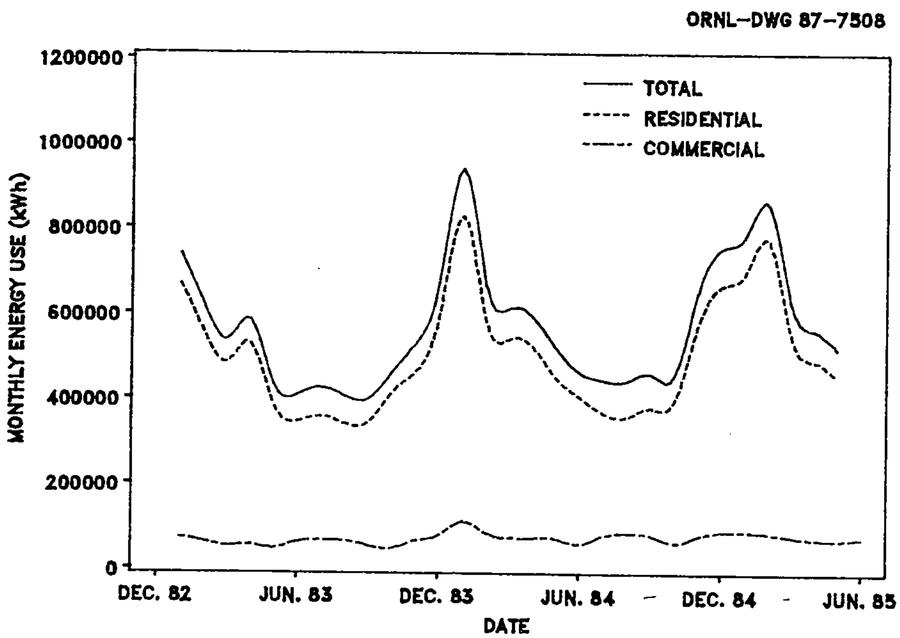

Figure D-1. **Monthly feeder energy use, based on monthly billing data.**

Most of the irrigation pumps and about one-third of the commercial customers are on a demand billing cycle that permits examination of their annual peak loads. The sum of these peak values increased from 358 kW in 1983 to 389 kW in 1984 and increased again to 428 kW in 1985. There is no way to determine the degree of coincidence of these peaks. The total energy consumption of the commercial customers also increased from 1983 to 1985 and is summarized in Table D-1. An artificial measure of commercial loads was derived by dividing the annual nonpump commercial energy consumption (in kWh) by 2,340, the number of business hours per year based on a five-day workweek and nine-hour business-day length and by the number of businesses, 42. Using this measure, there appeared to be a large increase between 1983 and 1984 although the commercial load was relatively constant between 1984 and 1985.

Table D-1. Feeder commercial customer loads

Year	Sum of measured commercial peak loads, noncoincident (kW)	Total commercial consumption[a] (kWh)	Total feeder consumption (kWh)	Estimated average business hourly load[b] (kW)
1983	358	723,000	c	6.6
1984	389	934,000	5,315,000	8.8
1985	428	936,000	5,416,000	8.8

[a] Including irrigation pumps.

[b] Based on the total commercial load (minus the pump loads) divided by 42, the number of commercial accounts.

[c] Not measured.

In summary, the commercial load was difficult to characterize and was not separately monitored. A trend toward increasing commercial loads with time, which may have served to mask any savings achieved by the residential customers participating in the conservation program, was noted. However, any attempt to modify the measured feeder load to remove the effect of these unmeasured commercial loads is likely to introduce as many, if not more, errors than it corrects.

About one-half of the residential customers on the feeder participated in the program (most of the others were ineligible because they were not electrically heated). About one-fourth of the residential customers on the feeder were also members of the monitored group of customers. Most of these monitored customers were retrofit between April and July 1985. The similar-day sets chosen for savings comparison were selected to avoid this period. The customers who were not in the monitored group, however, were retrofit over a much longer time period. About one-third of the feeder's program participants (or one-sixth of the feeder's residential customers) received their audit and water heater measures before November 1984, and a total of 28 percent of the feeder's program participants were weatherized before the end of the 1984-1985 winter season. Therefore, the comparison of before and after feeder loads will not reflect (i.e., will underestimate) all of the savings achieved by these customers. The feeder was not monitored during the winter of 1983-1984, so a better precomparison and postcomparison period is not available.

During the 1984-1985 winter season the feeder peaked on Friday, December 20, 1984. The highest 15-minute peak occurred between 7:00 and 7:15 a.m., the highest 30-minute peak between 7:00 and 7:30 a.m., and the highest hourly peak between 6:45 and 7:45 a.m. During the 1985-1986 winter season the feeder peaked on November 28, 1985. All three peak periods, 15 minute, 30 minute, and one hour, ended at 10:00 a.m. This second season peak occurs later in the morning because November 28 was a holiday, Thanksgiving. The peak values are given in Table D-2. Each value represents the average feeder load minus the sawmill load during the period given. As expected, the half-hour and hourly peaks are lower than the 15-minute peaks. Because the second season peak occurred on a holiday during an extreme cold spell (100-year temperature records were broken by subzero weather during November 1985), these two peaks are not directly comparable and cannot be used for any estimation of Project-related savings on the feeder load.

Table D-2. Peak loads on monitored feeder[a]

Date	Time (a.m.)	Peak load (kW)	Duration (min)
Dec. 20, 1984	7:00-7:15	2506	15 min
Dec. 20, 1984	7:00-7:30	2476	30 min
Dec. 20, 1984	6:45-7:45	2435	60 min
Nov. 28, 1985	9:45-10:00	2461	15 min
Nov. 28, 1985	9:30-10:00	2419	30 min
Nov. 28, 1985	9:00-10:00	2399	60 min

[a] All loads represent the feeder load minus the sawmill load. Note that other commercial loads are included, however, and these loads were probably lighter on Thanksgiving Day than on Friday, Dec. 20, 1984.

As discussed in Section 3.1, the regression-based weather-normalization method was unsatisfactory when applied to the feeder load and could not be used to produce more comparable peak load profiles for the feeder.

Figure D-2 shows the feeder load (without the sawmill load) on two days with very similar weather patterns, January 16, 1985, and January 15, 1986. The load during the second season is marginally lower (about 40 kW) and similar in shape. The evening and nighttime savings appear to be larger than the morning savings, perhaps because the commercial loads are much less at these times and improvements in the stock of residential buildings are more visible. The 15-, 30-, and 60-minute peaks for these two days are shown in Table D-3.

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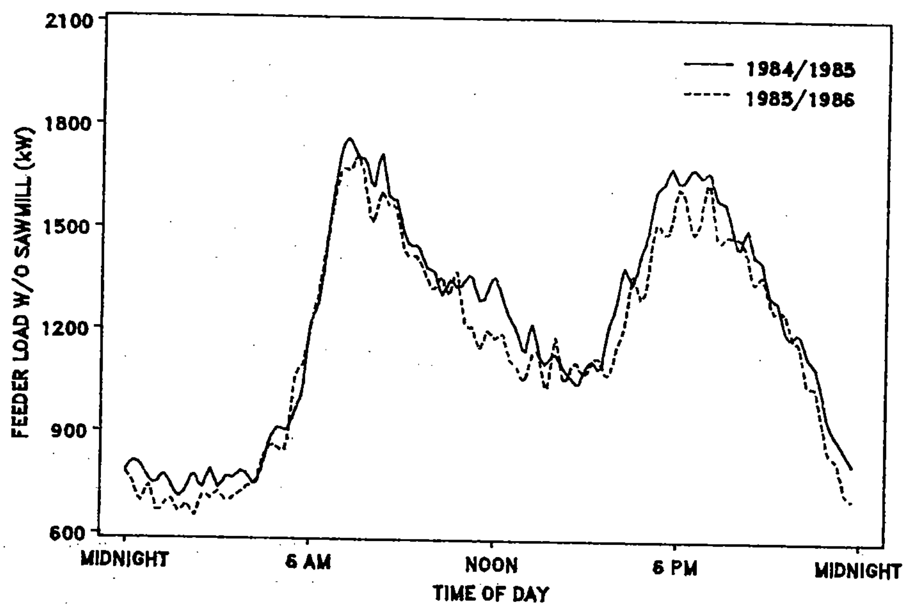

Figure D-2. Feeder load on selected similar cold days.

Table D-3. Peak feeder loads on two similar cold days[a]

Date	Time (a.m.)	Peak load (kw)	Duration (min)
Jan. 16, 1985	7:15-7:30	1752	15 min
Jan. 16, 1985	7:00-7:30	1745	30 min
Jan. 16, 1985	7:00-8:00	1720	60 min
Jan. 15, 1986	7:30-7:45	1712	15 min
Jan. 15, 1986	7:15-7:45	1691	30 min
Jan. 15, 1986	7:00-8:00	1664	60 min

[a] All loads represent the feeder load minus the sawmill load. Note that other commercial loads are included, however.

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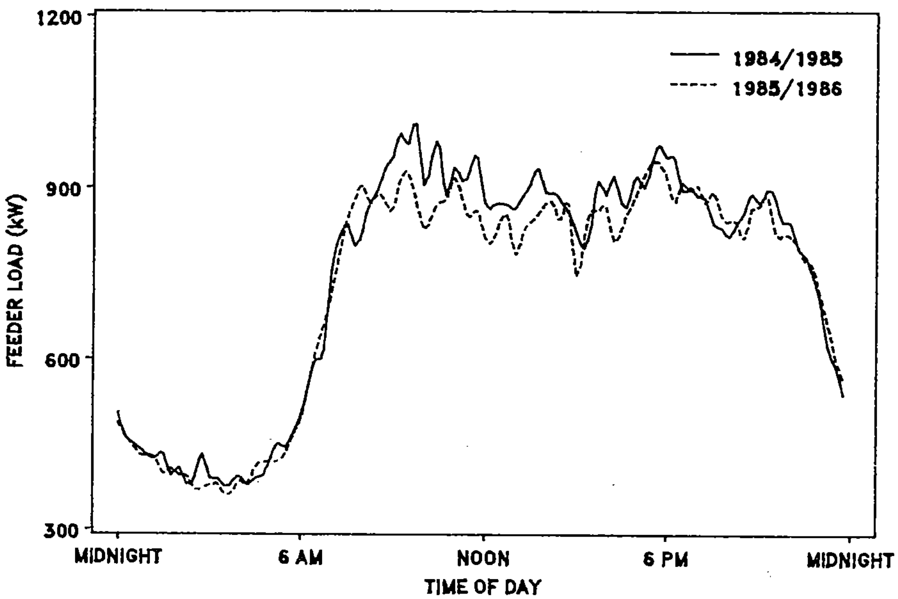

Figure D-3. Feeder load on selected similar hot days.

The total feeder load (including the sawmill) on two similar hot summer days, August 9, 1984, and July 26, 1985, is shown in Figure D-3. The daytime load during the second season appears to be slightly lower than that of the first season. The shape of the two curves is similar.

The average feeder loads during the similar-day periods discussed in Section 3.2 were examined to determine the impact of the Project on the feeder load. These loads for each season (normalized by using sets of similar days) are shown in Figure D-4. The average weekday feeder loads for all four seasons are shown against time-of-day in Figures D-5 to D-8. The winter savings are statistically insignificant, both with and without the sawmill load. The autumn savings are significant at the 90 percent level, and the spring and summer increases are significant at the 95 percent confidence level. A distribution of feeder loads shows (in Figures D-9 and D-10) that the feeder actually served higher loads during the second season with 53 15-minute periods at loads greater than 1,980 kW compared with only two 15-minute periods at this level during the first season.

The autumn comparison shows greater savings (significant at the 94% confidence level) of about 23 kW (3%). These savings may appear larger because fewer homes were retrofit before and during the preretrofit autumn period (16%) than in the preretrofit winter period (28%). Considering the magnitude and uncertainty of the commercial loads, these autumn and winter savings are so small that the impact of the conservation program is difficult to measure.

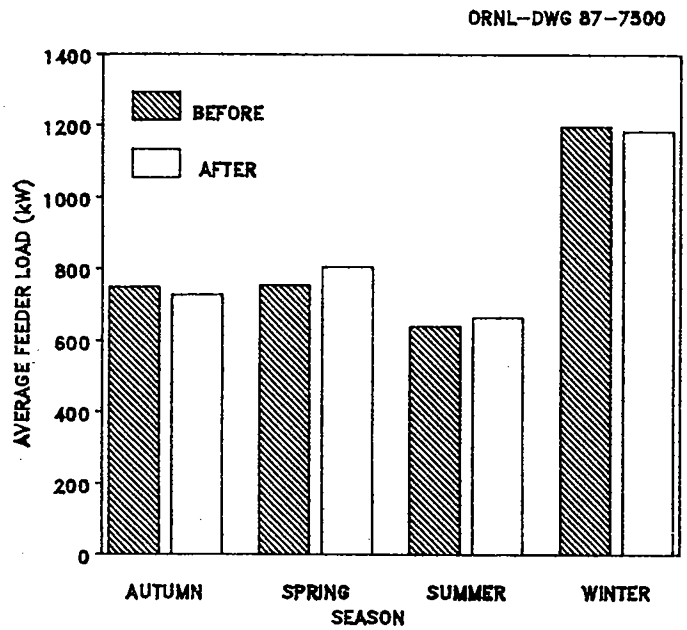

Figure D-4. Average seasonal feeder loads.

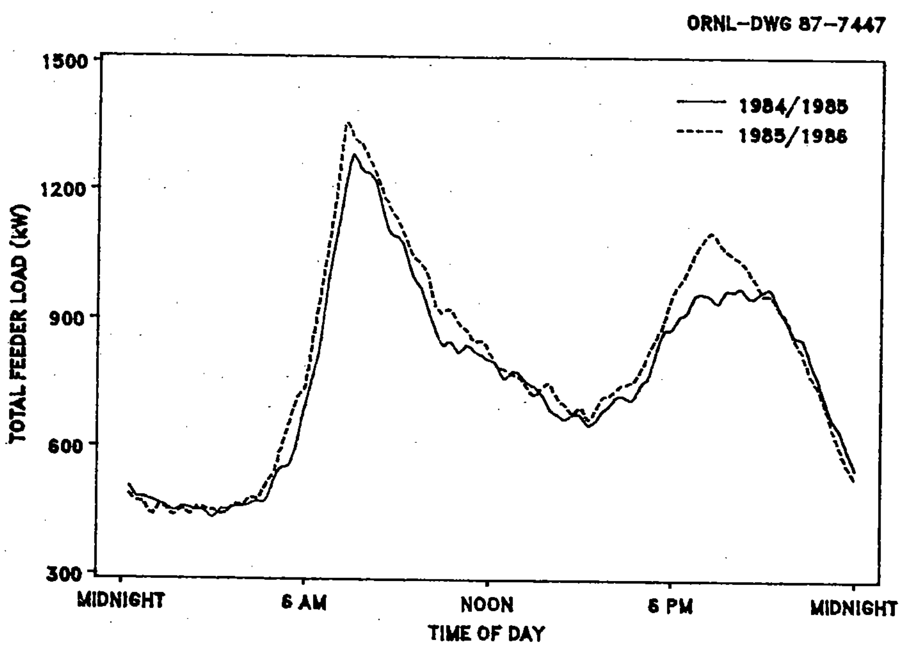

Figure D-5. Average weekday feeder load profile, spring.

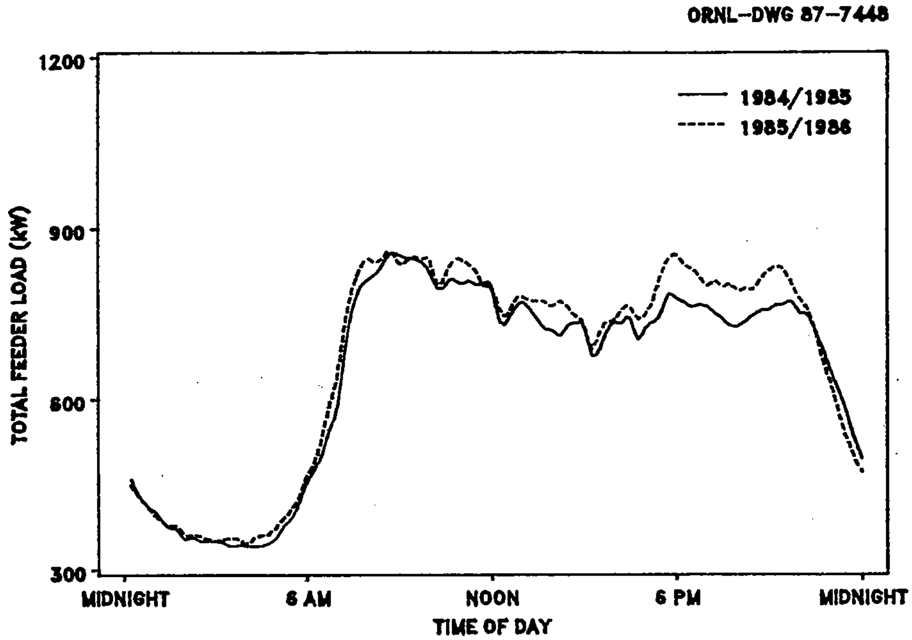

Figure D-6. Average weekday feeder load profiles, summer.

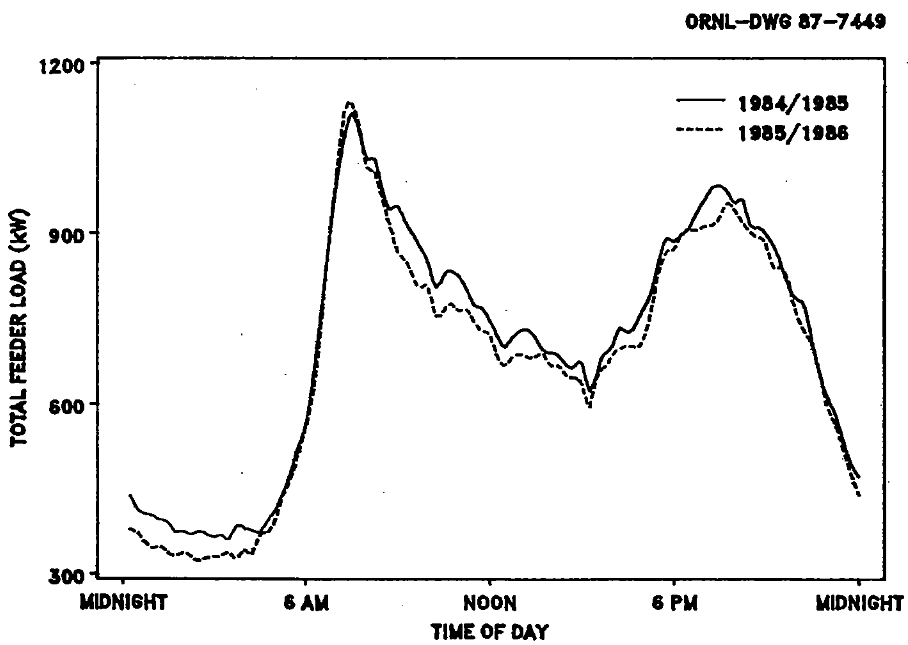

Figure D-7. Average weekday feeder load profile, autumn.

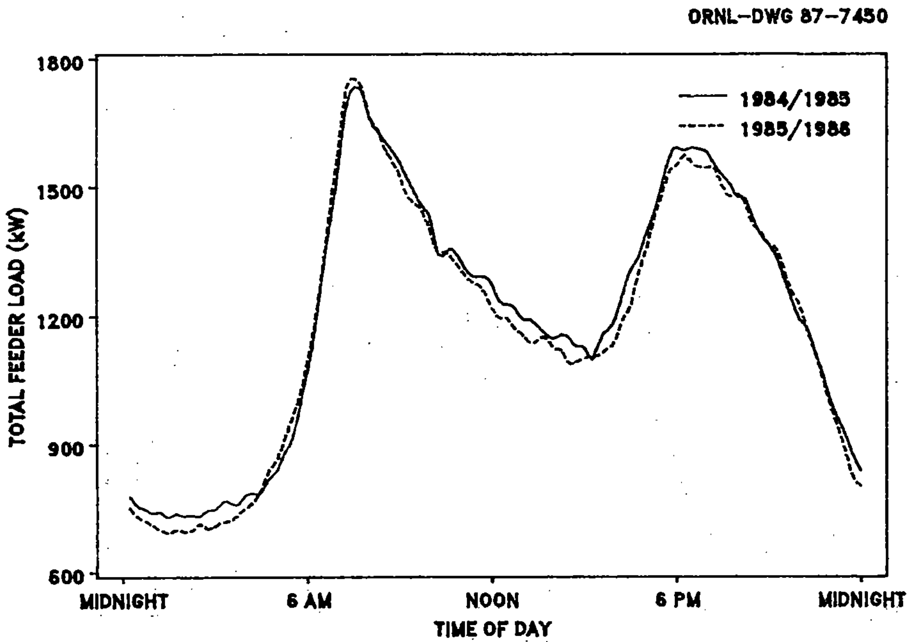

Figure D-8. Average weekday feeder load profile, winter.

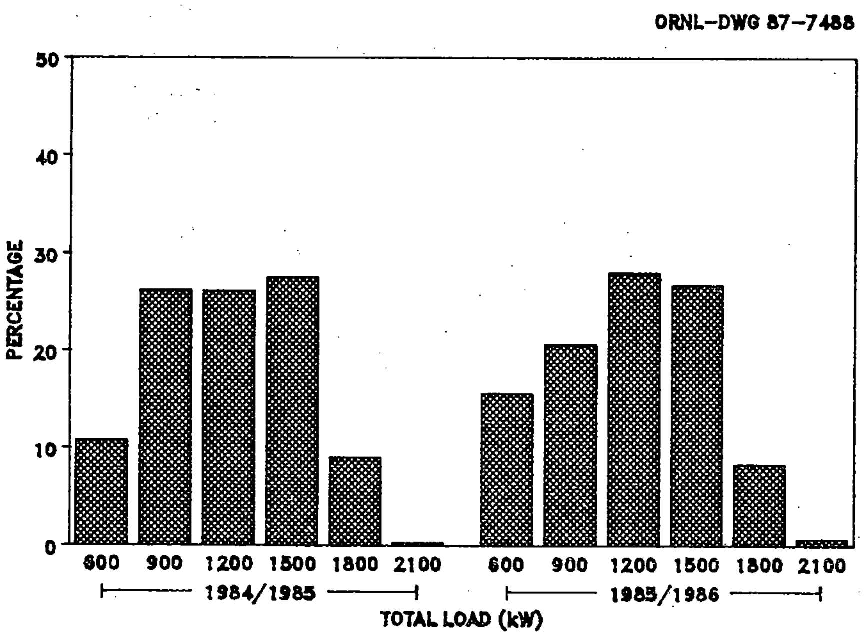

Figure D-9. Distribution of winter feeder loads.

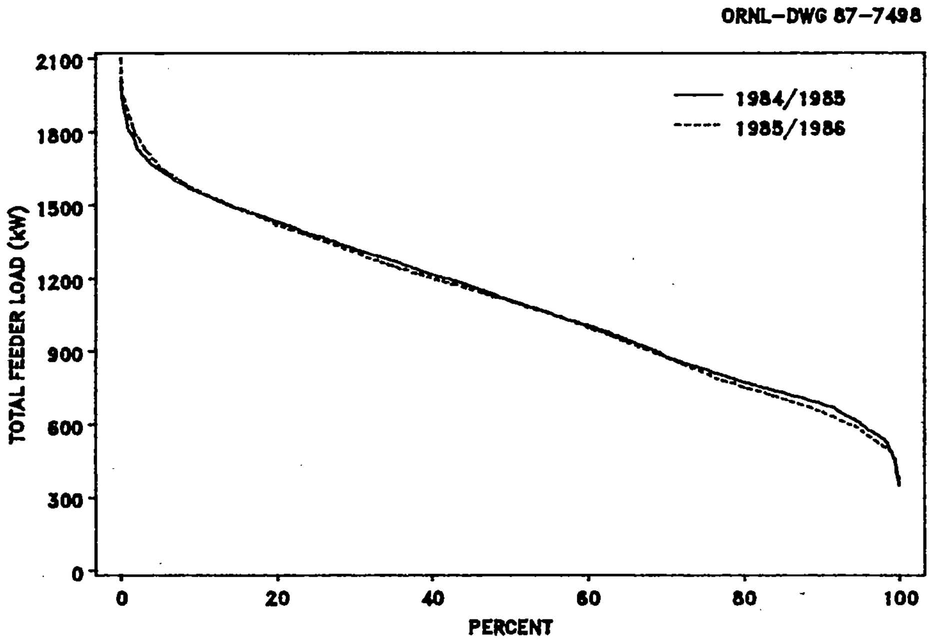

Figure D-10. Load duration curve for winter feeder loads.

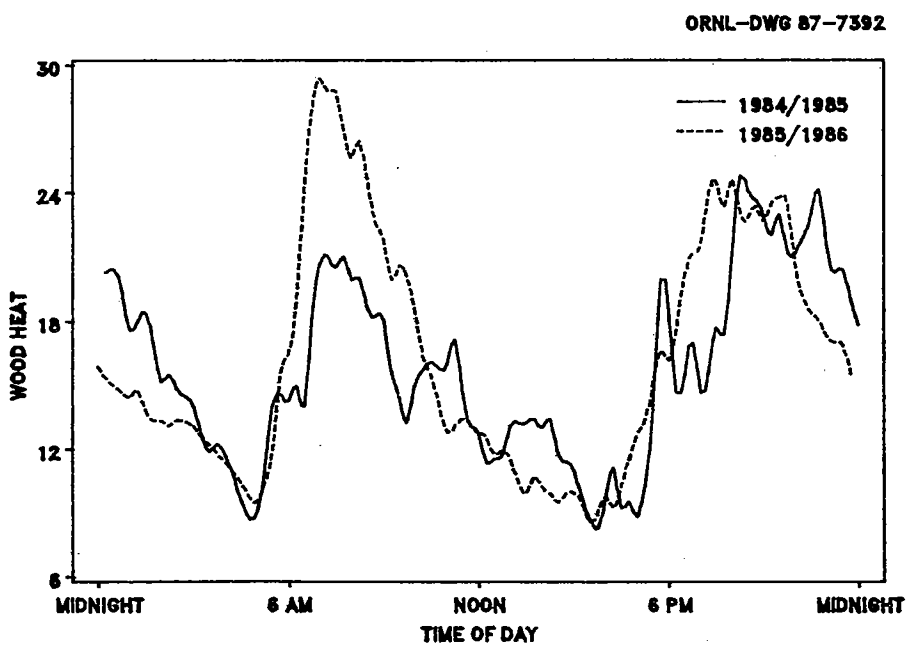

Figure D-11. Springtime wood heat use increased.

The spring and summer loads actually increased by an average of 50 kW (7%) in the spring and 25 kW (4%) in the summer. The springtime increase is most likely attributable to commercial customers because the diversified load of the monitored group of residential customers decreased both in average load (by 0.1 kW/household) and in peak load (by 0.5 kW/household). Also, the measured level of wood heat used during the spring increased between seasons 1 and 2 (see Figure D-11), so the feeder load increase was not likely caused by a shift from wood to electric heat. Small increases in summer air conditioning loads can be caused by the installation of floor insulation (see Boercker 1984). However, the average load among the monitored customers decreased for homes without air conditioning, homes with one air conditioner, and homes with two or more air conditioners. Therefore, the summer increase is also more likely attributable to the commercial customers than to the residential program participants.

The Pacific Power & Light feeder was monitored to help measure the effect of the program on the larger system. Additionally, it was hoped that some method of predicting system load savings from individual household savings could be derived. In particular, a relationship between changes in residential end uses, such as space or water heating, and changes in the feeder loads was desired. However, this was not realized because of the following considerations:

1. the feeder savings were very small, both as a percentage of feeder load and in absolute terms;
2. there were some indications (i.e., increasing spring and summer loads) that the commercial loads (unmonitored until February 1986) were increasing;
3. the conservation retrofit periods overlapped the feeder comparison periods, thus obscuring some savings and affecting the measured changes in end-use loads;
4. the changes in end-use loads were often positive when the change in feeder load was negative; and
5. the commercial-sector load characterization was insufficient to correct for the noted deficiencies (a few possible correction methods were judged to introduce errors larger than the small amount of measured savings).

Reference

Boercker, F. (1984). Technical Review of a Residential Conservation Service Measure: Insulation of Crawl Spaces, Oak Ridge National Laboratory, ORNL/CON-112, Oak Ridge, Tennessee, January.

Appendix E: User Group Load Profiles

Figures E-1 to E-6 compare the preconservation load shapes for several user groups discussed in Section 5.4.

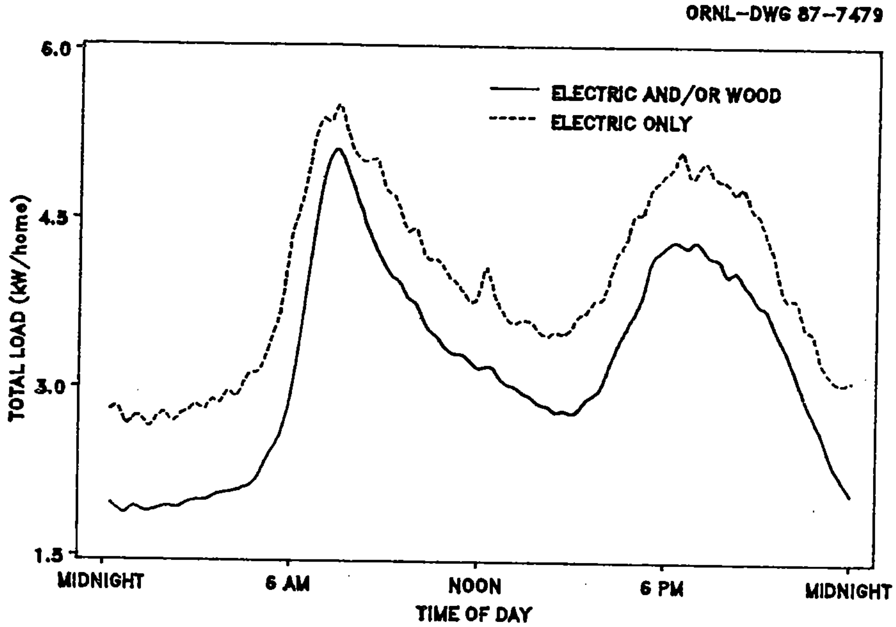

Figure E-1. Comparison of diversified total load in homes that use electric heat exclusively to that of all other homes.

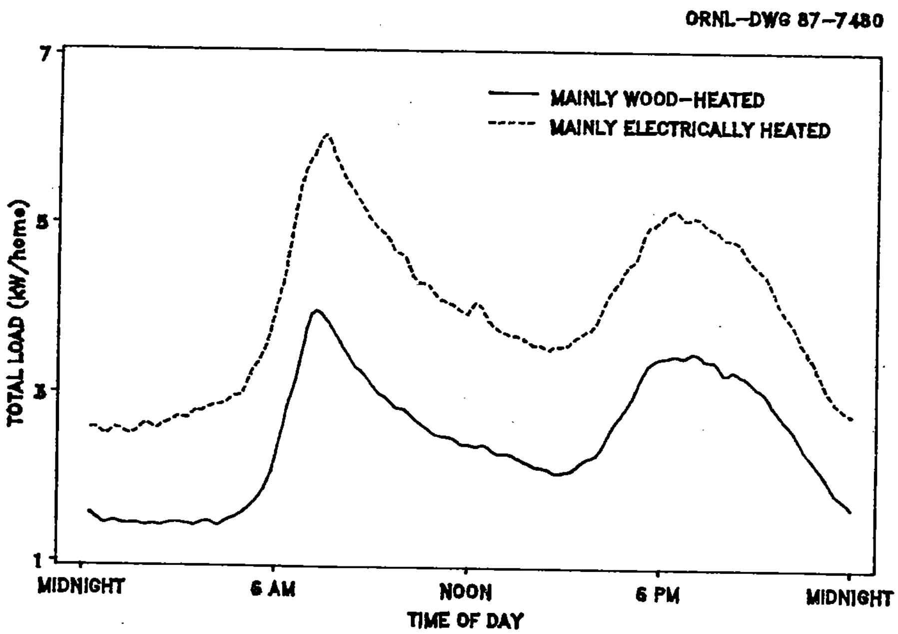

Figure E-2. Comparison of diversified total load in homes that use mainly electric heat to that of homes heated mainly with wood.

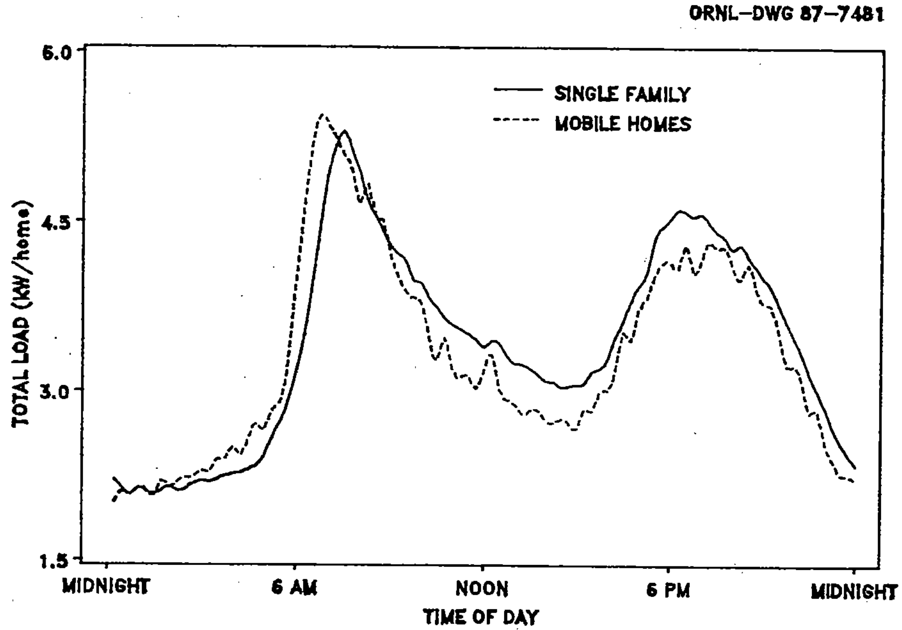

Figure E-3. Comparison of diversified total load in different dwelling types.

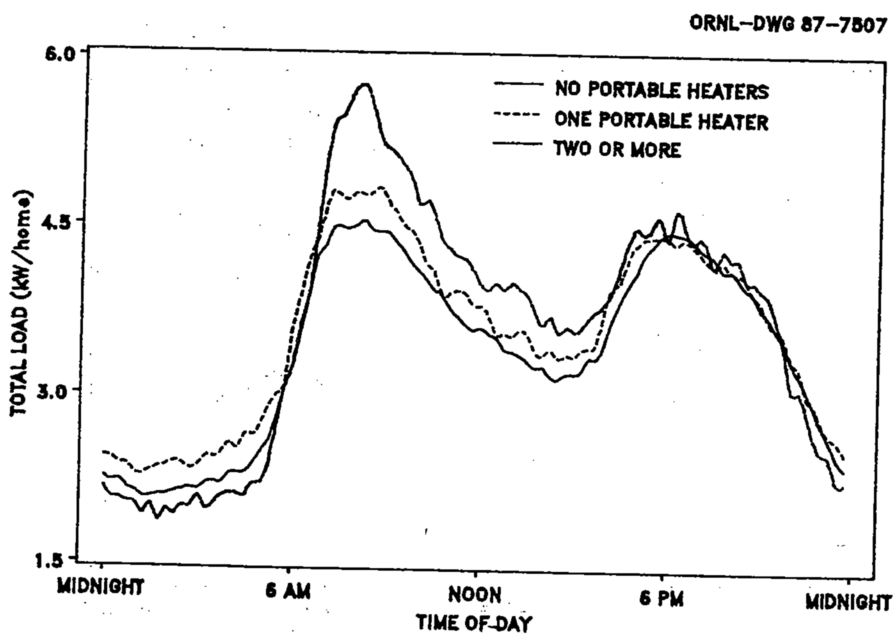

Figure E-4. Comparison of diversified total load in homes with and without portable heaters.

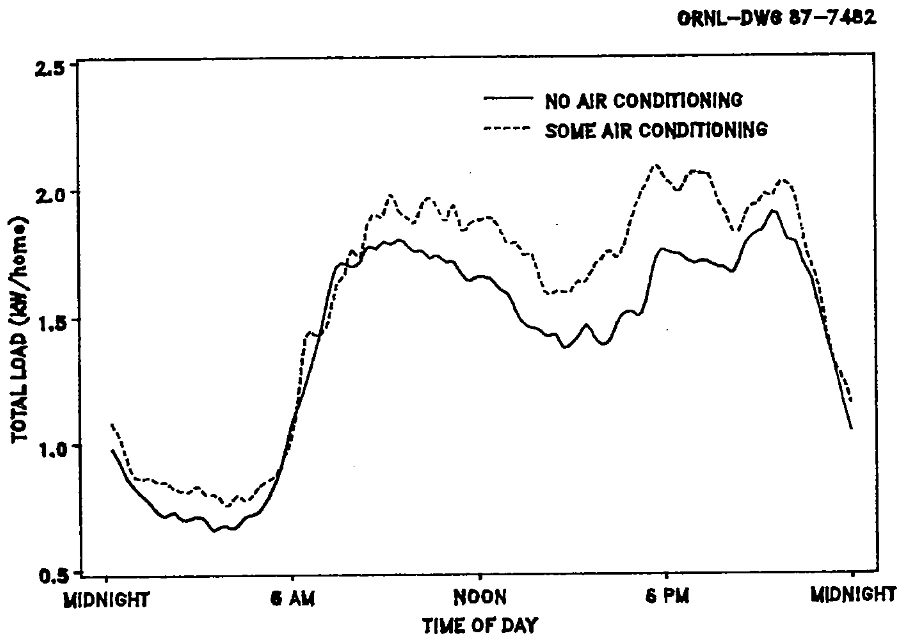

Figure E-5. Comparison of diversified total load in homes with and without air conditioners.

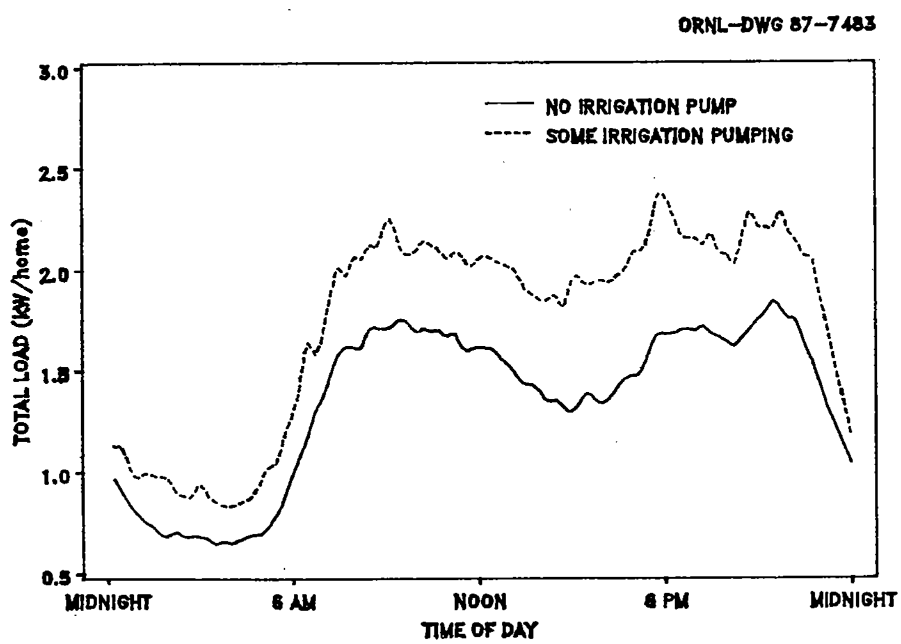

Figure E-6. Comparison of diversified total load in homes with and without irrigation pumps on the meter.