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ORNL/CON-321

Persistence of the Impact of the Hood River Conservation Project on Typical and Peak Loads Three Years After Weatherization

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MANAGED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
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GLOSSARY

baseload	the portion of a building's energy load that is not used for space heating or cooling, so that total energy load = space heating + space cooling + baseload
Bonneville	Bonneville Power Administration
contribution factor	the demand of a subdivision (e.g., residential), at the time of occurrence of the maximum system demand, divided by the maximum system demand; in this report, contribution factor refers to electricity unless otherwise stated; expressed as a proportion of maximum system demand
daily co-peak	the times of day (week day, weekend day, or system peak day) when the highest load is observed for PESHE/M customers at more than one time; when co-peaks are observed at two consecutive hours, there is probably only one peak, which most likely occurred at the half hour between the two consecutive hours (i.e., this type of co-peak is probably an artifact of the data aggregation methodology)
daily peak	the time of day (weekday, weekend day, or system peak day) when the highest load is observed for PESHE/M customers
diversified load	average load of a large number of customers at a given point in time; in this report, the diversified load refers to electricity unless otherwise stated
fuel switching	the change in reliance from one fuel to another for space heating needs, from one heating season to another; e.g., from woodfuel to electricity or electricity to woodfuel, as reported by the customer
HRCP	Hood River Conservation Project
peak load	highest, or maximum, electricity load during a period of time
Pacific or Pacific Power	Pacific Power & Light Company
PESHE	residential customers with permanently installed electric space heating equipment [in the present study, all houses have PESHE]
PESHE/M	refers to the existing mix of fuels used for space heating among Hood River residential customers; in this study, all of the submetered houses
PESHE/W	PESHE customers whose space heating needs are filled to a large degree by woodfuel, as reported by the customers; in the present study, PESHE/W is a subset of PESHE/M

pre-program	syn.: pre-retrofit; pre-weatherization; i.e., the one-year period that immediately precedes the conservation work or implementation of the program
secondary daily peak	the time of day (whether weekday, weekend day, or system peak day) when the second highest load is observed for PESHE/M customers (sometimes referred to as the evening peak)
typical	"combining or exhibiting the essential characteristics of a group," such as *typical* winter day
woodfuel	self-explanatory; aka residential wood combustion for space heating, or RWC-h, in the land planning literature

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EXECUTIVE SUMMARY

OVERVIEW

The Hood River Conservation Project (HRCP) was a major residential retrofit demonstration project, operated by Pacific Power & Light Company (Pacific Power) and funded by the Bonneville Power Administration (Bonneville). The project was designed to install as many cost-effective retrofit measures in as many electrically heated homes as possible in the community of Hood River, Oregon.

In order to displace, or defer, new generation, energy conservation must save not only energy (kilowatt-hours or kWh), but it must also save capacity (kilowatts or kW), especially at system peak times. This report focuses on the persistence of savings of the HRCP in typical and peak loads three years after weatherization.

The HRCP involved higher levels of conventional retrofit measures than generally offered in weatherization programs in the Pacific Northwest or elsewhere. In addition, Bonneville paid for installation of conservation measures up to a cost-effectiveness limit of $1.15 for each estimated kWh savings in the first year after retrofit. Thus, HRCP offered the chance to examine levels of retrofit installation and subsequent energy and load savings when customer cost and ineligibility due to prior retrofit activities were largely removed as barriers. Additional information on the purposes, design, operation, and findings of the HRCP is compiled in the project's comprehensive final report (Hirst 1987).

In order to conduct the original load study (Stovall 1987) and this follow-on report, Pacific Power HRCP planners selected a special group of 320 Hood River homes that represented a cross-section of the community. The end-use loads (electric space heating, electric water heating, or woodfuel space heating), total load, and the interior temperatures of these homes were monitored for one year before weatherization and three years after weatherization. Submetered data were collected at 15-minute intervals for each of these end-uses, total load, and interior temperature. Detailed 15-minute weather data were also collected. A control group was not used because it would have interfered with the maximum possible penetration goal of the HRCP.

Interior temperatures were recorded every 15 minutes. One recording device was mounted on an interior wall of each house, at eye level, in the house's most regularly occupied room during non-sleeping hours. There were important variations among the proximities of recording devices, heating ducts, and woodstoves. See Dinan (1987) for a thorough discussion of the protocol used for recording interior temperatures.

The weather data were collected at three weather stations and included: horizontal radiation, direct beam radiation, wind direction, wind speed, dry-bulb air temperature, relative humidity, 4-inch soil temperature, 20-inch soil temperature, 40-inch soil temperature, and barometric pressure. Not all of these weather elements were recorded at each station, and large blocks of data were sometimes missing (some as long as 2 weeks). For these reasons and because the analysis used diversified load, the weather data from all three stations were averaged. Three of the climate elements--dry-bulb air temperature, relative humidity, and barometric pressure--were used to select matched winter days across the 4 years of data.

Wood heat was measured using radiometers placed near the woodstoves. The radiometers were calibrated by Lawrence Berkeley Laboratory (LBL) to measure the energy output of specific brands and models of woodstoves (Modera 1986). LBL developed conversion factors that were found to vary widely among brands and were strongly affected by radiometer position relative to the stove. The Pacific Power staff were very careful to record the exact positions of these monitors and to correct the conversion factors to match the LBL correlations before generating another revision of the database. As a result of the combined efforts of LBL and Pacific Power, it was determined that group measures of central tendency can be compared but that the comparisons of individual houses were not defensible.

The data were collected in the field by Pacific Power and transferred to Oak Ridge National Laboratory (ORNL) in four primary installments: (1) submeter pulse values corresponding to 15-minute customer consumption data along with recorded values of interior temperatures, (2) weather pulse values corresponding to 15-minute climate information, (3) project data (audit and weatherization information), and (4) four occupant surveys for each of the 320 monitored houses. The database compiled for this analysis contained data for more than 90 million data points. The SAS Institute software (SAS) was used for all of the data management and analysis.

SAMPLING

The present analysis examined the electric load profiles, load savings, persistence of savings, and fuel switching for the HRCP end-use monitored (i.e., submetered) houses. The original evaluation plan identified 320 Hood River homes to be submetered. After more than four years of submetered data collection, 220 homes (Sample n_1) were available for analysis in this load study. The present load study was restricted to single-family detached housing. The screening criteria consisted of changes in occupancy, removal of metering equipment from homes, possible confounding loads like irrigation, and the single-family criterion.

The original evaluation plan called for total electricity, space heating electricity, and interior temperature monitors to be installed and metered in all submetered houses. Water heating electricity monitors were installed in 220 of the original 320 houses; radiometers were installed in 100 of the original houses in order to measure the heat output of woodstoves. Houses with water heating electricity submeters did not have radiometers and *vice versa*. The present load study examined the load dynamics of 145 homes (Sample n_2) with water heating electricity submeters and 75 homes (Sample n_3) with radiometers. Both of the water-heating and radiometer groups were subsets of the 220 homes available for this load study.

Data attrition was much smaller for this load study than was expected based upon the rates of data attrition observed in other studies of persistence of energy or load savings. In this study, nearly 70% of the original 320 households were retained; nearly 68% of the households with water heating electricity submeters were retained; and 75% of the houses with radiometers were retained, three years after weatherization in the HRCP. As a result of this high rate of data retention, it was decided to select one set of four matched weekdays (i.e., one weekday from each year of the four years in which data were collected) to weather-normalize the loads, one set of four matched weekend days, and the Pacific Power System peak days for analysis. The Pacific Power System peak days coincide in most cases with Bonneville System peak days.

The matched weekdays were all Wednesdays, with average daily temperatures of 32.34° F., 32.62, 34.69, and 34.19, with a range of 2.35° F. The matched weekend days were all Saturdays, with average daily temperatures of 29.37° F., 30.46, 30.93, and 30.15, with a range of 1.56° F. The Pacific Power System peak days were Monday, Friday, Friday, and Tuesday, with average daily temperatures of 25.25, 21.59, 22.20, and 25.52° F., with a range of 3.93° F. All matched days had comparable relative humidity and barometric pressure.

The electricity load of primary interest in this study was the peak hourly load, rather than the peak 15-minute load. The hourly load was derived from the 15-minute consumption data by summing the four 15-minute kW values in each hour. The product is the diversified hourly load or the average load per hour.

Except when otherwise indicated, the data were averaged across households and then other arithmetic operations were performed to obtain sample values for loads, interior temperatures, and other group values.

FINDINGS AND CONCLUSIONS

The most significant changes due to the HRCP from the pre-program year to three years after weatherization include the following:

- During typical weekdays at the peak hour, whole-house electricity load was reduced by 0.8 kW/house. Space heating electricity load was also reduced by 0.8 kW/house. Water heating electricity load *increased* by 10%. Baseload electricity was virtually unchanged. Woodfuel users saved 0.5 kW/house of whole-house electricity, 0.6 kW/house of space heating electricity, and practically no baseload. (See sections 5.1 and 5.3.)

- During typical weekend days, whole-house electricity load was reduced by 1.0 kW/house. The space heating electricity load peak hour shifted from 9 AM to 11 AM, with a load savings of 0.8 kW/house. Baseload electricity was reduced by 7%. The water heating electricity load declined by 6%, in contrast to the weekday finding. (See sections 5.1 and 5.3.)

- During typical weekend days, woodfuel users reduced whole-house electricity load by 1.3 kW/house. Approximately 0.5 kW/house of space heating electricity was saved. Baseload electricity was reduced by 0.8 kW/house. (See sections 5.2 and 5.3.)

- During Pacific Power System peak days at the peak hour, whole-house electricity load was reduced by 1.5 kW/house (estimated to be 207 MW system-wide). Space heating electricity load comprised most of this savings (87%). Water heating electricity load *increased* by 0.1 kW/house (8%). Baseload electricity was virtually unchanged. (See section 5.3.)

- In general, indications were found suggesting that water-heating electricity load and outdoor temperature are more correlated than has usually been hypothesized.

- The HRCP effectuated an improvement in comfort as indicated by generally large increases in interior temperature, some as large as 3° F. (See section 5.6.)

- Nearly 28% of the submetered homes reported that they switched primary space heating fuel at least one time between 1984 and 1989. During the same six years, 47% of the households never switched from electricity and 25% never switched from woodfuel. (See section 6.2.)

- Four fuel selection paths were modelled, indicating that the propensity to switch fuels was related to the age of the household head, the education level of the household head, household income, the number of rooms in the house, and the change in perceived comfort level due to the HRCP. This categorical/logistic regression model had an R-squared analog of 0.251. (See section 6.1.)

- Woodfuel users demonstrated erratic responses to weatherization effects. The changes in their load profiles and interior temperature profiles indicated that the first and second postretrofit years were trials, and that woodfuel users did not adjust to the HRCP until the third postretrofit year. HRCP participants that heated predominantly with electricity showed a less dramatic and more consistent response. Electricity loads were much more unpredictable in woodfuel houses. (See sections 5.2 and 5.4.)

The HRCP effectuated lower load profiles and sustained load savings for three postretrofit years, all at the same time that the same participants were regularly switching primary space heating fuels back and forth between electricity and woodfuel. Additionally, with no reduction in baseload, residential conservation efforts may need to be refocused on end-uses, rather than space heating.

New studies to examine nonenergy phenomena, like the customers' propensity to alter behavior in ways that are consistent with but not induced by residential conservation programs, and a comprehensive study of woodfuel use would appear to provide valuable inputs into load forecasters' models. Woodfuel users in the HRCP reduced electricity loads at a lesser rate than non-woodfuel users, while all participants benefitted from improved housing. Different market segments can be targeted for the same residential energy conservation program with benefits accruing to all participants, but different targets will respond in different ways.

Energy conservation programs will need to be either multifaceted in order to appeal to multiple audiences for broad purposes or narrowly focused in order to appeal to a specific audience. In both instances, nonparticipants will be affected by the benefits and costs. The principal questions become: **what** are the benefits and costs and **how** are they measured?

ABSTRACT

The Hood River Conservation Project (HRCP) was a major residential retrofit demonstration project, operated by Pacific Power & Light Company (Pacific Power) between 1984 and 1988, and funded by the Bonneville Power Administration (Bonneville). The project was designed to install as many cost-effective retrofit measures in as many electrically heated homes as possible in the community of Hood River, Oregon.

The Pacific Power HRCP planners statistically selected a special group of 320 Hood River homes that represented a cross-section of the community. The end-use loads (electric space heating, electric water heating, and woodfuel space heating) and the interior temperatures of these homes were monitored for one year before weatherization and three years after weatherization.

After more than four years of submetered data collection, 220 single-family, detached homes were available for analysis in this second load study. Weather was normalized for the four heating seasons by matching one day from the pre-program year with one day from each postretrofit year.

Three years after weatherization, these data show that load savings were persistent across the sample. Other analysis results show (1) significant differences in electricity use between homes heated by wood and by electricity; (2) significant fuel switching patterns; (3) negligible baseload electricity savings, and (4) erratic water-heating energy use.

1. INTRODUCTION AND BACKGROUND

The Hood River Conservation Project (HRCP) was a major residential retrofit demonstration project, operated by Pacific Power & Light Company (Pacific Power) and funded by the Bonneville Power Administration (Bonneville). The project was designed to install as many cost-effective retrofit measures in as many electrically heated homes as possible in the community of Hood River, Oregon.

In order to displace, or defer, new generation, energy conservation must save not only energy (kilowatt-hours or kWh), but it must also save capacity (kilowatts or kW), especially at system peak times. This report focuses on the persistence of savings of the HRCP in typical and peak loads three years after weatherization.

The HRCP involved higher levels of conventional retrofit measures than generally offered in weatherization programs in the Pacific Northwest or elsewhere. In addition, Bonneville paid for installation of conservation measures up to a cost-effectiveness limit of $1.15 for each estimated kWh savings in the first year after retrofit. Thus, HRCP offered the chance to examine levels of retrofit installation and subsequent energy and load savings when cost to the household and prior retrofit activities were largely removed as barriers. Additional information on the purposes, design, operation, and findings of the HRCP is compiled in the project's comprehensive final report (Hirst 1987).

In order to conduct the original load study (Stovall 1987) and this follow-on report, Pacific Power HRCP planners statistically selected a special group of 320 Hood River homes to represent a cross-section of the community. The end-use loads (electric space heating, electric water heating, and woodfuel space heating) and the interior temperatures of these homes were monitored for one year before weatherization and three years after weatherization. Submetered data were collected at 15-minute intervals for each of the three end uses and interior temperature. Detailed 15-minute weather data were also collected. A control group was not used because it would have interfered with the maximum possible penetration goal of the HRCP.

The evaluation design for this study is described in Chapter 2. In Chapter 3, diversified hourly load profiles for the pre-program year are examined for total electricity, space heating electricity, baseload electricity, and water heating electricity for HRCP homes that are heated primarily by electricity and supplemented with wood and other fuels. For a subset of these homes that have woodstoves, total electricity, space heating electricity, baseload electricity, and woodfuel space heating are examined.

The contributions of HRCP loads to Pacific Power System loads are examined in Chapter 4. Residential load savings three years after weatherization are examined in Chapter 5. In Chapter 6, the intervening effects of fuel switching on electric space heating loads are examined. The results are summarized in Chapter 7, which also includes a set of conclusions about the impacts of the HRCP on residential loads.

2. EVALUATION DESIGN

2.1. DATA MANAGEMENT AND QUALITY

The data were collected in the field by Pacific Power and transferred to ORNL in four primary installments: (1) submeter pulse values corresponding to 15-minute customer consumption data, along with recorded values of interior temperature, (2) weather pulse values corresponding to 15-minute climate information, (3) project data (audit and weatherization information), and (4) four occupant surveys for each of the 314 monitored houses. The database compiled for this analysis contained data for more than 90 million data points. The SAS Institute software (SAS 1985) was used for all of the data management and analysis.

Data quality flags for each submetered value were reviewed to identify anomalous data, and data values were set to missing when indicated. This screening did not lead to any analytic bias. It was determined that data quality was correlated with operation of the submetering equipment. Data quality was suspect when it was learned that the equipment was not operating properly. When the equipment was repaired or replaced, data quality was determined to be as good as the original calibration of the equipment (no more than 2.5% out of tolerance, on average).

The database was screened several times, with tighter error checking and more complete screening imposed with each iteration. The overall quality of the data was determined to be practically free of human error.

Interior temperatures were recorded every 15 minutes. One recording device was mounted on an interior wall of each house, at eye level, in the house's most regularly occupied room during non-sleeping hours. There were important variations among the proximities of recording devices, heating ducts, and woodstoves. See Dinan (1987) for a thorough discssion of the protocol used for recording interior temperatures.

The weather data were collected at three weather stations and included: horizontal radiation, direct beam radiation, wind direction, wind speed, dry-bulb air temperature, relative 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 large blocks of data were sometimes missing (some as long as 2 weeks). For these reasons and because the analysis used diversified load, the weather data from all three stations were averaged. Only three climate elements--dry-bulb air temperature, relative humidity, and barometric pressure--were used to select matched winter days across the 4 years of data.

Wood heat was measured using radiometers placed near the woodstoves. The radiometers were calibrated by Lawrence Berkeley Laboratory (LBL) to measure the energy output of specific brands and models of woodstoves (Modera 1986). Modera developed conversions factors that were found to vary widely among brands and were strongly affected by radiometer position relative to the stove. The Pacific Power staff were very careful to record the exact positions of these monitors and to correct the conversion factors to match the Modera correlations before generating another revision of the database. As a result of the combined efforts of Modera and Pacific Power, it was determined that groups can be compared but that the comparisons of individual houses was not defensible. See Tonn and White (1987, Appendix A) for a comprehensive discussion of the validity of measuring heat output from woodstoves.

2.2. DATA ANALYSIS

2.2.1. Sample Selection

The present analysis examined the electric load profiles, load savings, persistence of savings, and fuel switching for the HRCP end-use monitored (i.e., submetered) houses. The original evaluation plan identified 320 Hood River homes to be submetered. After more than four years of submetered data collection, 220 homes (Sample n_1) were available for analysis in this second load study. The second load study was restricted to single-family detached housing.[1]

The original evaluation plan called for total electricity, space heating electricity, and interior temperature to be metered in all submetered houses. Water heating electricity meters were installed in 220 of the original 320 houses; radiometers were installed in 100 of the original houses in order to measure the heat output of woodstoves. Houses with water heating electricity submeters did not have radiometers and *vice versa*. The present load study examined the load dynamics of 145 homes (Sample n_2) with water heating electricity submeters and 75 homes

[1]The screening criteria consisted of changes in occupancy, removal of metering equipment from homes, possible confounding loads like irrigation, and the single-family criterion.

(Sample n_3) with radiometers. Both the water-heating and radiometer groups were subsets of the 220 homes available for the second load study.

2.2.2. Weather Normalization

The most common and most basic method used to weather normalize load data is selecting similar days for direct comparison. Weather normalization was critical to the load analysis because a control group was not used.

In order to maintain consistency between the initial peak loads study (Stovall 1987) and the present analysis, the winter days to be examined included 28 winter days for each year of the 4-year period. Altogether, submetered data for 112 days were analyzed. The 112 days were matched over the 4-year period by the day of the week, the average daily outdoor temperature within 5 degrees F, and keeping the minimum daily temperature within 5 degrees F. The matched days that were selected covered a typical range of extremely cold, moderately cold, and mild winter days. All matched days had similar relative humidity and barometric pressure. The submetered data for at least 30 houses were available for each day of the 112 days (Table 2.1).

Data attrition was much smaller for this second load study than was expected based upon the rates of data attrition observed in other studies of persistence of energy or load savings. Data attrition in other studies that span three or four years of data collection approach 50% of the original sample. In this study, nearly 70% of the original 320 households were retained; nearly 68% of the households with water heating electricity submeters were retained; and 75% of the houses with radiometers were retained, three years after weatherization in the HRCP. As a result of this high rate of data retention, it was decided to select one set of four matched weekdays, one set of four matched weekend days, and the Pacific Power System peak days for analysis (Table 2.1).

The matched weekdays were all Wednesdays, with average daily temperatures of 32.34° F., 32.62, 34.69, and 34.19, with a range of 2.35° F. The matched weekend days were all Saturdays, with average daily temperatures of 29.37° F., 30.46, 30.93, and 30.15, with a range of 1.56° F. These matched days were selected because they were most similar weather-wise and because they occurred in the heating season about the same time each year. The Pacific Power

Table 2.1. Typical weekdays, weekend days, and Pacific Power System peak days

1984/85	1985/86	1986/87	1987/88
Jan 17, 1985(Su)	Jan 12, 1986(Su)	Jan 25, 1987(Su)	Jan 24, 1988(Su)
Jan 28, 1985(M)	Jan 13, 1986(M)	Jan 26, 1987(M)	Jan 25, 1988(M)
Jan 29, 1985(Tu)	Jan 28, 1986(Tu)	Jan 27, 1987(Tu)	Jan 26, 1988(Tu)
Jan 23, 1985(W)	Jan 29, 1986(W)	Jan 28, 1987(W)	Jan 27, 1988(W)
Jan 24, 1985(Th)	Jan 30, 1986(Th)	Jan 29, 1987(Th)	Jan 28, 1988(Th)
Jan 15, 1985(Tu)	Jan 14, 1986(Tu)	Jan 20, 1987(Tu)	Jan 12, 1988(Tu)
Jan 16, 1985(W)	**Jan 15, 1986(W)**	**Jan 14, 1987(W)**	**Jan 13, 1988(W)**
Typical weekdays			
Jan 22, 1985(Tu)	Jan 16, 1986(Th)	Jan 8, 1987 (Th)	Jan 14, 1988(Th)
Mar 18, 1985(M)	Mar 24, 1986(M)	Mar 16, 1987(M)	Mar 14, 1988(M)
Mar 19, 1985(Tu)	Mar 25, 1986(Tu)	Mar 17, 1987(Tu)	Mar 15, 1988(Tu)
Dec 27, 1984(Th)	Dec 5, 1985 (Th)	Dec 18, 1986(Th)	Dec 17, 1987(Th)
Dec 28, 1984(F)	Dec 6, 1985 (F)	Dec 19, 1986(F)	Dec 18, 1987(F)
Jan 12, 1985(Sa)	**Jan 4, 1986 (Sa)**	**Jan 10, 1987(Sa)**	**Jan 9, 1988 (Sa)**
Typical weekend days			
Jan 13, 1985(Su)	Jan 5, 1986 (Su)	Jan 11, 1987(Su)	Jan 10, 1988(Su)
Nov 12, 1984(M)	Nov 11, 1985(M)	Nov 17, 1986(M)	Nov 9, 1987 (M)
Nov 13, 1984(Tu)	Nov 5, 1985 (Tu)	Nov 18, 1986(Tu)	Nov 10, 1987(Tu)
Jan 31, 1985(Th)	Feb 13, 1986(Th)	Feb 26, 1987(Th)	Feb 4, 1988 (Th)
Feb 1, 1985 (F)	Feb 14, 1986(F)	Jan 23, 1987(F)	Jan 8, 1988 (F)
Feb 9, 1985 (Sa)	Feb 8, 1986 (Sa)	Jan 31, 1987(Sa)	Jan 16, 1988(Sa)
Nov 2, 1984 (F)	Nov 8, 1985 (F)	Nov 14, 1986(F)	Nov 20, 1987(F)
Nov 3, 1984 (Sa)	Oct 26, 1985(Sa)	Nov 18, 1986(Sa)	Nov 14, 1987(Sa)
Dec 9, 1984 (Su)	Dec 8, 1985 (Su)	Dec 7, 1986 (Su)	Nov 29, 1987(Su)
Dec 16, 1984(Su)	Nov 10, 1985(Su)	Dec 14, 1986(Su)	Dec 20, 1987(Su)
Oct 29, 1984(M)	Oct 21, 1985(M)	Oct 20, 1986(M)	Oct 19, 1987(M)
Dec 5, 1984 (W)	Dec 10, 1985(Tu)	Dec 10, 1986(W)	Dec 30, 1987(W)
Oct 17, 1984(W)	Oct 30, 1985(W)	Nov 12, 1986(W)	Oct 21, 1987(W)
Mar 1, 1985 (F)	Feb 28, 1986(F)	Mar 6, 1987 (F)	Mar 4, 1988 (F)
Dec 8, 1984 (Sa)	Dec 7, 1985 (Sa)	Dec 6, 1986 (Sa)	Dec 12, 1987(Sa)
Feb 2, 1985 (M)	**Dec 13, 1985(F)**	**Jan 16, 1987(F)**	**Feb 2, 1988 (Tu)**
Pacific Power System peak days			

System peak days were Monday, Friday, Friday, and Tuesday, with average daily temperatures of 25.25, 21.59, 22.20, and 25.52° F., with a range of 3.93° F.

2.2.3 Method of Analysis

The electricity load of primary interest in this study was the peak hourly load. The hourly load was derived from the 15-minute consumption data by summing the four 15-minute kW values in each hour. The product is the diversified hourly load or the average load per hour.

Except when otherwise indicated, the data were averaged across households and then other arithmetic operations were performed to obtain sample values for loads, interior temperatures, and other group values.

The analysis presented in Chapter 6 was conducted using SAS. In particular, PROC GLM (with the SCHEFFE option) was used to conduct multiple comparisons on all main-effect means of structural features, occupant characteristics, behaviors, and attitudes, related to fuel switching. PROC CATMOD was used in order to confirm and further explain the relationships defined with PROC GLM.

2.2.4. Extrapolation of HRCP Findings to Pacific Power System

In several sections of this report, the HRCP load study findings have been extrapolated to the entire residential division of the Pacific Power System. In order to make defensible extrapolations, a set of assumptions were defined as follows.

- Pacific Power generates and delivers power to **communities.**
- Hood River is a representative community of the Pacific Power System.
- Residential customers whose collective space heating needs were filled by a mix of fuels (PESHE/M, the existing condition) and those whose space heating needs were filled almost exclusively by woodfuel (PESHE/W) were represented in the HRCP as they were in the Pacific Power service territory.
- Woodfuel was used for space heating in the HRCP like it is used in the Pacific Power service territory.
- Numbers reflecting impacts on the Pacific Power System were calculated as follows: kW/house for the HRCP X 138,000 (number of customers with permanently installed electric space heating equipment) = kW Impact.

3. DIVERSIFIED LOAD PROFILES

In this chapter, diversified hourly load profiles (i.e., load profiles) are presented for total electricity, space heating electricity, and baseload electricity for PESHE/M households ($n_1 = 220$); water heating electricity for PESHE/M households ($n_2 = 145$); and total electricity, space heating electricity, and baseload electricity for PESHE/W households ($n_3 = 75$). The diversified hourly load profile is the average load of a specific subdivision of customers at 1-hour intervals plotted against the time of day. The load profiles are presented for the pre-weatherization year for two primary reasons: (1) to simplify the presentation of data and (2) to define pre-program diversified load profiles in order to more readily observe changes over time. Changes in the diversified load profiles will be discussed in Chapter 5.

PESHE is defined as a residential customer with permanent electric space heating equipment; in the present study, all customers have PESHE. PESHE/M is analagous to PESHE and represents the existing mix of fuels, predominantly electricity, used for space heating in the Pacific Northwest. PESHE/W customers make greater use of woodfuel for space heating. In the present study, PESHE/W customers were the sample of households that had radiometers installed in order to measure the heat output of the woodstoves. PESHE/W is a subset of PESHE/M.

The load profiles were examined for these groups in order to understand the effects of weatherization in the HRCP on electricity loads in general. The load profiles were also examined in order to specify the different effects of weatherization on (1) the existing residential customer base (PESHE/M) and (2) the customer base if woodfuel were a more prominent space heating fuel (PESHE/W).

3.1. CHARACTERIZATION OF ELECTRICITY LOADS

3.1.1. Typical Weekday

The load profiles of Hood River residential customers were the load profiles that one would expect to find for electric space heating residential customers in northern moderate U.S. climates where winter peaks are standard (Fig. 3-1). The weekday daily peak load, which appeared to be driven by electric space heating, occurred at about 8 AM. The weekday secondary daily peak, apparently driven by electric baseload, occurred at about 7 PM. The load profiles remained relatively consistent from the pre-retrofit year through the third postretrofit year. However, electric baseload--the difference between total load and space heating and cooling--began to drive the whole-house electricity daily peak after weatherization. This new dynamic will be discussed in section 5.4.

For customers that used woodfuel as a prominent space heating fuel, the load profile for whole-house electricity had less of a peak and was less smooth (Fig. 3-2). At nearly all periods during the day, the whole-house electricity loads were lower for PESHE/W customers. It is clear that woodfuel displaced electricity for space heating before weatherization, especially at the morning and evening peaks, and that the levels of this displacement at different times of the day reflected the erratic woodfuel load and the difficulty in measuring woodfuel load with precision.

The interior temperature profiles for PESHE/M and PESHE/W customers were similar (Fig. 3-3). However, woodfuel customers maintained a higher interior temperature during the late evening and early morning hours, from approximately 10 PM to 8 AM. The widest difference in interior temperature occurred at 3 AM when PESHE/W houses were 1.6° F. warmer (at 70.7° F.) than PESHE/M houses.[2] This difference could have been due to woodfuel fires burning down.

3.1.2. Typical Weekend Day

The load profiles of Hood River residential customers reflected a greater demand for electricity on weekends than during the week (Fig. 3-4 and Fig. 3-1). Additionally, the daily peak occurred later in the morning, and loads for both space heating electricity and baseload electricity remained higher for longer periods than observed during the week. For instance, the load profile for whole-house electricity, although not flat, was flatter, especially between the morning peak and the evening peak during the weekend.

The whole-house electricity load profiles for both PESHE/M and PESHE/W customers peaked at 11 AM on weekend days, compared to 8 AM during the week. The load profiles of

[2]If the incidence of woodfuel space heating in Hood River had been representative of woodfuel use in the Pacific Power System, this difference in interior temperature would have corresponded to 0.26 to 0.29 kW load per house, or approximately 40 MW for the system at 3 AM.

PESHE/W customers (Fig. 3-5) differed in important ways from the weekday load profiles (Fig. 3-2). Additionally, the load declined from the peak more sharply on weekend days for the woodfuel customers. This sharp decline in load from the peak can be attributed to the inconstant contribution of woodfuel to space heating.

Woodfuel users maintained higher interior temperatures than PESHE/M customers during all times of the day and evening (Fig. 3-6). For both PESHE/M and PESHE/W customers, however, the interior temperature profiles suggested that both customer groups got up at about the same time on weekends and left the house at about the same time. In other words, PESHE/M and PESHE/W groups were probably only different in the ways they use energy and practice residential conservation.

3.1.3. System Peak Day

The whole-house electricity load at the peak hour for PESHE/M customers was 0.6 kW (9%) greater than the load for woodfuel customers (Fig. 3-7 and Fig. 3-8). The space heating electricity load was 0.7 kW (21%) greater than the space heating electricity load of PESHE/W customers. The proportion of electricity used for space heating on peak days was 10% greater in PESHE/M houses. The essential difference between the two load shapes was the magnitudes of the loads, not the shapes of the loads.

Although PESHE/W customers also maintained higher interior temperatures during peak load periods, the interior temperature profiles for woodfuel and PESHE/M customers were more similar on peak load days than for these customers on typical weekdays or weekend days (Fig. 3-9).

3.2. DAILY DIVERSIFIED ELECTRIC WATER HEATING LOAD

The water heating electricity load peaked at 8 AM and reached the secondary daily peak at 8 PM, one hour after both the secondary space heating electricity and baseload electricity peaks were observed. Moreover, water heating electricity load contributed a smaller proportion to the evening baseload electricity peak than to the morning peak (Fig. 3-10).

The water heating load profile virtually paralleled the space heating electricity load profile during the week, on weekends, and on system peak load days (see figures 3-11, 3-12, 3-1, 3-4, and 3-7). This pattern indicates that water heating was behaviorally driven in the HRCP, and that this behavior is not independent of other energy-related conservation behaviors. At the same time, this pattern suggests a stronger correlation between outdoor temperature and hot-water heating than has usually been hypothesized. Interestingly, the water heating electricity load profile for weekdays and peak days revealed that water heating load peaked at 8 AM and began to decline gradually during weekdays while remaining slightly higher on peak days. On weekend days, the water heating electricity load peaked two hours later at 10 AM and declined sharply after a couple of hours. See Brown, White, and Purucker (1987) for a complete analysis of HRCP impacts on residential electric water heating.

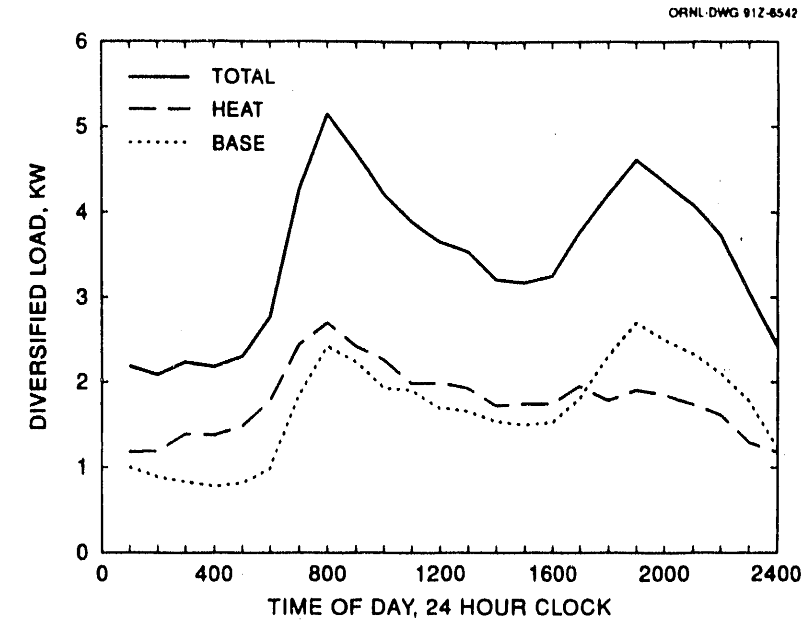

Fig. 3-1. Pre-program diversified load profile for PESHE/M sample (n, 220), typical weekday

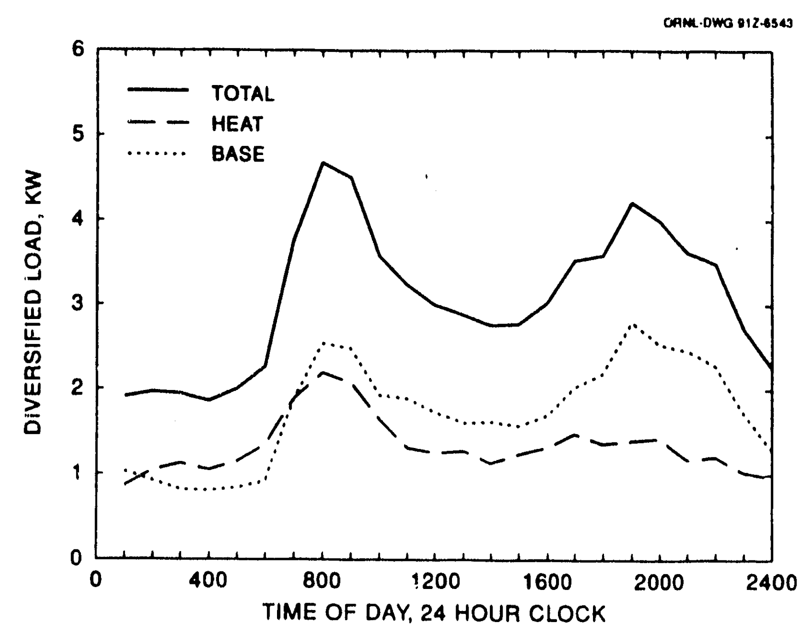

Fig. 3-2. Pre-program diversified load profile for PESHE/W sample (n, 75), typical weekday

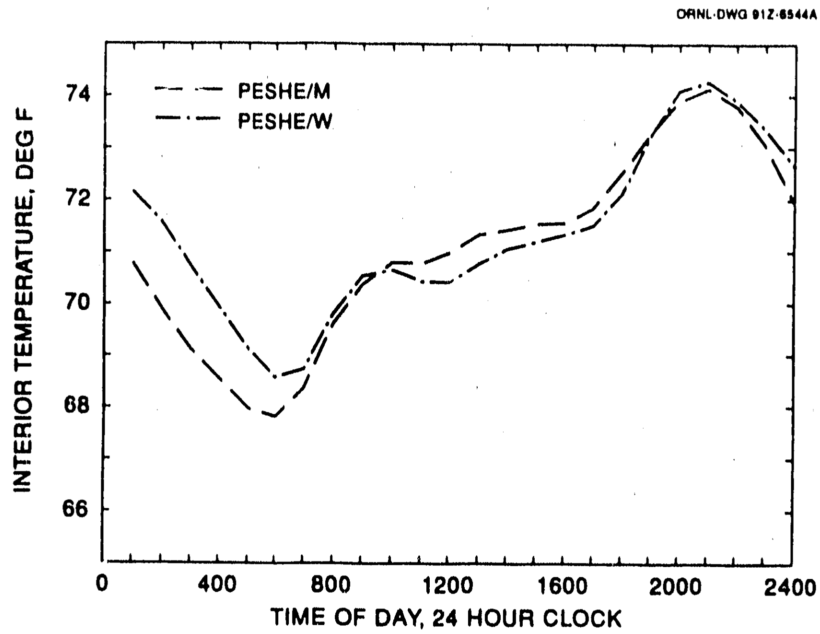

Fig. 3-3. Pre-program profile of interior temperature for PESHE/M (n, 220) and PESHE/W (n, 75) samples, typical weekday

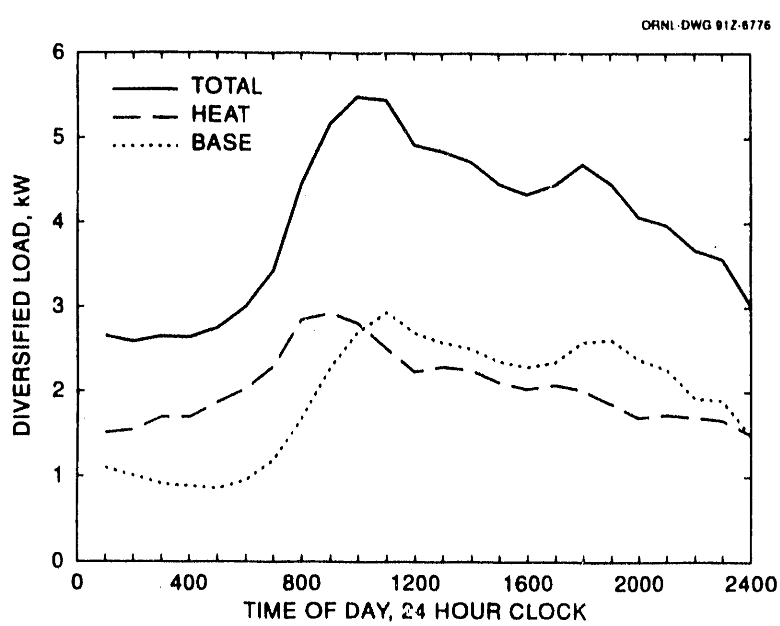

Fig. 3-4. Pre-program diversified load profile for PESHE/M sample (n, 220), typical weekend day

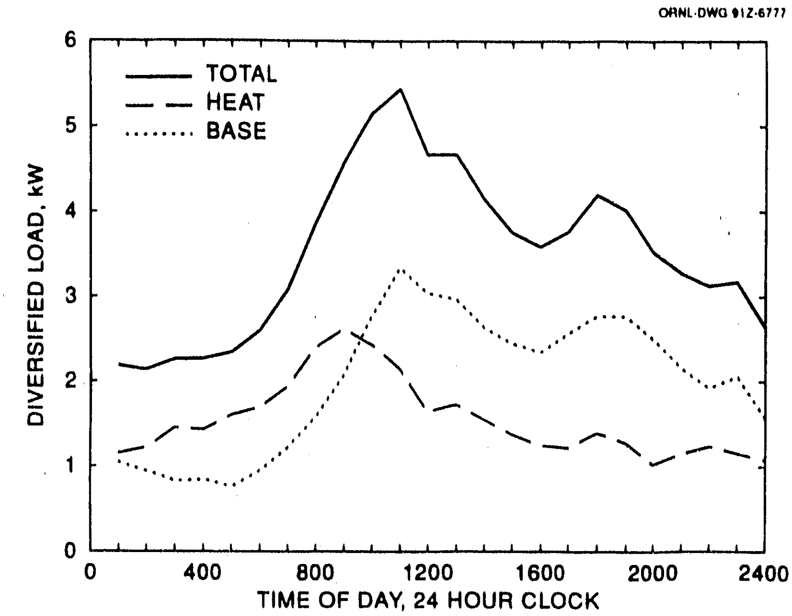

Fig. 3-5. Pre-program diversified load profile for PESHE/W sample (n, 75), typical weekend day

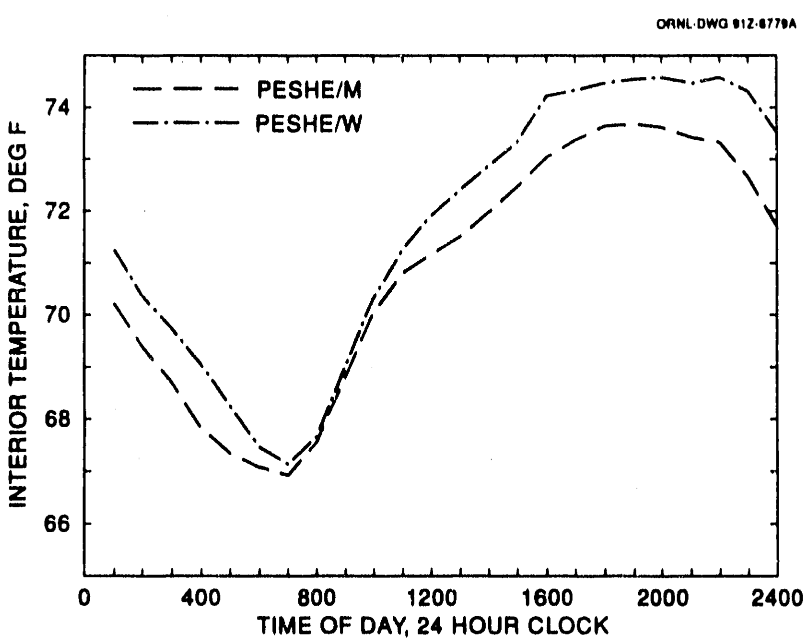

Fig. 3-6. Pre-program profile of interior temperature for PESHE/M (n, 220) and PESHE/W (n, 75) samples, typical weekend day

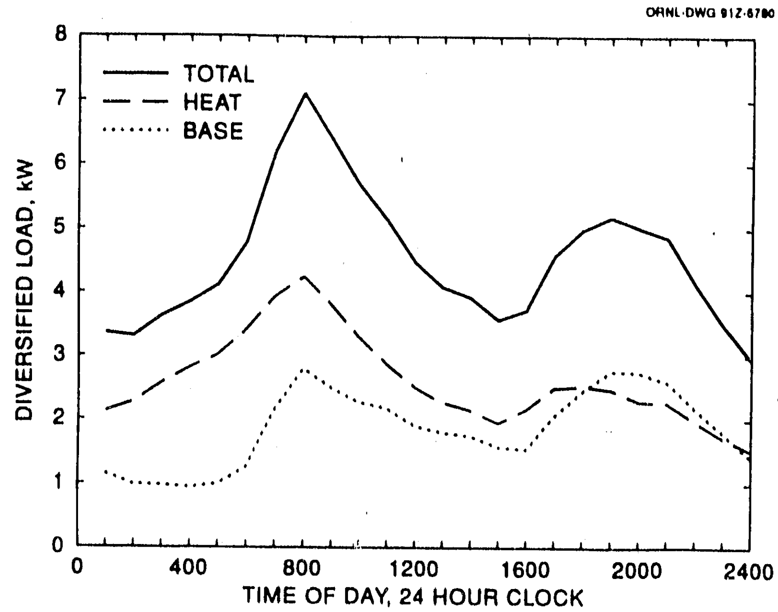

Fig. 3-7. Pre-program diversified load profile for PESHE/M sample (n, 220), system peak day

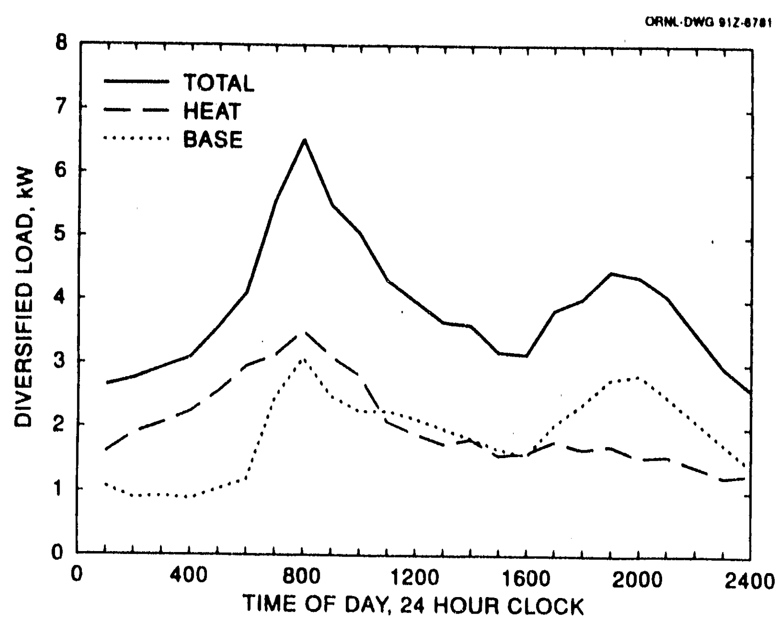

Fig. 3-8. Pre-program diversified load profile for PESHE/W sample (n, 75), system peak day

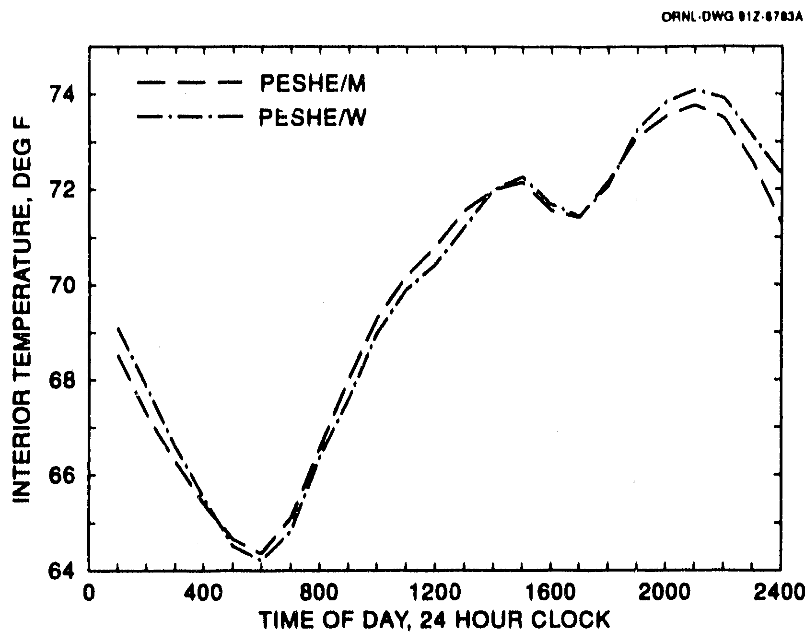

Fig. 3-9. Pre-program profile of interior temperature for PESHE/M (n, 220) and PESHE/W (n, 75) samples, system peak day

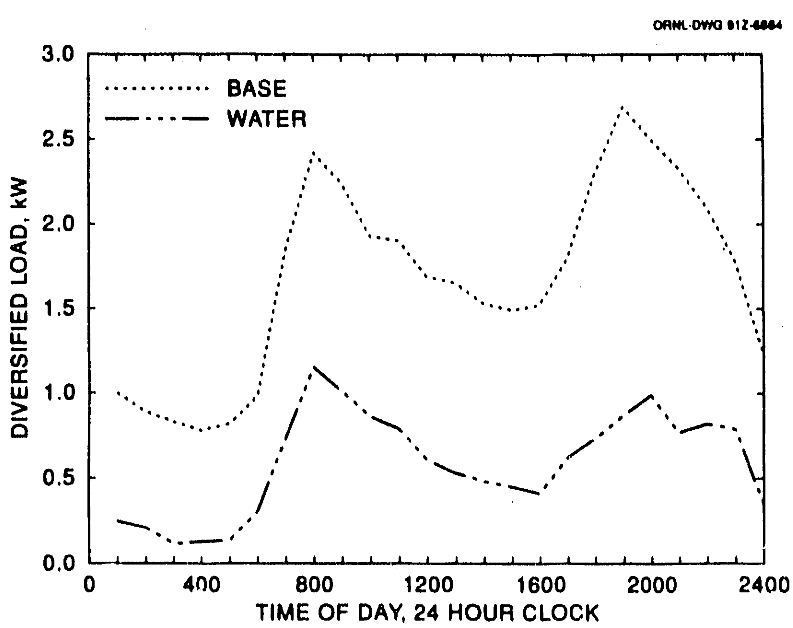

Fig. 3-10. Pre-program electric water heating load profile for PESHE/M sample 2 (n, 145), typical weekday

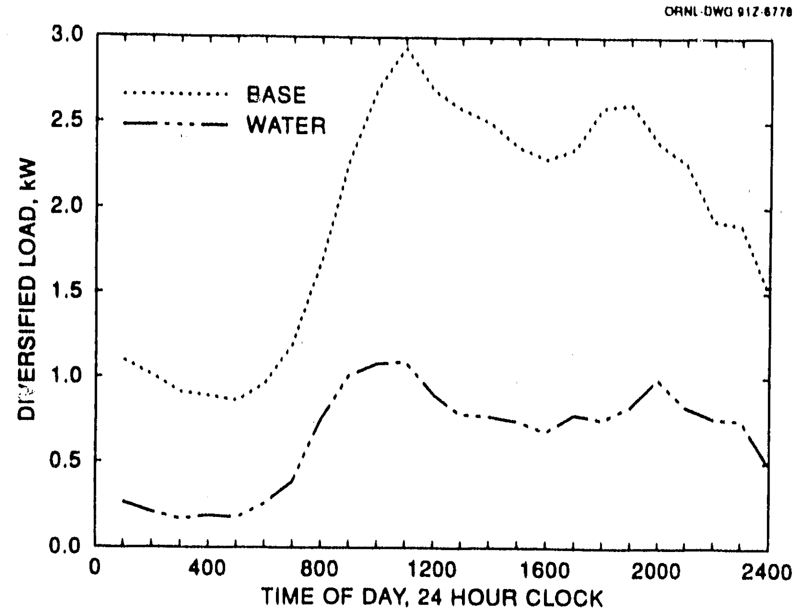

Fig. 3-11. Pre-program electric water heating load profile for PESHE/M sample 2 (n, 145), typical weekend day

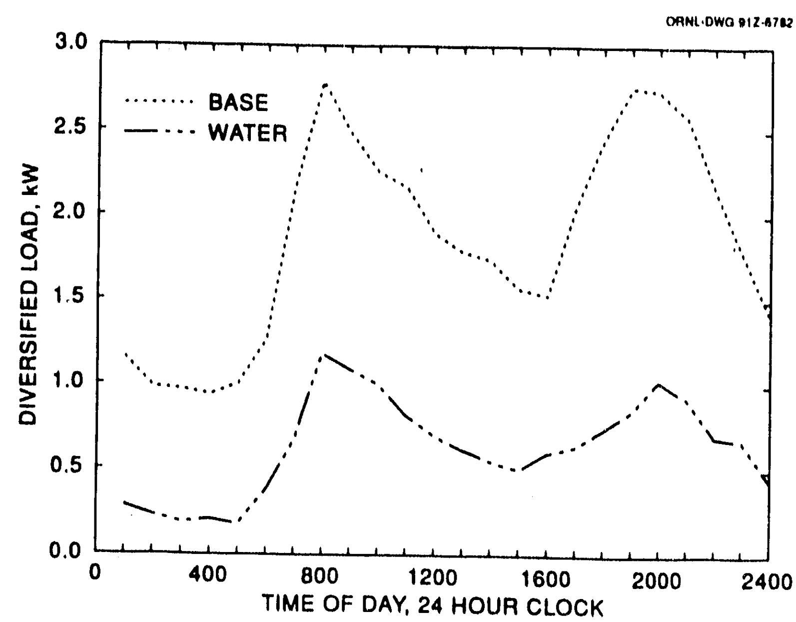

Fig. 3-12. Pre-program electric water heating load profile for PESHE/M sample 2 (n, 145), system peak day

3.3. DIVERSIFIED LOAD PROFILES IN HOUSES WITH WOODFUEL SPACE HEATING

The weekend, whole-house electricity load of PESHE/W customers was higher from 11 PM to 6 AM compared to weekdays, but the weekday load was lower from 7 AM to 10 PM, especially during the period from 8 AM to 4 PM (Fig. 3-5 and Fig. 3-2). Space heating electricity load profiles were similar for weekdays and weekend days, although they were somewhat higher on weekend days. In contrast to this, the "woodfuel load profile" for the weekend days was different than the woodfuel load profile for weekdays after 8 AM. Between midnight and 7 AM, the load profiles were comparable.[3] The woodfuel load profile is discussed in sub-section 5.4.4.

On extremely cold days (i.e., the Pacific Power System peak days), the PESHE/W customer electricity load profiles resembled their load profiles for weekdays (Fig. 3-8 and Fig. 3-2). However, whole-house electricity and space heating electricity loads were substantially higher during peak days, especially at the peak hour. The evening peaks for all loads were nearly the same for typical weekdays and peak days.[4]

3.4. SUMMARY

In this chapter, diversified hourly load profiles were presented for total electricity, space heating electricity, and baseload electricity for pre-retrofit PESHE/M households (Sample n_1, 220); water heating electricity for PESHE/M households (Sample n_2, 145); and total electricity, space heating electricity, and baseload electricity for PESHE/W households (Sample n_3, 75).

The load profiles of Hood River residential customers were as expected for electric space heating residential customers in northern moderate U.S. climates during both weekdays and

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[3]Since the measuring of heat content from the output of woodstoves and other wood burning devices is neither straightforward nor precise, this discussion of a "woodfuel load profile" is presented only to illustrate the different ways in which electricity and woodfuel are used for space heating.

[4]Recall that the peak days fell on Monday, Friday, Friday, and Tuesday for the four years between 1984/85 and 1987/88, and that the typical weekdays were all Wednesdays and the typical weekend days were all Saturdays.

weekend days. In general, space heating electricity drove the morning primary peak while electric baseload drove the evening peak.

Woodfuel displaced electricity for space heating before weatherization, especially at the morning primary and evening secondary peaks. The level of this displacement, although substantial, reflected the erratic woodfuel load and the difficulty in measuring woodfuel load with precision.

Woodfuel customers maintained a higher interior temperature during the late evening and early morning hours, from approximately 10 PM to 8 AM. However, the interior temperature profiles suggested that PESHE/M and PESHE/W groups were probably only different in the ways they use energy and practice energy conservation in the home. The *interior temperature profiles for PESHE/W and PESHE/M customers were more similar on peak load days* than for these customers on typical weekdays or weekend days.

Water heating electricity load contributed a smaller proportion to the evening baseload electricity secondary peak than to the morning primary peak. The water heating load profile virtually paralleled the whole-house electricity load profile during the week, on weekends, and on system peak load days. This pattern suggests a stronger correlation between outdoor temperature and hot-water heating than has usually been hypothesized.

4. RESIDENTIAL CONTRIBUTION TO SYSTEM LOAD

Utility load forecasters expect residential weatherization programs like the HRCP to provide conservation resources that can be used to defer costly capacity needs and serve new residential customers or customers in other sectors. Pacific has 138,000 single-family, residential customers with permanently installed electric space heating equipment. In this chapter, the effects of weatherization on the residential contribution to system load are examined. Whole-house electricity, space heating electricity, baseload electricity, and water-heating electricity loads are examined for the existing residential customer base (PESHE/M: Sample n_1, 220).

The Pacific Power System peak days are listed in Table 4.1. In this chapter, loads in HRCP homes for the system peak days are compared to system peak loads in order to estimate the residential contribution to system load.

The Bonneville System peak days correspond with Pacific Power System peak days except in 1985/86, when the Bonneville System load peaked on November 23, 1985. However, the second highest Bonneville System load during 1985/86 occurred on the Pacific Power System peak day. The Bonneville System load on December 13, 1985 was only 2.6% less than the 9,436 MW Bonneville System peak load on November 23. Thus, no separate analysis was conducted for the Bonneville System peak days.[5]

Table 4.1. Pacific Power System peak days during the study period

HEATING SEASON	DATE/TIME	PEAK LOAD (MW)
1984/85	February 2, 1985 /9 AM	4,253
1985/86	December 13, 1985/9 AM	4,064
1986/87	January 16, 1987 /9 AM	4,138
1987/88	February 2, 1988 /8 AM	4,242

[5]In 1985/86, the Bonneville System Load of 9,190 MW on December 13, 1985, exceeded the Pacific System Peak Load of 4,064 MW by a factor of 2.26.

Loads for the participants in the HRCP peaked one hour before the Pacific Power System peaks, except in 1987/88 when both the community peak and the system peak occurred at 8 AM. For the purposes of this analysis, this time-lag in load peaking between the community and the system was ignored[6]. HRCP and Pacific Power System peak loads are listed in Table 4.2. It was assumed that the Hood River community residential load was comparable to the residential load throughout the Pacific Power service area.

In 1984/85, whole-house, single-family detached electricity load accounted for 23% of the Pacific Power System load. Space heating electricity made up 60% of the whole-house electricity load, or 14% of the system load. Baseload electricity made up 40% of the Hood River residential load, or 9% of the Pacific Power System load.

In the first year after weatherization, 1985/86, the residential contribution to system load declined by 21%, from 23% to 18% of the Pacific Power System load.

Slight decreases in the contribution of residential load were also observed between 1985/86 and 1986/87. In the third postretrofit year, however, whole-house electricity load contributed more than 18% toward the Pacific Power System load. Space heating electricity made up 52% of the whole-house electricity load, or 9.5% of the system load. The residential contribution to system load is summarized in Table 4.3.

Table 4.2. Hood River community residential load at time of Pacific Power System peak load

HEATING SEASON	HOOD RIVER COMMUNITY RESIDENTIAL LOAD[a]	PACIFIC POWER RESIDENTIAL LOAD[b,c]
1984/85	7.11	982
1985/86	5.35	739
1986/87	5.35	739
1987/88	5.65	780

[a]kW/house, whole-house electricity.
[b]MW, whole-house electricity.
[c]Estimated as follows: (Hood River community average residential load per house / 1,000) X 138,000 [the number of PESHE customers in the Pacific service area].

[6]There are several plausible explanations for this difference in peak times, including differences in primary industry, commuting distance, urban/rural settings, among others.

Table 4.3. Residential load contribution factors in the Pacific Power System

HEATING SEASON	ELECTRICITY LOADS/CONTRIBUTION FACTORS[a] BASELOAD	SPACE HEATING	WHOLE-HOUSE
1984/85	385/0.09	585/0.14	982/0.23
1985/86	368/0.09	353/0.09	739/0.18
1986/87	384/0.09	357/0.09	739/0.18
1987/88	382/0.09	401/0.09	780/0.18

[a]Loads and contribution factors computed at the time of occurrence of the maximum system load. (See Table 4.1.)

A Pacific Power System-wide HRCP could result in a reduction in *residential load* of approximately 200 MW, or 21% of the residential load before weatherization. *System peak load* could be reduced by almost 5% of the highest load recorded before the HRCP.

To summarize, in this chapter, the effects of weatherization on the residential contribution to system load were examined. Whole-house electricity, space heating electricity, baseload electricity, and water-heating electricity loads were examined for the existing residential customer base (PESHE/M: Sample n_1, 220).

Loads for the participants in the HRCP peaked one hour before the Pacific Power System peaks, except in 1987/88 when both the community peak and the system peak occurred at 8 AM.

In the first year after weatherization, 1985/86, the residential contribution to system load declined by 21%, from 23% to 18% of the Pacific Power System load. Slight decreases in the contribution of residential load were also observed between 1985/86 and 1986/87. In the third postretrofit year, however, whole-house electricity load contributed more than 18% toward the Pacific Power System load.

5. RESIDENTIAL LOAD SAVINGS

A fundamental assumption of audit and weatherization programs has been that installation of retrofit measures will lead to substantial reductions in residential *energy use*, and that the value of these savings will justify the utility and household costs of implementation. Load savings and management programs have been based, primarily, on the same assumption.

This assumption has been tested in several program evaluations. Typical evaluations have been characterized by a short-term analysis--examinations of data over a period usually shorter than three years. This short-term focus has been valuable in helping program planners and implementers to optimize program benefits. On the other hand, utility planners and forecasters have been hard pressed to translate these short-term impacts into planning models that span much longer periods. The analysis of the durability or persistence of program benefits, especially load savings, is important in order for planners and forecasters to develop the best informed plans and models.

It has been demonstrated in previous evaluations of Bonneville's Interim and Long-Term Regionwide Weatherization Programs (RWP) that *energy savings* accrue through the second postretrofit year, and that *energy use* increases slightly in the third postretrofit year. This suggests that, among other things, energy savings peak two years after weatherization (White and Brown 1990). In this chapter, load savings will be examined one, two, and three years after weatherization.

EXPLANATORY NOTE FOR ILLUSTRATIONS IN CHAPTER 5.

By definition, total (i.e., whole-house electricity) load is the sum of electric space heating and baseload. The sample selection procedure used in this evaluation of the HRCP was based upon the house as the analysis unit. The sample sizes for the three groups studied varied across the days used in analysis and across the hours of the days. This variation in sample sizes was caused primarily by the loss of observations due to malfunctioning monitoring equipment. This variation did not distort analyses or program effects. The distributive principles of addition, subtraction, multiplication, and division apply only when the sample size within the group is constant. Thus, mean total load cannot be calculated by summing electric space heating and baseload averages--in the illustrations--unless all of the sample sizes (i.e., the denominators for calculating the averages) are the same. The sample sizes on different days and at various hours of the day were not posted in the illustrations in order to save space and minimize confusion.

5.1. LOAD SAVINGS IN PESHE/M SAMPLE

5.1.1. Typical Weekday

In Hood River, the community residential peak occurs at 8 AM during the week. For the PESHE/M customers (n_1, 220 houses), large load savings were obtained one year after weatherization at the residential peak hour; but, greater load savings were obtained during late morning and early afternoon. PESHE/M customers became more conservationist--or they did not exercise "takeback" behaviors--or the thermal performance of the house may have improved considerably after weatherization.

In the first year after weatherization, peak whole-house electricity load for PESHE/M customers was reduced by 15%, from 5.2 to 4.4 kW/house (or 109 MW savings for the Pacific Power system)[7] (Table 5.1). Space heating electricity load was reduced by 30%, from 2.7 to 1.9 kW. At the peak hour, baseload electricity was virtually unchanged from the pre-retrofit year.

For every hour after 8 AM until 1 PM, whole-house electricity load and space heating electricity load were reduced by more than the reduction measured at 8 AM. Baseload electricity savings were also maximized after 8 AM, from 9 AM until 11 AM. The HRCP reduced "phantom" (i.e., apparently random and unexplained) or waste electricity loads, either by establishing a basic conservation ethic among Hood River residents or by tightening the house.

Interestingly, space heating electricity load savings were smallest at 7 AM and 6 and 7 PM. The pre-retrofit space heating electricity load at 7 AM was 2.4 kW/house, or 10% less than the pre-retrofit load observed at 8 AM. At 6 PM and 7 PM, the pre-retrofit space heating electricity loads were 1.8 and 1.9 kW. The secondary daily peak load occurred at 7 PM in 1984/85. Collectively, these observations imply that the whole-house electricity peak load can be significantly reduced--and it was--but weatherization will yield a lesser effect--and it did--on residential electricity load first thing in the morning and early in the evening at the time when the family reassembles after being dispersed for the day. This characteristic of residential electricity demand represents a variation of the expected relationship between household size and energy use.

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[7]See sub-section 2.2.4 for a description of the procedure used to extrapolate HRCP values to the Pacific Power System.

5.1.2. Typical Weekend Day

In Hood River, the community residential peak occurred between 10 and 11 AM on weekend days. In the first year after weatherization, 1985/86, PESHE/M customers obtained the largest absolute load savings at 10 AM. Although this 25% reduction in whole-house electricity load was equivalent to 1.4 kW/house (193 MW for the Pacific system), larger percentage reductions were obtained at many other periods during the day, especially from midnight until 9 AM (Table 5.2). These larger "off-peak" load reductions suggested that PESHE/M customers improved their comfort through conservation--not by substantially increasing their thermostat settings at the off-peak after weatherization--and through a general improvement in the thermal integrity of the house.

The smallest load savings during weekends were observed between 5 and 10 PM. None of the load savings during this period exceeded 9% of pre-retrofit load.

Space heating electricity load savings were also maximized in absolute terms at 10 AM. Load was reduced from the pre-retrofit peak of 2.8 kW/house to 1.7 kW/house, an absolute reduction of 1.1 kW, or 40% of pre-retrofit space heating electricity load, which is equivalent to 155 MW for the Pacific Power System.

Load savings for space heating electricity were quite large throughout the day. The smallest savings occurred at 8 PM. Nonetheless, 13% load savings were obtained at 8 PM. Load savings for other periods of the weekend ranged from more than 13% at 7 PM to nearly 60% at 2 AM.

5.1.3. System Peak Day

In Hood River, the community residential peak occurred at 8 AM in the pre-retrofit year, as noted in the original study (Stovall 1987). The Hood River community peak occurred one hour earlier than the Pacific Power System peak load. In Hood River, the absolute load savings for whole-house electricity in the first postretrofit year at 8 AM was 1.8 kW/house, a reduction in load of 25% (Table 5.3). At 9 AM, the load in Hood River was also reduced by 1.8 kW/house, or 28% of pre-retrofit load. On peak days, the first-year load savings was equivalent to 242 MW for the Pacific system. This load savings represents 6% of the system peak load of

Table 5.1. Electricity load savings on typical *weekday one year after* weatherization, for PESHE/M sample

	LOAD SAVINGS[a,b]				LOAD SAVINGS[a,b]		
TIME	BASELOAD	SPACE HEATING	WHOLE-HOUSE	TIME	BASELOAD	SPACE HEATING	WHOLE-HOUSE
1 am	0.12/12.4	0.48/40.8	0.57/26.0	1 pm	0.04/02.3	0.77/40.3	0.74/21.1
2	0.09/10.1	0.47/39.6	0.53/25.2	2	0.04/02.6	0.49/28.5	0.54/16.8
3	0.10/12.3	0.56/40.5	0.63/28.1	3	0.11/07.4	0.49/28.2	0.54/16.9
4	0.03/03.4	0.49/36.1	0.48/21.9	4	0.03/01.7	0.43/24.8	0.43/13.4
5	0.02/02.0	0.43/28.7	0.34/14.9	5	0.12/06.4	0.45/22.8	0.49/13.0
6	0.00/-0.2	0.38/21.3	0.28/10.1	6	0.02/00.9	0.29/16.2	0.31/07.4
7	0.06/03.0	0.39/15.9	0.42/09.8	7	0.02/00.6	0.30/15.7	0.35/07.5
8	***-.01/-0.4***	***0.82/30.3***	***0.79/15.3***	8	0.00/00.0	0.51/27.5	0.49/11.3
9	0.29/13.1	0.89/36.9	1.19/25.2	9	0.02/00.9	0.46/26.3	0.50/12.2
10	0.20/10.1	0.79/34.9	0.95/22.6	10	0.11/05.0	0.41/25.3	0.49/13.2
11	0.34/17.7	0.72/36.1	0.99/25.5	11	0.09/05.3	0.45/35.1	0.51/16.5
noon	0.00/-0.1	0.86/43.3	0.79/21.7	12	0.00/-0.1	0.48/40.7	0.43/17.7

[a]Value to the left of the "/" is the load savings in kW/house; value to the right of the "/" is the percentage change.

[b]Load savings are calculated for each electricity load as follows: load savings = $load_{(base\ year)}$ - $load_{(next\ succeeding\ year)}$, so that a positive value indicates that load was reduced. Pre-retrofit community daily peak is represented in bold print.

Table 5.2. Electricity load savings on typical *weekend day one year after* weatherization, for PESHE/M sample

	LOAD SAVINGS[a,b]				LOAD SAVINGS[a,b]		
TIME	BASELOAD	SPACE HEATING	WHOLE-HOUSE	TIME	BASELOAD	SPACE HEATING	WHOLE-HOUSE
1 am	0.06/05.3	0.88/56.0	0.91/34.2	1 pm	0.07/02.7	0.84/36.6	0.79/16.3
2	0.12/12.2	0.91/59.0	1.00/38.6	2	0.04/02.3	0.77/40.3	0.74/21.1
3	0.12/13.0	0.95/56.0	1.03/38.8	3	0.14/09.4	0.49/28.0	0.54/16.9
4	0.14/15.4	0.80/47.5	0.93/35.2	4	0.11/07.5	0.43/24.8	0.43/13.4
5	0.09/09.9	0.88/46.8	0.91/32.9	5	0.12/06.4	0.45/22.8	0.49/13.0
6	0.06/21.7	0.79/38.7	0.89/29.5	6	0.02/00.9	0.29/16.2	0.31/07.4
7	0.10/08.8	0.79/34.5	0.86/25.2	7	0.02/00.6	0.30/15.7	0.35/07.5
8	0.20/11.9	1.01/35.4	1.14/25.7	8	0.00/00.0	0.51/27.5	0.49/11.3
9	0.26/11.5	0.93/31.8	1.08/20.9	9	0.02/00.9	0.46/26.3	0.50/12.2
10	***0.34/12.5***	***1.12/39.7***	***1.35/24.6***	10	0.11/05.0	0.41/25.3	0.49/13.2
11	***0.40/13.6***	***0.79/31.5***	***1.01/18.6***	11	0.09/05.3	0.45/35.1	0.51/16.5
noon	0.14/05.1	0.79/35.2	0.79/16.1	12	0.00/-0.1	0.48/40.7	0.43/17.7

[a]Value to the left of the "/" is the load savings in kW/house; value to the right of the "/" is the percentage change.

[b]Load savings are calculated for each electricity load as follows: load savings = $load_{(base\ year)}$ - $load_{(next\ succeeding\ year)}$, so that a positive value indicates that load was reduced. Pre-retrofit community daily peak is represented in bold print.

4,064 MW, observed on December 13, 1985, in the first year after weatherization. This load savings exceeds the load savings observed on typical winter weekdays and weekend days by 123% and 25%.

Whole-house electricity load savings were smallest on peak days between 6 PM and midnight. It can be concluded that during the coldest periods of the day (near sunrise) on the coldest days (when occupants are at home and awake), the weatherization effect on load is minimal. It can be speculated that appliance use was more intensive during these periods and that ,possibly, alternative electric-heating sources were being used for supplemental heat. Load savings were maximized on peak days between 1 AM and 5 PM.

Space heating electricity load savings were also largest at the 8 AM community peak on Pacific Power System peak days. In the first postretrofit year, load was reduced by 1.68 kW/house, or 40% of pre-retrofit load. Load savings for space heating electricity never fell below 17% during any period of the peak day.

The HRCP had the greatest impact on loads on system peak days. *Whole-house and space heating electricity loads were reduced at the peak hour on the system peak day by more absolute load and at least as much proportional load as the same loads were reduced on week days and weekend days.*

5.2. LOAD SAVINGS IN PESHE/W SAMPLE

5.2.1. Typical Weekday

The whole-house electricity peak loads of PESHE/M and PESHE/W customers both occurred during the week in the pre-retrofit year at 8 AM. The whole-house electricity peak load for PESHE/W customers was 4.7 kW/house, or 22% lower than the same load for PESHE/M customers (Table 5.4). If residential customers in the Pacific Power service area had used woodfuel in the same, approximate proportion as the Hood River woodusers, whole-house electricity load could have been reduced by as much as 65 MW *without weatherization.* Alternatively, Pacific Power woodusers could have demanded as much as an additional 65 MW of electricity *after weatherization*. See Lerman (1988) for an analysis of Bonneville's Wood Heat Displacement Program.

Table 5.3. Electricity load savings on *system peak day one year after* weatherization, for PESHE/M sample

TIME	LOAD SAVINGS[a,b] BASELOAD	SPACE HEATING	WHOLE-HOUSE	TIME	LOAD SAVINGS[a,b] BASELOAD	SPACE HEATING	WHOLE-HOUSE
1 am	0.03/02.4	0.97/45.5	1.00/29.0	1 pm	0.11/05.9	0.91/40.4	1.07/26.3
2	0.00/00.3	1.00/43.8	1.00/30.2	2	0.17/10.0	0.84/39.3	1.08/27.5
3	0.01/01.5	1.10/42.9	1.12/31.0	3	0.08/05.2	0.67/34.8	0.75/21.2
4	-.06/-6.7	1.30/46.3	1.28/33.2	4	0.03/01.8	0.68/31.5	0.66/17.8
5	-.06/-6.1	1.14/37.7	1.14/27.7	5	0.17/08.3	0.72/29.1	0.81/17.7
6	-.07/-6.0	1.18/34.5	1.11/23.2	6	0.07/02.9	0.60/23.9	0.57/11.5
7	0.03/01.6	1.20/30.4	1.34/21.6	7	0.09/03.2	0.47/18.8	0.42/08.1
8	***0.12/04.4***	***1.68/39.5***	***1.76/24.8***	8	0.31/11.1	0.41/18.0	0.66/13.1
9	0.22/08.9	1.48/39.1	1.76/27.5	9	0.39/14.9	0.44/19.5	0.72/14.7
10	0.00/-0.1	1.35/41.2	1.43/25.2	10	0.14/06.5	0.33/16.7	0.36/08.8
11	0.22/09.9	1.11/38.6	1.39/27.2	11	0.02/01.4	0.36/21.3	0.33/09.5
noon	0.06/03.2	0.95/37.7	1.08/24.0	12	0.04/02.6	0.34/22.4	0.29/09.9

[a]Value to the left of the "/" is the load savings in kW/house; value to the right of the "/" is the percentage change.

[b]Load savings are calculated for each electricity load as follows: load savings = $\text{load}_{(\text{base year})} - \text{load}_{(\text{next succeeding year})}$, so that a positive value indicates that load was reduced. Pre-retrofit community daily peak is represented in bold print.

Table 5.4. Electricity load savings on typical *weekday one year after* weatherization, for PESHE/W sample

TIME	LOAD SAVINGS[a,b] BASELOAD	SPACE HEATING	WHOLE-HOUSE	TIME	LOAD SAVINGS[a,b] BASELOAD	SPACE HEATING	WHOLE-HOUSE
1 am	0.14/13.4	0.46/52.4	0.57/30.0	1 pm	-.32/-0.2	0.34/26.4	0.08/02.9
2	0.13/14.0	0.50/47.6	0.58/29.7	2	-.01/-0.6	0.29/25.6	0.30/11.0
3	0.11/13.0	0.54/47.6	0.61/31.2	3	0.06/04.1	0.34/28.0	0.45/16.1
4	0.11/13.7	0.39/37.1	0.41/22.1	4	0.04/02.1	0.39/29.8	0.46/15.2
5	0.11/13.1	0.29/25.4	0.41/20.3	5	0.37/18.2	0.38/25.7	0.75/21.2
6	-.15/-0.2	0.25/18.5	0.03/01.5	6	-.25/-0.1	0.25/18.4	-.02/-0.1
7	-.20/-0.1	0.09/04.6	-.12/-0.0	7	-.16/-5.8	0.12/08.8	0.02/00.6
8	***-.19/-0.1***	***0.78/35.6***	***0.50/10.7***	8	0.02/00.9	0.57/40.1	0.61/15.1
9	0.43/17.3	1.12/54.0	1.54/34.0	9	0.01/00.5	0.36/30.2	0.40/10.9
10	0.10/05.4	0.57/34.9	0.66/18.5	10	0.07/02.9	0.44/36.1	0.54/15.4
11	0.10/05.1	0.34/25.8	0.55/16.9	11	0.00/00.2	0.52/50.4	0.55/20.2
noon	-.32/-0.2	0.47/37.5	0.26/08.8	12	0.06/04.6	0.52/54.0	0.52/23.1

[a]Value to the left of the "/" is the load savings in kW/house; value to the right of the "/" is the percentage change.

[b]Load savings are calculated for each electricity load as follows: load savings = $\text{load}_{(\text{base year})} - \text{load}_{(\text{next succeeding year})}$, so that a positive value indicates that load was reduced. Pre-retrofit community daily peak is represented in bold print.

After weatherization, at the peak hour, whole-house electricity load for PESHE/W customers declined by 11%. Space heating electricity load declined by 36%. By comparison, the same loads for PESHE/M customers declined by 15% and 30% one year after weatherization.

Load savings in whole-house electricity one year after weatherization for PESHE/W customers were inconsistent throughout the day during weekdays. For instance, load actually increased marginally at 7 AM and 6 PM, and virtually zero load savings were observed at 6 AM, 1 PM, and 7 PM. Space heating electricity load savings usually exceeded 20% at all periods during the day, except for marginal savings of 4% and 8% at 7 AM and 7 PM.

The influence of woodfuel use on whole-house and space heating electricity loads cannot be precisely determined (Yoder 1987).[8] However, previous studies have concluded that PESHE/W customers actually reduce woodfuel use after weatherization (Tonn and White 1987). In effect, this woodfuel savings displaces potential electricity savings.

In the HRCP, electricity load savings were also displaced. During the first year after weatherization, 23% woodfuel load savings were obtained at the daily peak because customers apparently elected voluntarily to cut back on their use of wood burning equipment and use electricity to maintain warmth and comfort in their homes. At 7 AM, when space heating *electricity* load savings were lowest (5%), space heating *woodfuel* load savings were also lowest (14%). Since 23% woodfuel load savings were obtained at the next hour (and this load savings increased hour by hour through 11 AM), *PESHE/W customers were using electricity to warm their homes early in the morning and only then starting fires in their woodstoves*, the approximate heat contribution of which was not realized until about one hour later. Additionally, woodfuel load remained fairly even during the day until peaking at 7 PM, which indicated, obviously, that woodstoves were not dampered down, either before or after weatherization, when residents left their homes. This will be discussed further in sub-section 5.4.4.

[8]See Yoder, Spolek, and Modera (1987) for a comprehensive explanation of measuring heat output of woodstoves.

5.2.2. Typical Weekend Day

The differences between PESHE/M and PESHE/W customers in the ways that electricity was used before weatherization were less distinct during weekend days. It was reported earlier in this report that whole-house electricity loads for PESHE/M customers peaked between 10 and 11 AM during weekends. For PESHE/W customers, the peak was observed at 11 AM. Only .05 kW/house (only 7 MW systemwide) separated the higher PESHE/M whole-house electricity load from the PESHE/W load (Table 5.5 and Table 5.2).

One year after weatherization, the whole-house electricity loads for PESHE/W declined by 2.1 kW/house (41%) and 1.7 kW/house (31%) at 10 AM and 11 AM on weekend days. The corresponding loads for PESHE/M customers declined by 1.4 kW/house (25%) and 1.0 kW/house (19%). The load reduction in PESHE/W houses was 57% greater than the load reduction in PESHE/M houses. The 2.1 kW/house load savings for PESHE/W customers is equivalent to 293 MW systemwide and an improvement over PESHE/M customers by 106 MW systemwide. Between 3 PM and 10 PM, whole-house electricity savings for PESHE/W customers were marginal, averaging 0.1 kW/house. These load savings were approximately 75% lower than the load savings obtained by PESHE/M customers between 5 PM and 12 PM, 0.4 kW/house on average.

PESHE/W customers reduced space heating electricity load by more than half at the peak hour. The 1.4 kW/house reduction was equivalent to 186 MW systemwide.

5.2.3. System Peak Day

PESHE/W customers reduced whole-house electricity load at the peak hour by almost 2 kW/house (30%) after weatherization (Table 5.6). Nearly all of this load savings was related to savings in space heating electricity (1.8 kW/house or 52% of pre-program load). Compared to PESHE/M customers, PESHE/W customers saved an additional 0.2 kW/house (28 MW systemwide) or 10% more load.

PESHE/W customers also reduced baseload electricity after weatherization by 0.3 kW/house (9%). PESHE/W customers may have reduced their use of portable electric space heaters, whose loads would not have been monitored as space heating. Because baseload did

Table 5.5. Electricity load savings on *weekend day one year after* weatherization, for PESHE/W sample

TIME	LOAD SAVINGS[a,b] BASELOAD	SPACE HEATING	WHOLE-HOUSE	TIME	LOAD SAVINGS[a,b] BASELOAD	SPACE HEATING	WHOLE-HOUSE
1 am	0.11/10.3	0.74/64.1	0.81/36.9	1 pm	0.22/07.6	0.59/34.4	0.85/18.2
2	0.06/06.4	0.84/69.1	0.81/38.0	2	-.11/-0.0	0.53/34.1	0.43/10.3
3	0.03/03.0	1.04/71.6	0.99/43.9	3	-.15/-0.1	0.43/31.7	0.20/05.3
4	0.16/18.8	0.90/62.8	1.00/44.2	4	-.18/-7.8	0.22/00.2	-.01/-0.2
5	-.01/-0.0	0.87/54.5	0.78/33.3	5	0.10/04.1	0.18/14.6	0.19/05.0
6	0.15/15.4	0.79/47.0	0.86/33.0	6	0.03/01.1	0.33/23.9	0.30/07.2
7	0.14/11.9	0.82/42.4	0.92/29.9	7	-.13/-4.7	0.10/08.2	-.09/-2.1
8	0.16/10.5	1.01/28.3	1.09/28.3	8	0.28/11.2	0.06/05.6	0.36/10.1
9	0.36/17.1	1.06/40.5	1.34/29.3	9	0.00/-0.1	0.24/21.0	0.22/06.7
10	***0.75/27.1***	***1.35/55.6***	***2.12/41.1***	10	-.06/-3.2	0.33/26.8	0.23/07.2
11	***0.78/23.3***	***1.01/47.4***	***1.69/31.0***	11	0.21/10.2	0.46/39.4	0.65/20.3
noon	0.39/09.7	0.79/48.1	1.14/24.4	12	0.34/21.5	0.66/61.2	0.97/36.6

[a]Value to the left of the "/" is the load savings in kW/house; value to the right of the "/" is the percentage change.

[b]Load savings are calculated for each electricity load as follows: load savings = $load_{(base\ year)}$ - $load_{(next\ succeeding\ year)}$, so that a positive value indicates that load was reduced. Pre-retrofit community daily peak is represented in bold print.

Table 5.6. Electricity load savings on *system peak day one year after* weatherization, for PESHE/W sample

TIME	LOAD SAVINGS[a,b] BASELOAD	SPACE HEATING	WHOLE-HOUSE	TIME	LOAD SAVINGS[a,b] BASELOAD	SPACE HEATING	WHOLE-HOUSE
1 am	-.11/-10.	0.76/47.3	0.61/23.0	1 pm	0.38/19.5	0.84/48.2	1.22/33.3
2	-.14/-15.	0.86/45.4	0.66/23.7	2	0.14/07.7	0.98/54.2	1.19/32.9
3	-.10/-10.	0.85/41.5	0.66/22.6	3	-.08/-5.1	0.77/49.2	0.71/22.2
4	-.14/-16.	1.11/49.7	0.91/29.3	4	-.11/-7.2	0.45/28.4	0.40/12.5
5	-.04/-4.0	1.10/43.1	1.05/29.6	5	-.02/-1.1	0.45/25.2	0.46/12.1
6	-.26/-22.	0.99/33.5	0.67/16.4	6	-.28/-12.	0.22/13.1	-.15/-3.7
7	-.01/-0.3	0.97/31.1	0.94/16.9	7	-.15/-5.5	0.16/09.1	-.03/-0.6
8	***0.27/08.7***	***1.84/52.4***	***1.95/29.9***	8	0.36/12.7	-.04/-2.5	0.33/07.5
9	0.09/03.6	1.52/49.2	1.57/28.6	9	0.19/07.7	0.07/04.3	0.25/06.2
10	-.24/-11.	1.58/55.9	1.39/27.5	10	0.01/00.6	0.10/07.1	0.06/01.8
11	0.07/03.3	0.89/42.6	1.04/24.0	11	0.05/02.6	0.47/38.5	0.51/17.1
noon	0.31/14.4	0.80/42.3	1.12/27.9	12	0.06/04.3	0.49/37.9	0.50/19.0

[a]Value to the left of the "/" is the load savings in kW/house; value to the right of the "/" is the percentage change.

[b]Load savings are calculated for each electricity load as follows: load savings = $load_{(base\ year)}$ - $load_{(next\ succeeding\ year)}$, so that a positive value indicates that load was reduced. Pre-retrofit community daily peak is represented in bold print.

change after weatherization, the metering of water-heating electricity load in PESHE/W households might have suggested a more definitive answer to the questions raised by changes in baseload.

5.3. PERSISTENCE OF RESIDENTIAL LOAD SAVINGS

The pattern of load savings one, two, and three years after weatherization was similar to the pattern of *energy savings* observed in many residential energy conservation programs, including the HRCP (Schoch 1990). In general, load savings continued to accrue through the second postretrofit year. Then, in the third postretrofit year, the loads either stayed at the second-year levels or *increased* slightly.

5.3.1. Typical Weekday

The whole-house electricity load at the peak hour (8 AM) for PESHE/M customers declined by 15% one year after weatherization. Load declined by another 11% in the second year for a cumulative savings of 25% after retrofit. However, between the second and third postretrofit years, load *increased* by 13%. In effect, load savings three years after weatherization were 15% (0.8 kW/house), virtually identical to the first year savings (Table 5.7).

Space heating electricity load savings at 8 AM from year one to year three followed the pattern observed for whole-house electricity. In the first and second years after weatherization, space heating electricity load declined by 30% and 22%, for a cumulative savings after two years of 46%. However, in the third postretrofit year, load *increased* by 27%. Like whole-house electricity load, space heating electricity load after three years was similar to the load after the first postretrofit year, at a reduction of 31% (0.8 kW/house) in pre-retrofit load, such that savings in electric space heating load accounted for all of the load savings in whole-house electricity.

Water heating electricity load savings were erratic for the three postretrofit years. In the first year, load declined by 3%, then *increased* in the second year by a little more than 3%. Three years after weatherization, water heating electricity load had *increased* by 10%. The HRCP included 3 measures designed to reduce water heating electricity load: efficient showerheads, water-pipe wrap, and water-tank blankets. Any or all of these measures could have become ineffective or been removed during the postretrofit years.

The whole-house electricity load for PESHE/W customers declined by 0.5 kW/house (11%) one year after weatherization. An additional 0.7 kW/house (17%) of load was saved in the second year. However, load between years 2 and 3 *increased* by 0.7 kW/house (20%), resulting in a cumulative savings of 11% (0.5 kW/house) three years after weatherization (Table 5.8). This load savings of 11% is equivalent to 97 MW systemwide.

Savings of space heating electricity load for PESHE/W customers were, in one word, dramatic. The first and second years savings were 0.8 kW/house (36%) and 0.4 kW/house (29%). However, in the third year after retrofit, load *increased* by 0.6 kW/house (58%). Three years after weatherization, the cumulative change in load was a savings of 0.6 kW/house (28%) (Table 5.8).

Baseload electricity was virtually unchanged for PESHE/M customers. No load savings were observed during the first two postretrofit years. In the third year after weatherization, baseload electricity *increased* by 6% over the pre-retrofit load.

For PESHE/W customers, baseload electricity savings three years after weatherization were effectively zero. Year by year, the load changed by -8%, 9%, and 3%.

5.3.2. Typical Weekend Day

The whole-house electricity load for PESHE/M customers peaked between 10 AM and 11 AM. Three years after weatherization, the 10 AM load had declined by 1.0 kW/house (18%) and the 11 AM load had declined by 1.1 kW/house (21%) (Table 5.9).

The space heating electricity load peak actually shifted after weatherization from 9 AM to 11 AM. Prior to weatherization, the 8 AM and 9 AM loads for space heating electricity were both higher than the 10 AM or 11 AM loads. As observed with the loads previously discussed in this sub-section, the 10 AM space heating electricity load declined in the first and second years after weatherization by 40% and 8% for a cumulative load reduction *two years after weatherization* of 1.3 kW/house (45%); however, space heating electricity load *increased* in year

Table 5.7. Electricity load savings on typical *weekday three years after* weatherization, for PESHE/M sample

TIME	LOAD SAVINGS[a,b] BASELOAD	SPACE HEATING	WHOLE-HOUSE	TIME	LOAD SAVINGS[a,b] BASELOAD	SPACE HEATING	WHOLE-HOUSE
1 am	0.04/04.0	0.50/42.4	0.53/24.2	1 pm	0.12/07.3	0.90/46.9	0.96/27.2
2	-.01/-1.1	0.48/40.3	0.47/22.5	2	0.00/00.0	0.67/39.0	0.63/19.6
3	0.02/02.4	0.02/02.4	0.62/27.7	3	-.13/-8.7	0.65/37.4	0.49/15.5
4	-.06/-7.7	0.59/43.1	0.58/26.6	4	-.11/-6.9	0.56/32.2	0.42/12.9
5	-.03/-3.7	0.45/30.4	0.41/17.8	5	-.04/-2.2	0.75/38.5	0.72/19.1
6	-.10/-10.	0.45/25.3	0.36/13.0	6	-.17/-7.4	0.28/15.7	0.22/05.2
7	0.01/00.5	0.83/34.0	0.83/19.4	7	-.05/-1.8	0.51/26.8	0.48/10.4
8	***-.14/-5.8***	***0.83/30.7***	***0.78/15.1***	8	-.09/-3.6	0.63/34.1	0.54/12.4
9	0.15/06.7	1.02/42.1	1.23/26.2	9	-.12/-5.2	0.70/17.2	0.59/14.4
10	0.11/05.7	1.02/45.1	1.20/28.5	10	-.36/-17.	0.69/42.9	0.36/09.6
11	0.25/13.2	0.81/40.9	1.09/28.0	11	-.07/-3.9	0.52/40.3	0.39/12.7
noon	0.00/00.0	0.93/46.7	0.87/23.8	12	-.02/-1.6	0.56/47.4	0.55/22.7

[a]Value to the left of the "/" is the load savings in kW/house; value to the right of the "/" is the percentage change.

[b]Load savings are calculated for each electricity load as follows: load savings = $load_{(base\ year)}$ - $load_{(next\ succeeding\ year)}$, so that a positive value indicates that load was reduced. Pre-retrofit community daily peak is represented in bold print.

Table 5.8. Electricity load savings on typical *weekday three years after* weatherization, for PESHE/W sample

TIME	LOAD SAVINGS[a,b] BASELOAD	SPACE HEATING	WHOLE-HOUSE	TIME	LOAD SAVINGS[a,b] BASELOAD	SPACE HEATING	WHOLE-HOUSE
1 am	0.24/23.3	0.48/55.2	0.70/36.6	1 pm	0.20/12.5	0.68/53.5	0.87/30.2
2	0.12/13.0	0.59/56.2	0.69/35.0	2	0.13/08.0	0.51/45.1	0.64/23.2
3	0.12/14.6	0.57/50.4	0.68/34.9	3	0.02/01.3	0.67/54.5	0.72/25.9
4	0.08/09.9	0.49/46.7	0.56/30.1	4	0.12/07.1	0.59/44.7	0.68/22.4
5	0.08/09.5	0.38/33.0	0.49/24.5	5	0.09/04.4	0.63/42.6	0.70/19.8
6	0.02/02.2	0.22/16.3	0.11/04.8	6	-.49/-22.	0.44/32.4	-.01/-0.2
7	0.08/04.2	0.66/34.9	0.65/17.2	7	0.17/06.1	0.29/20.7	0.56/13.3
8	***-.01/-0.4***	***0.61/27.9***	***0.52/11.1***	8	0.00/0.00	0.50/35.0	0.63/15.7
9	0.71/28.6	1.07/51.4	1.72/38.1	9	0.00/0.00	0.64/54.2	0.70/19.3
10	0.05/02.6	0.92/56.1	0.99/27.7	10	-.12/-5.2	0.67/55.4	0.56/16.0
11	0.37/19.6	0.62/47.3	1.01/31.2	11	-.08/-4.7	0.51/49.5	0.41/15.1
noon	0.19/11.0	0.59/47.2	0.77/25.7	12	-.01/-0.8	0.60/61.9	0.58/25.6

[a]Value to the left of the "/" is the load savings in kW/house; value to the right of the "/" is the percentage change.

[b]Load savings are calculated for each electricity load as follows: load savings = $load_{(base\ year)}$ - $load_{(next\ succeeding\ year)}$, so that a positive value indicates that load was reduced. Pre-retrofit community daily peak is represented in bold print.

three by 32%, resulting in a cumulative load reduction from the pre-retrofit year to the third postretrofit year of 0.8 kW/house (27%).

Baseload electricity changed marginally three years after weatherization. The first-, second-, and third-year savings were 13%, -3%, and 3%, for a cumulative change of 0.2 kW/house (7%).

The water heating electricity load did not change in years one or two. In the third year after weatherization, the load declined by 6%. At the same time, the water heating electricity load during the week *increased* three years after weatherization by 0.12 kW/house (10%). There could be several reasons for this shift in water heating electricity load from weekend to weekday. For instance, an increase in household size would precipitate changes in behavior related to using hot water.

The whole-house electricity load for PESHE/W customers peaked at 11 AM during weekends. Load declined by 1.7 kW/house (31%) one year after weatherization and stabilized, with only very slight changes in years two and three, such that load savings after three years were equivalent to the first year savings (228 MW systemwide) (Table 5.10). Interestingly, the load savings at 11 AM exceeded the load savings at 10 AM, such that the peak moved back one hour in the third year after weatherization. Load savings at 10 AM were 2.1 kW/house (41%), -0.2 kW/house (-5%), and -0.7 kW/house (-23%), for a cumulative three-year savings of 1.3 kW/house (24%). These savings resulted in a load reduction from 5.2 kW/house to 3.9 kW/house at 10 AM, which exceeded the 11 AM load in 1987/88 of 3.8 kW/house.

Weekend peak loads were apparently driven by baseload electricity, probably water heating and cooking. Like the PESHE/M customers, the space heating electricity load for PESHE/W customers peaked (at 9 AM) earlier than the whole-house electricity load. Savings for the 9 AM and 10 AM loads varied significantly from one another over the three years. The 9 AM savings during the three years were 1.1 kW/house (40%), 0.7 kW/house (46%), and -0.6 kW/house (-71%) for a 3-year cumulative savings of 1.2 kW/house (45%); at 10 AM, the savings were 1.4 kW/house (56%), 0.2 kW/house (16%), and -0.5 kW/house (-59%), for a cumulative 3-year savings of 1.0 kW/house (41%) (Table 5.10).

Table 5.9. Electricity load savings on typical *weekend day three years after* weatherization, for PESHE/M sample

TIME	LOAD SAVINGS[a,b] BASELOAD	SPACE HEATING	WHOLE-HOUSE	TIME	LOAD SAVINGS[a,b] BASELOAD	SPACE HEATING	WHOLE-HOUSE
1 am	0.05/04.5	0.71/47.0	0.80/30.1	1 pm	0.18/07.0	0.86/37.6	0.98/20.2
2	0.09/08.9	0.69/44.5	0.80/30.9	2	0.23/09.2	0.92/40.9	1.08/22.9
3	0.04/04.4	0.78/45.9	0.84/31.7	3	0.30/12.7	0.78/37.0	1.06/23.7
4	0.05/05.6	0.74/43.7	0.86/32.6	4	0.36/15.7	0.78/38.4	1.15/26.5
5	-.01/-1.1	0.71/38.0	0.71/25.8	5	0.07/03.0	0.77/37.0	0.84/18.9
6	0.01/01.0	0.75/36.8	0.74/24.6	6	-.25/-9.7	0.85/42.1	0.64/13.6
7	0.07/05.9	0.72/31.4	0.76/22.2	7	-.06/-2.2	0.67/36.0	0.57/12.8
8	0.29/17.4	1.05/37.0	1.28/28.8	8	0.09/03.8	0.58/34.1	0.64/15.7
9	0.32/14.0	0.97/33.2	1.27/24.6	9	0.04/01.8	0.68/39.3	0.66/16.6
10	**0.20/07.4**	**0.77/27.4**	**0.99/18.0**	10	-.04/-2.1	0.65/38.2	0.65/17.7
11	**0.33/11.2**	**0.78/31.1**	**1.13/20.7**	11	0.23/12.1	0.83/49.7	1.04/29.1
noon	0.12/04.5	0.68/30.5	0.73/14.8	12	0.13/08.7	0.67/44.6	0.81/26.7

[a]Value to the left of the "/" is the load savings in kW/house; value to the right of the "/" is the percentage change.

[b]Load savings are calculated for each electricity load as follows: load savings = $load_{(base\ year)}$ - $load_{(next\ succeeding\ year)}$, so that a positive value indicates that load was reduced. Pre-retrofit community daily peak is represented in bold print.

Table 5.10. Electricity load savings on typical *weekend day three years after* weatherization, for PESHE/W sample

TIME	LOAD SAVINGS[a,b] BASELOAD	SPACE HEATING	WHOLE-HOUSE	TIME	LOAD SAVINGS[a,b] BASELOAD	SPACE HEATING	WHOLE-HOUSE
1 am	0.01/01.0	0.61/53.0	0.50/22.8	1 pm	0.73/24.7	0.79/45.9	1.48/31.7
2	-.06/-6.3	0.62/50.8	0.52/24.3	2	0.59/22.4	0.68/43.9	1.21/29.2
3	-.06/-7.2	0.85/58.6	0.74/32.7	3	0.44/18.0	0.40/29.2	0.76/20.2
4	0.05/05.9	0.73/51.0	0.75/33.0	4	0.65/27.8	0.45/36.3	1.06/29.6
5	-.13/-16.	0.55/34.3	0.38/16.2	5	0.33/12.9	0.42/34.7	0.72/19.1
6	0.03/03.2	0.68/40.2	0.64/24.6	6	-.15/-5.4	0.69/50.0	0.58/13.8
7	0.13/10.7	0.46/23.7	0.51/16.5	7	0.02/00.7	0.56/44.1	0.60/14.9
8	0.17/10.8	0.75/31.3	0.81/20.9	8	0.23/09.2	0.33/32.4	0.58/16.4
9	0.20/09.7	1.18/45.0	1.23/26.9	9	0.10/04.6	0.41/35.7	0.47/14.3
10	**0.29/10.5**	**1.00/41.2**	**1.22/23.7**	10	0.16/08.3	0.48/38.7	0.60/19.2
11	**0.77/23.1**	**0.97/45.3**	**1.65/30.3**	11	0.56/27.2	0.63/54.3	1.16/36.5
noon	0.67/22.0	0.65/39.6	1.28/27.4	12	0.27/17.2	0.56/51.9	0.79/30.0

[a]Value to the left of the "/" is the load savings in kW/house; value to the right of the "/" is the percentage change.

[b]Load savings are calculated for each electricity load as follows: load savings = $load_{(base\ year)}$ - $load_{(next\ succeeding\ year)}$, so that a positive value indicates that load was reduced. Pre-retrofit community daily peak is represented in bold print.

Baseload electricity and whole-house electricity both peaked at 11 AM. One-, two-, and three-year baseload electricity savings were 0.8 kW/house (23%), 0.2 kW/house (7%), and -0.2 kW/house (-8%), for a cumulative three-year savings of 0.8 kW/house (23%).

5.3.3. <u>System Peak Day</u>

In Hood River, the community residential peak occurred at 8 AM in the pre-retrofit year, one hour earlier than the Pacific Power System peak. The following discussion ignores this time-lag in peaks and assumes that loads and the system peaks occurred at the same time.

The whole-house electricity load for PESHE/M customers declined by 21% in the first year after weatherization, *increased* slightly by 0.1% in the second year, and *increased* again in the third year by 6%. The cumulative savings after three years was 1.5 kW/house (21%) (207 MW systemwide) (Table 5.11).

After three years, the space heating electricity load had declined by 1.3 kW/house (31%) (180 MW systemwide) (Table 5.11). Year-by-year load savings were 1.7 kW/house (40%), -1%, and -12%.

Baseload electricity was virtually unchanged from year one to year three. Baseload declined by 4% one year after weatherization, *increased* by 4% in the second year, and remained at the second-year level in year three.

First-year savings for water heating electricity load were near zero. In the second year, load *increased* by 7% and *increased* another 2% in the third year. Three years after weatherization, water heating electricity load had *increased* by 0.1 kW/house (8%). Since weekday loads increased like peak day loads, and since weekend day loads declined three years after weatherization, there is strong support for the trend that occupants have shifted water heating electricity demand from weekends and from the infrequent extremely cold days to weekdays. The motivation for this shift was not clear.

The whole-house electricity load for PESHE/W customers declined by 1.6 kW/house (25%) three years after weatherization (Table 5.12). However, the load declined only in the first year by 2.0 kW/house (52%), and *increased* in the second and third years by 17% and 9%.

Table 5.11. Electricity load savings on *system peak day three years after* weatherization, for PESHE/M sample

	LOAD SAVINGS[a,b]				LOAD SAVINGS[a,b]		
TIME	BASELOAD	SPACE HEATING	WHOLE-HOUSE	TIME	BASELOAD	SPACE HEATING	WHOLE-HOUSE
1 am	0.10/08.6	0.82/38.5	1.00/29.8	1 pm	0.29/16.2	1.01/44.7	1.34/32.8
2	-.04/-4.1	0.78/34.2	0.78/23.6	2	0.25/14.4	0.90/42.1	1.22/31.1
3	-.02/-2.1	1.02/39.7	1.10/30.3	3	0.19/12.1	0.83/42.8	1.12/31.5
4	-.06/-6.4	1.18/42.0	1.20/31.3	4	0.19/12.4	0.86/39.8	1.10/29.6
5	-.02/-2.0	1.07/35.4	1.16/28.2	5	0.48/23.3	1.10/44.2	1.52/33.2
6	0.02/01.6	1.03/30.2	1.10/23.0	6	0.12/04.9	0.77/30.6	0.93/18.7
7	0.08/03.7	1.01/25.7	1.20/19.3	7	0.21/07.6	1.02/41.3	1.18/22.8
8	***0.02/00.7***	***1.33/31.4***	***1.46/20.5***	8	0.23/08.4	0.86/37.6	1.08/21.5
9	0.30/12.0	1.46/38.4	1.86/29.0	9	0.27/10.4	0.99/43.8	1.28/26.3
10	0.43/19.0	1.27/38.6	1.85/32.5	10	0.06/02.8	0.80/40.4	0.85/20.6
11	0.51/23.5	1.24/43.2	1.85/36.1	11	0.00/00.0	0.80/46.5	0.78/22.3
noon	0.40/21.1	1.13/45.0	1.62/36.2	12	0.17/12.1	0.73/48.0	0.82/27.8

[a]Value to the left of the "/" is the load savings in kW/house; value to the right of the "/" is the percentage change.

[b]Load savings are calculated for each electricity load as follows: load savings = $load_{(base\ year)}$ - $load_{(next\ succeeding\ year)}$, so that a positive value indicates that load was reduced. Pre-retrofit community daily peak is represented in bold print.

Table 5.12. Electricity load savings on *system peak day three years after* weatherization, for PESHE/W sample

	LOAD SAVINGS[a,b]				LOAD SAVINGS[a,b]		
TIME	BASELOAD	SPACE HEATING	WHOLE-HOUSE	TIME	BASELOAD	SPACE HEATING	WHOLE-HOUSE
1 am	0.12/11.2	0.49/30.4	0.58/21.9	1 pm	0.48/24.4	0.87/50.0	1.31/35.8
2	0.00/00.0	0.46/24.2	0.42/15.2	2	0.33/18.0	0.88/48.1	1.17/32.4
3	0.07/07.6	0.81/39.3	0.84/28.7	3	0.16/09.6	0.72/46.2	0.84/26.3
4	-.01/-1.1	1.11/49.6	1.07/34.6	4	0.15/09.6	0.61/38.1	0.74/23.5
5	0.10/09.7	0.91/35.7	0.97/27.2	5	0.27/13.2	0.62/30.4	0.90/23.4
6	0.05/04.2	0.88/29.8	0.89/21.7	6	-.03/-1.3	0.17/10.2	0.15/03.7
7	0.35/14.3	0.44/14.1	0.78/14.1	7	0.07/02.5	0.68/39.8	0.70/15.7
8	***0.32/10.4***	***1.30/38.0***	***1.62/24.8***	8	0.10/03.5	0.68/44.2	0.77/17.6
9	0.40/16.1	1.08/34.8	1.40/25.5	9	0.14/05.6	0.76/48.7	0.89/21.8
10	0.47/20.9	1.32/46.8	1.76/34.8	10	-.05/-2.4	0.66/47.1	0.55/15.7
11	0.54/24.0	0.98/46.9	1.52/35.2	11	0.00/00.0	0.76/61.8	0.73/24.7
noon	0.54/25.4	1.07/56.6	1.61/40.4	12	0.28/20.0	0.79/61.2	0.98/37.5

[a]Value to the left of the "/" is the load savings in kW/house; value to the right of the "/" is the percentage change.

[b]Load savings are calculated for each electricity load as follows: load savings = $load_{(base\ year)}$ - $load_{(next\ succeeding\ year)}$, so that a positive value indicates that load was reduced. Pre-retrofit community daily peak is represented in bold print.

PESHE/W customers reduced space heating electricity load at the peak hour on the Pacific Power System peak day by 1.8 kW/house (52%) in the first year after weatherization (Table 5.6). In succeeding years, they *increased* this load by 0.3 kW/house (a -17% savings) and by 0.2 kW/house (-12%), for a cumulative three-year load reduction of 1.3 kW/house, 38% of pre-retrofit load at the peak hour on the system peak day.

Unlike PESHE/M customers, PESHE/W customers saved baseload electricity. One year after weatherization, PESHE/W customers reduced baseload by 0.3 kW/house (4%), *increased* baseload by 0.2 kW/house (3%) in year two, and saved 0.2 kW/house (7%) in year three. The cumulative three-year baseload electricity savings was 0.3 kW/house (10%).

None of the retrofit measures were expected to directly affect baseload electricity. PESHE/W customers may have reduced their use of electric space heaters whose loads would have been picked up in the calculation of baseload.

5.4. CHANGES IN DIVERSIFIED LOAD PROFILES

5.4.1. Typical Weekday

During the pre-program year and all three postretrofit years, the whole-house electricity diversified load of PESHE/M customers only slightly changed shape (Fig. 5-1). During each of the first two postretrofit years, PESHE/M customers saved load at virtually every hour of the day. However, in the third postretrofit year, the diversified load profile resembled the profile from the first postretrofit year. In effect, changes (i.e., savings) in the load profile in the second postretrofit years were reversed in the third postretrofit year.

The changes in the space heating electricity diversified load profiles in the three postretrofit years were somewhat unsystematic (Fig. 5-2). In the first postretrofit year, changes in the diversified load resulted in a flatter profile (but still peaky), which looked like a scaled-down pre-program diversified load. Except for an apparent shift in the peak hour from 8 AM in the pre-program year to 7 AM in the first postretrofit year, the shapes of the two diversified load profiles were nearly congruent, differing only in magnitude of load.

In the second postretrofit year, the load profile flattened substantially, with the morning peak dropping to approximately the same magnitude as the afternoon peak. Although the diversified load profile in the third postretrofit year was consistently lower than the pre-program profile, the flattening of the profile in the second year was reversed in the third year. As a result, three years after weatherization, the diversified load profile had a shape similar to the shape of the first postretrofit year profile.

During the pre-program year and all three postretrofit years, the whole-house electricity diversified load of PESHE/W customers also only slightly changed shape (Fig. 5-3). However, the profiles crossed over one another at important times during the day: at 6 AM to 10 AM; at 4 PM to 10 PM. These cross-overs suggest that (1) electricity loads are much more unpredictable in woodfuel houses and (2) this unpredictability is greater when the houses are occupied during the daytime and sleeping hours.

The changes in the space heating electricity diversified load profiles in the three postretrofit years were even more erratic in PESHE/W houses than in PESHE/M houses (Fig. 5-4). In the first and second postretrofit years, it appeared that PESHE/W customers did not consistently adjust to the improved thermal integrity of their houses. For instance, like the PESHE/M customers, the peak hour in the first postretrofit year was observed at 7 AM instead of 8 AM. In the second postretrofit year, the electric space heating peak occurred at 5 PM. Although the space heating diversified load profile was much flatter in the second postretrofit year, the flattening of the profile was associated with a shift in the peak load from 8 AM to 5 PM. These changes suggest that PESHE/W customers did respond to weatherization in ways that were both incremental and either uncertain or cautious, rather than instantaneously. Consequently, the effects of weatherization on the electric space heating loads of PESHE/W customers may not be entirely realized for several months or years after weatherization. In the meantime, PESHE/W customers could significantly remodel their houses or households, thereby making the interpretation of the effects of weatherization on woodfuel use more problematic.

5.4.2. Typical Weekend Day

During the pre-program year and all three postretrofit years, the whole-house electricity diversified load of PESHE/M customers did not change shape (Fig. 5-5). During each of the first two postretrofit years, PESHE/M customers continued to save load at virtually every hour of the day, except at about 6 and 7 AM. However, in the third postretrofit year, the diversified load profile resembled the profile from the pre-program year, without as much "curve." Changes (i.e., savings) in the load profile in the third postretrofit year, especially after 8 AM, looked like the composite of changes from the first and second postretrofit years.

The changes in the space heating electricity diversified load profiles paralleled the changes in the whole-house profiles except for the exaggeration in the changes in the space heating loads (Fig. 5-6). Additionally, the changes in the space heating diversified load in the third postretrofit year were choppier from one hour to the next, and the evening peak introduced during the second year was elimated.

PESHE/W customers appeared to adjust even more erratically to weatherization during weekends than they did to weekdays after weatherization. As indicated in Fig. 5-7, PESHE/W customers adapted to weatherization after the third postretrofit year, when the whole-house diversified load profile showed a morning peak much lower and nearly at the level of the evening peak.

The changes in the space heating electricity diversified load profiles for PESHE/W customers support speculations about the woodusers' adjustment to the effects of weatherization. In the first and second postretrofit years, the woodusers appeared to be positioning themselves or feeling out the weatherization effect (Fig. 5-8). Three years after weatherization, it appeared that PESHE/W customers had learned to burn woodfuel and use electricity with some consistency in response to the weatherization. Yet it could not be determined if this consistency were correlated with other forms of behavioral consistency, or with fulfillment in lifestyle, or with other causes.

5.4.3. System Peak Day

The coldest days, when warmth and comfort should be the most problematic to obtain, it appeared that the Hood River residents knew exactly how to best use the benefits of weatherization. In the first postretrofit year, PESHE/M customers virtually maximized both whole-house electricity and space heating electricity loads (Fig. 5-9 and Fig. 5-10). Except for slight perturbations (i.e., cross-overs of profiles) in the diversified load profiles, especially between 8 PM and 11 PM, the load profiles for all three postretrofit years were comparable.

Again, PESHE/W customers demonstrated some indecision in adjusting to the benefits of weatherization. However, their adjustments to the coldest days in terms of whole-house and

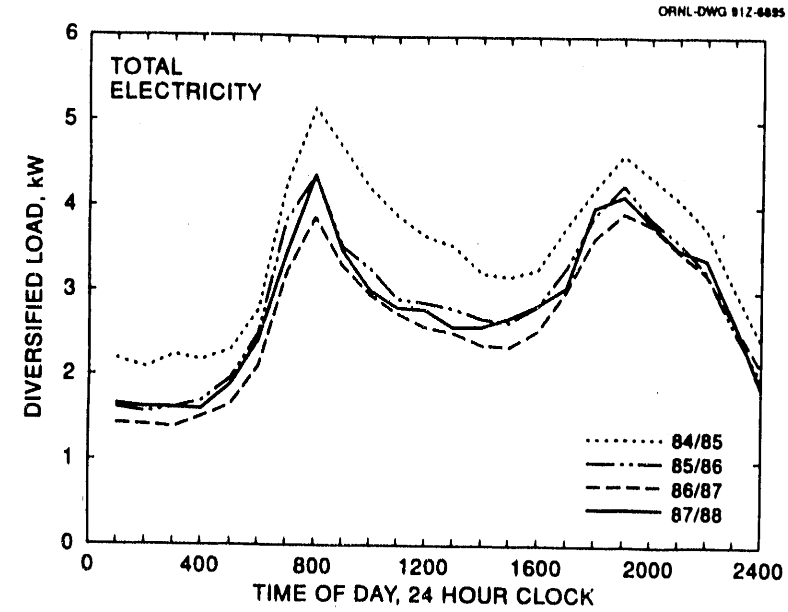

Fig. 5-1. Postretrofit diversified load profile--whole-house electricity--for PESHE/M sample (n, 220), typical weekday

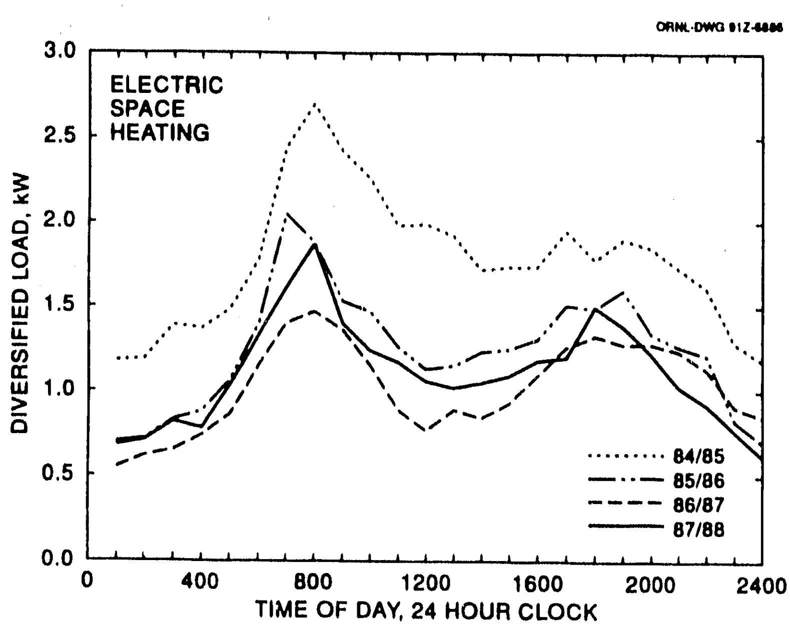

Fig. 5-2. Postretrofit diversified load profile--space-heating electricity--for PESHE/M sample (n, 220), typical weekday

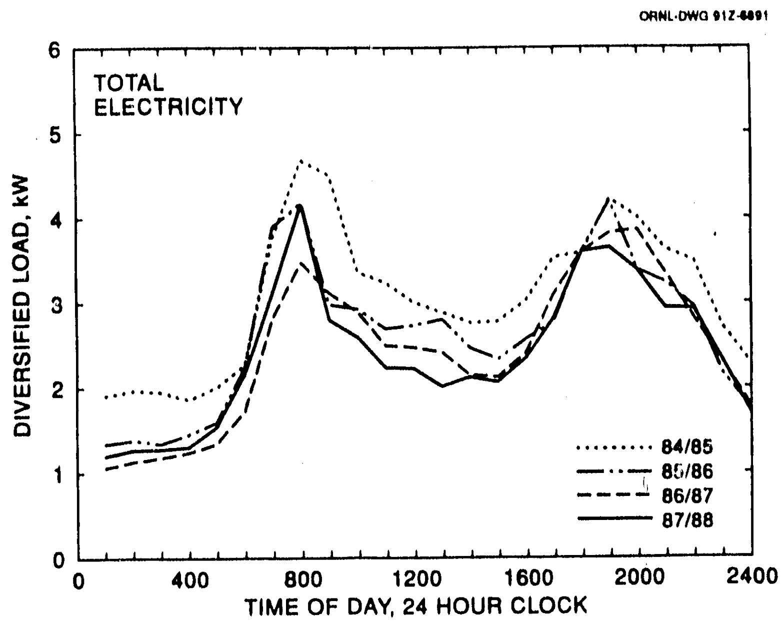

Fig. 5-3. Postretrofit diversified load profile--whole-house electricity--for PESHE/W sample (n, 75), typical weekday

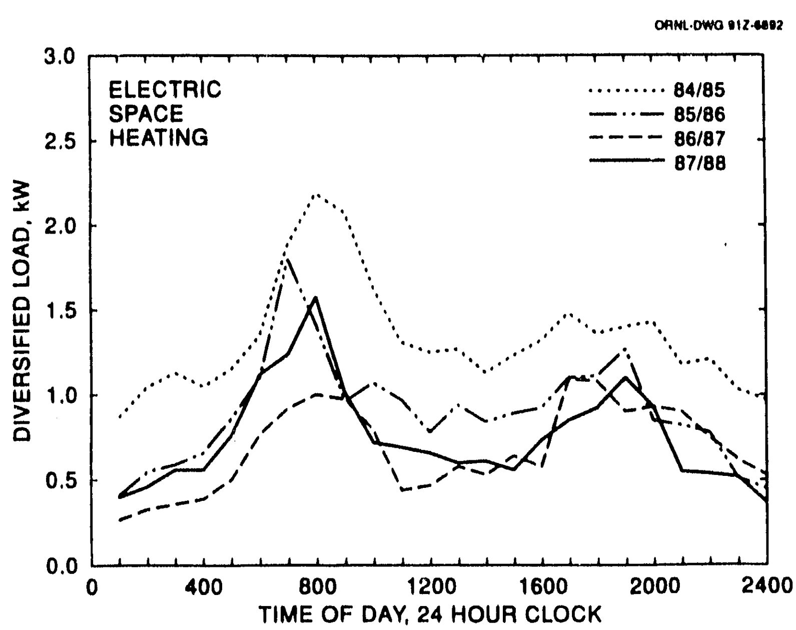

Fig. 5-4. Postretrofit diversified load profile--space-heating electricity--for PESHE/W sample (n, 75), typical weekday

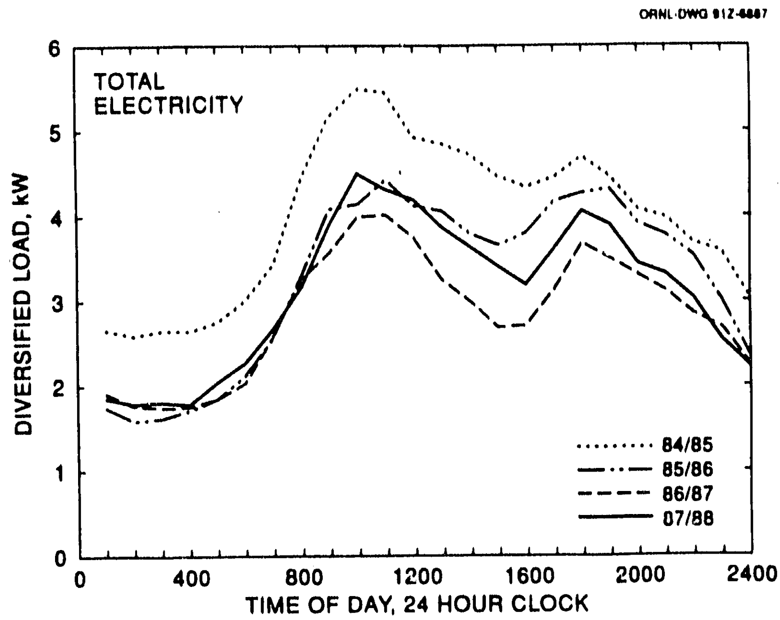

Fig. 5-5. Postretrofit diversified load profile--whole-house electricity--for PESHE/M sample (n, 220), typical weekend day

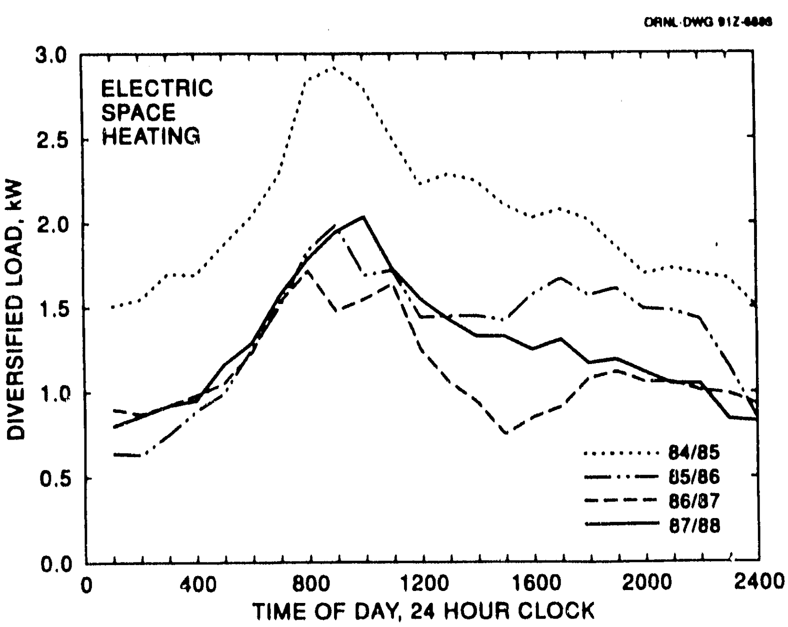

Fig. 5-6. Postretrofit diversified load profile--space-heating electricity--for PESHE/M sample (n, 220), typical weekend day

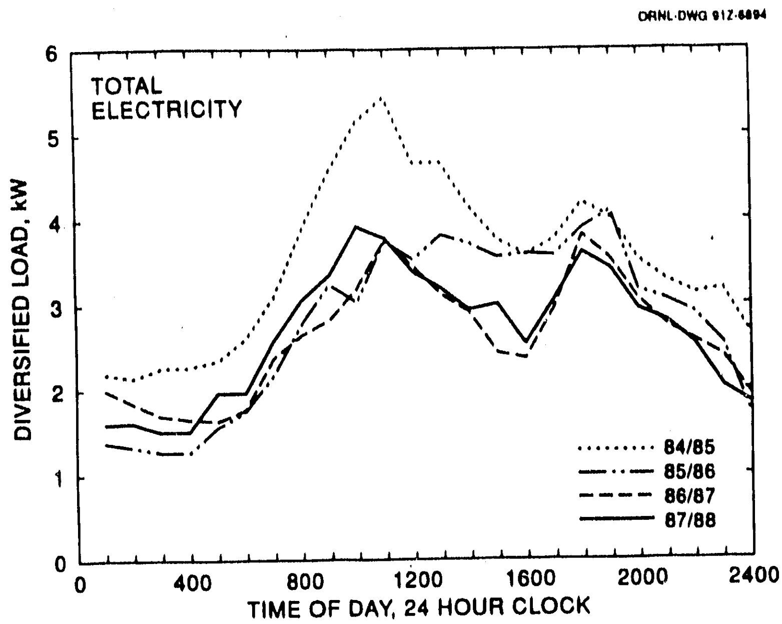

Fig. 5-7. Postretrofit diversified load profile--whole-house electricity--for PESHE/W sample (n, 75), typical weekend day

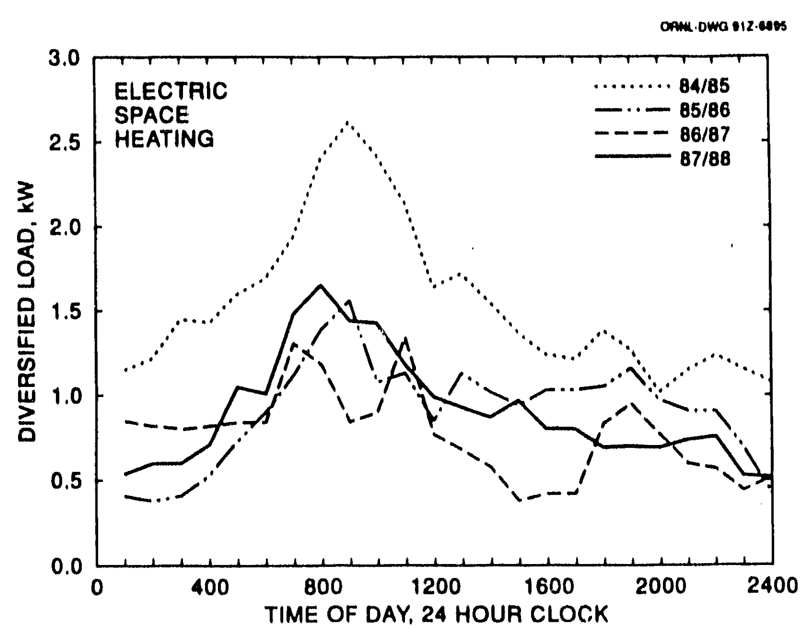

Fig. 5-8. Postretrofit diversified load profile--space-heating electricity--for PESHE/W sample (n, 75), typical weekend day

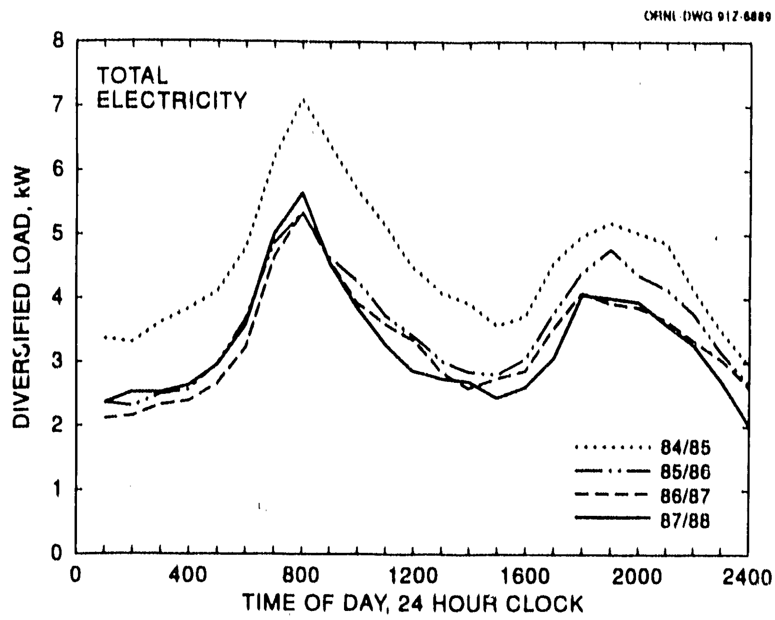

Fig. 5-9. Postretrofit diversified load profile--whole-house electricity--for PESHE/M sample (n, 220), system peak day

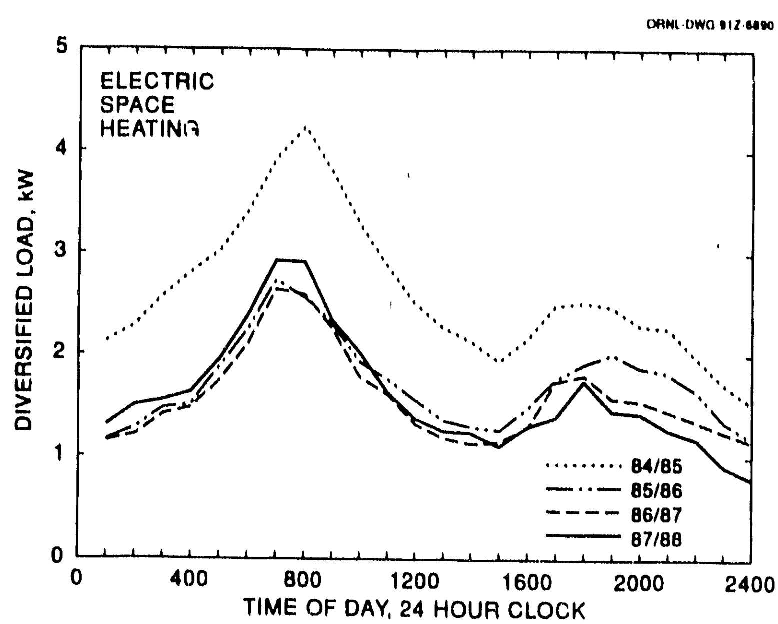

Fig. 5-10. Postretrofit diversified load profile--space-heating electricity--for PESHE/M sample (n, 220), system peak day

space heating electricity loads were less severe than their adjustments during weekdays or weekends.

As indicated in Fig. 5-11, PESHE/W customers appeared to establish a distinguishable evening peak in whole-house load by the third postretrofit year. Like PESHE/M customers, slight perturbations appeared in the diversified load profiles.

PESHE/W customers reversed the pattern of adjustment to benefits of weatherization in their space heating electricity loads (Fig. 5-12). In the second postretrofit year, load savings were maximized. By the third postretrofit year, a portion of the original savings was lost and PESHE/W customers appeared to establish an evening peak load in response to the program.

5.4.4. Residential Wood Combustion for Space Heating

During weekdays, the diversified load profiles for woodfuel space heating in PESHE/W households, PESHE/W (n_3, 75), changed moderately during each of the three postretrofit years (Fig. 5-13). In general, the profiles became flatter each succeeding year. However, during usual sleeping hours (11 PM to 6 AM), the profiles changed only negligibly.

On weekend days, the changes in diversified load profiles were similar during each of the three postretrofit years (Fig. 5-14). It appeared that PESHE/W customers adjusted to the effects of weatherization incrementally and cautiously, as suggested by their woodfuel space heating diversified load profiles.

On Pacific Power System peak days, the changes in diversified load profiles for woodfuel space heating were systematic (Fig. 5-15). For PESHE/W customers, reduced woodfuel peaks corresponded with reduced space heating electricity peaks.

5.5. CHANGES IN ELECTRIC WATER HEATING LOAD

Although moderate, the weekday water heating electricity load savings for PESHE/M (n_2, 145) customers were consistent throughout the day one year after weatherization (Table 5.13). However, in the second postretrofit year, the diversified load profile crossed over the load profile from the first postretrofit year, and load savings became unpredictable (Fig. 5-16). By the third postretrofit year, water heating conservation was no longer effective in the HRCP as loads

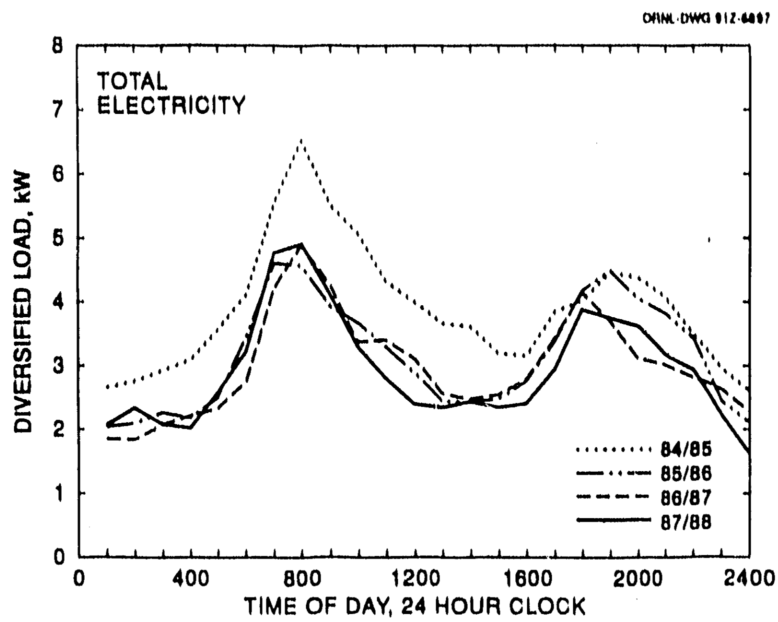

Fig. 5-11. Postretrofit diversified load profile--whole-house electricity--for PESHE/W sample (n, 75), system peak day

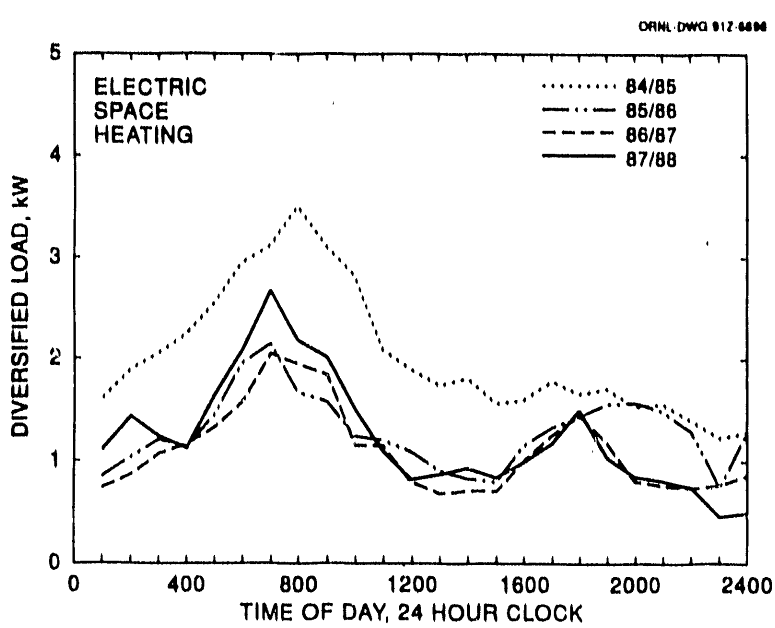

Fig. 5-12. Postretrofit diversified load profile--space-heating electricity--for PESHE/W sample (n, 75), system peak day

Note: Heat output from the woodstoves was converted to units of electricity in order to facilitate comparison. It should be understood that the measuring of heat output of woodstoves is imprecise relative to electrical or natural gas energy.

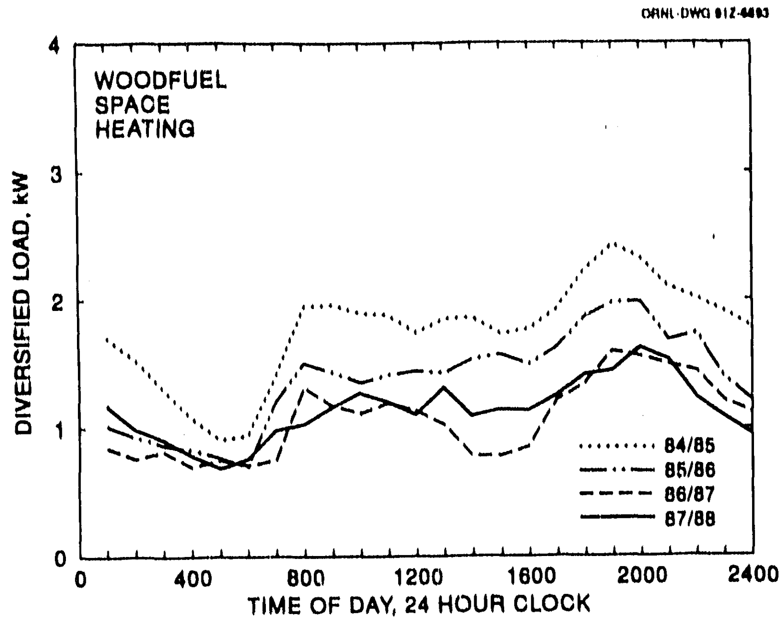

Fig. 5-13. Postretrofit diversified load profile--woodfuel space heating--for PESHE/W sample (n, 75), typical weekday

Note: Heat output from the woodstoves was converted to units of electricity in order to facilitate comparison. It should be understood that the measuring of heat output of woodstoves is imprecise relative to electrical or natural gas energy.

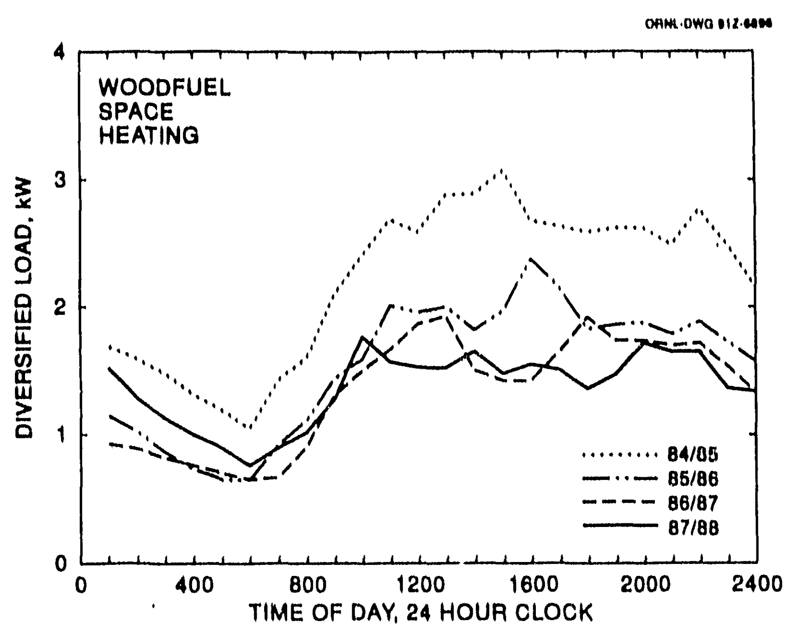

Fig. 5-14. Postretrofit diversified load profile--woodfuel space heating--for PESHE/W sample (n, 75), typical weekend day

Note: Heat output from the woodstoves was converted to units of electricity in order to facilitate comparison. It should be understood that the measuring of heat output of woodstoves is imprecise relative to electrical or natural gas energy.

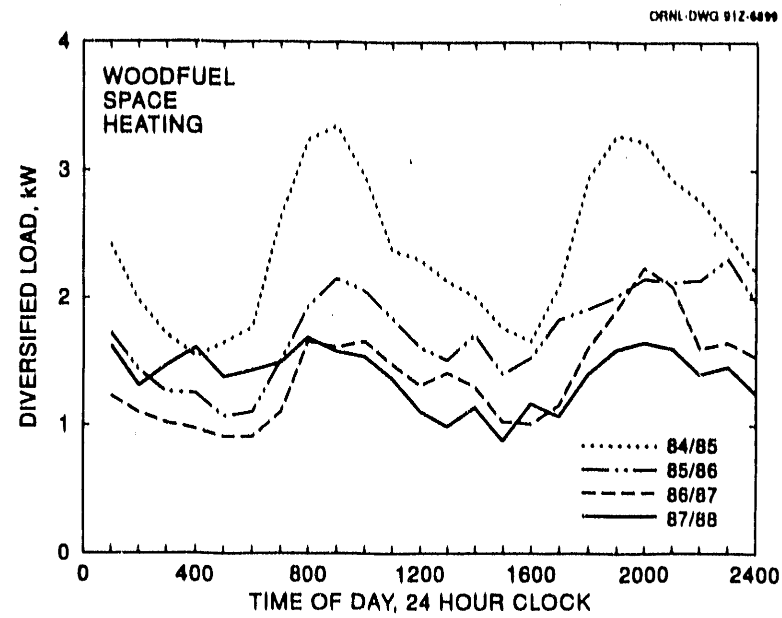

Fig. 5-15. Postretrofit diversified load profile--woodfuel space heating--for PESHE/W sample (n, 75), system peak day

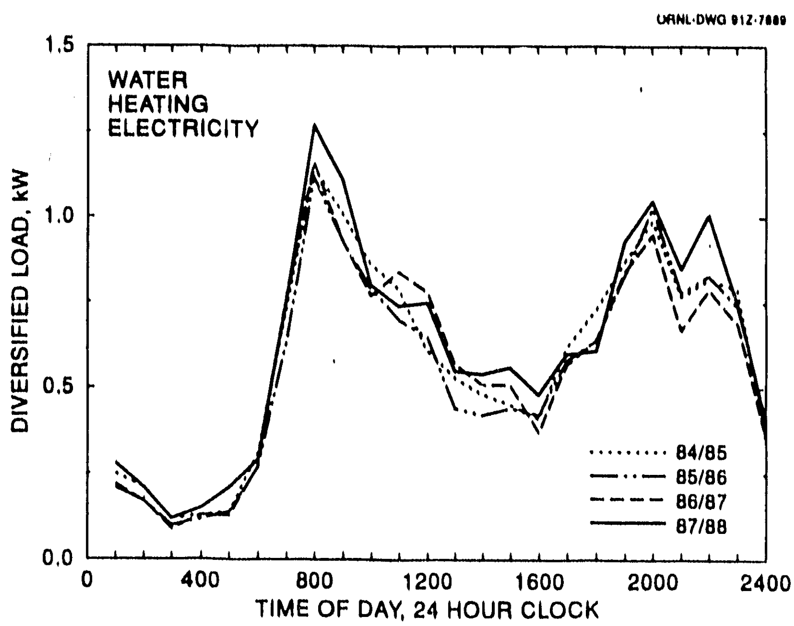

Fig. 5-16. Postretrofit diversified load profile--water-heating electricity--for PESHE/M sample 2 (n, 145), typical weekday

Table 5.13. Water heating electricity load savings on typical *weekday one, two, and three years after* weatherization

TIME	PRE-PROGRAM WATER HEATING	LOAD SAVINGS[a,b,c] 1985/86	1986/87	1987/88
1 am	0.25	0.04/16.0	0.03/12.0	-.03/-12.
2	0.21	0.04/19.0	0.04/19.0	0.00/00.0
3	0.12	0.02/16.7	0.03/25.0	0.00/00.0
4	0.13	0.01/07.7	0.00/00.0	-.02/-15.
5	0.14	0.00/00.0	0.01/07.1	-.07/-50.
6	0.31	0.04/12.9	0.04/12.9	0.02/06.5
7	0.73	0.10/13.7	-.03/-4.1	-.02/-2.7
8	**1.15**	**0.03/02.6**	**-.01/-0.9**	**-.12/-10.**
9	1.01	0.08/07.9	0.08/07.9	-.10/-10.
10	0.86	0.07/08.1	0.09/10.5	0.06/07.0
11	0.79	0.09/11.4	-.05/-6.3	0.05/06.3
noon	0.61	-.04/-6.6	-.17/-28.	-.14/-23.
1 pm	0.53	0.09/17.0	-.04/-7.5	-.02/-4.8
2	0.48	0.06/12.5	-.03/-6.3	-.06/-13.
3	0.45	0.01/02.2	-.06/-13.	-.11/-24.
4	0.41	-.01/-2.4	0.04/09.8	-.07/-17.
5	0.62	0.04/06.5	0.05/08.1	0.02/03.2
6	0.73	0.09/12.3	0.09/12.3	0.12/16.4
7	0.87	0.04/04.6	0.03/03.4	0.06/06.9
8	0.99	-.04/-4.0	0.04/04.0	-.06/-6.1
9	0.77	-.01/-1.3	0.10/13.0	-.08/-10.
10	0.82	-.01/-1.2	0.03/03.7	-.19/-23.
11	0.79	0.05/06.3	0.10/12.7	0.04/05.1
12	0.35	-.06/-17.	0.01/02.9	-.05/-14.

[a]Value to the left of the "/" is the load savings in kW/house; value to the right of the "/" is the percentage change.

[b]Load savings are cumulative; that is, savings are calculated as follows: load savings = $load_{(base\ year,\ or\ pre\text{-}program\ year)}$ - $load_{(current\ year)}$, so that a positive value indicates that load was reduced. Pre-retrofit community daily peak is represented in bold print.

[c](n_2, 145).

increased over the pretrofit levels at 15 points on the 24-point load profile. Water heating electricity load actually increased at the peak hour (8 AM) by 0.12 kW/house (10%) over the pre-retrofit level. An examination of duty cycles would provide additional evidence for the relative ineffectiveness of water-heating conservation.

Most water-heating conservation measures were aimed at standby losses (and they are only effective if the water heater is located in non-conditioned space). Only low-flow showerheads were aimed at energy consumption associated with use of heated water. All high percentage load savings were observed at times of lowest demand indicating that the water-heating measures were ineffective in saving both load and energy.

Load savings and the diversified load profiles for weekend days indicated that the increased loads observed during weekdays may be the outcome of a trend to shift the most intensive water heating needs to weekdays from weekends (Table 5.14 and Fig. 5-17). Three years after weatherization, PESHE/M customers reduced their water heating electricity load at the peak hour on weekend days by 0.07 kW/house (7%). And only 7 points on the 24-point load profile revealed increased loads. The diversified load profile indicated a flattening and smoothing of the weekend water heating electricity load three years after weatherization.

On Pacific Power System peak days, the effects of HRCP water heating conservation were mixed. The load increased at the peak hour (8 AM) by almost 9% (0.1 kW/house), significant load savings of 0.3 kW/house (28%) and 0.2 kW/house (29%) were obtained at 10 and 11 AM (Table 5.15 and Fig. 5-18). This was understandable since the peak days usually occurred on weekdays at the time of day when people shower.

5.6. CHANGES IN INTERIOR TEMPERATURE

The interior temperatures of both PESHE/M and PESHE/W customers increased three years after weatherization. All of the interior temperature profiles were smoother; the profiles of PESHE/M customers were a little smoother than the PESHE/W profiles. All profiles were also flatter.

During weekdays, PESHE/M customers increased interior temperatures by nearly 1° F. on average (Fig. 5-19). PESHE/W customers increased interior temperatures by less than 0.5° F. (Fig. 5-20). After weatherization, PESHE/M customers maintained interior temperatures that were approximately 0.5° F. warmer than the PESHE/W interiors. This difference in interior temperature between PESHE/M and PESHE/W customers indicated that the existing mixed-fuels (i.e., PESHE/M) customers received greater benefits from the HRCP in terms of comfort. Before weatherization, PESHE/M customers maintained higher interior temperatures during the daytime while the wood burning (i.e., PESHE/W) customers maintained higher interior temperatures in the evening, late night, and early morning.

The interior temperature profiles for both groups were comparably shaped three years after weatherization, resembling the similarities between the pre-retrofit profiles. In the analysis of diversified load profiles over time, it was observed that the first and second postretrofit years are periods of adjustment to the effects of weatherization, particularly for woodusers (PESHE/W).

Table 5.14. Water heating electricity load savings on typical *weekend day one, two, and three years after* weatherization

		LOAD SAVINGS[a,b,c]		
TIME	PRE-PROGRAM WATER HEATING	1985/86	1986/87	1987/88
1 am	0.27	-.02/-7.4	0.08/29.6	0.02/07.4
2	0.21	0.02/09.5	0.03/14.3	0.03/14.3
3	0.17	0.04/23.5	0.06/35.3	0.05/29.4
4	0.19	0.06/31.6	0.09/47.4	0.06/31.6
5	0.18	0.05/27.8	0.02/11.1	0.04/22.2
6	0.26	0.06/23.1	0.07/26.9	0.02/07.7
7	0.39	-.02/-5.1	-.03/-7.7	-.03/-7.7
8	0.75	0.07/09.3	-.02/-2.7	0.11/14.7
9	1.01	0.05/05.0	0.01/01.0	0.24/23.8
10	**1.08**	**-.00/-0.0**	**0.00/00.0**	**0.07/06.5**
11	**1.09**	**-.05/-4.6**	**0.03/02.8**	**0.07/06.4**
noon	0.90	-.09/-10.	-.10/-11.	-.04/-4.4
1 pm	0.78	-.14/-18.	-.02/-2.6	-.03/-3.8
2	0.77	0.04/05.2	0.01/01.3	-.04/-5.2
3	0.74	0.16/21.6	0.08/10.8	0.10/13.5
4	0.68	0.15/22.1	0.11/16.2	0.08/11.8
5	0.78	0.01/01.3	0.02/02.6	-.03/-3.8
6	0.75	0.15/20.0	0.04/05.3	-.06/-8.0
7	0.83	0.10/12.0	0.02/02.4	-.04/-4.8
8	0.99	-.02/-2.0	0.02/02.2	0.09/09.1
9	0.83	0.09/10.8	0.13/15.7	0.00/00.0
10	0.76	0.02/02.6	0.12/15.8	0.09/11.8
11	0.75	0.11/14.7	0.18/24.0	0.07/09.3
12	0.48	0.06/12.5	0.16/33.3	0.04/08.3

[a]Value to the left of the "/" is the load savings in kW/house; value to the right of the "/" is the percentage change.

[b]Load savings are cumulative; that is, savings are calculated as follows:
load savings = $\text{load}_{(\text{base year, or pre-program year})}$ - $\text{load}_{(\text{current year})}$, so that a positive value indicates that load was reduced. Pre-retrofit community daily peak is represented in bold print.

[c](n_2, 145).

The interior temperature profiles supported this observation, that HRCP participants do not settle into a systematic response to weatherization during the first two postretrofit years.

During weekend days, PESHE/M customers gradually increased interior temperatures over three years (Fig. 5-21). By the third postretrofit year, their average interior temperatures were 1.5° F. higher than pre-retrofit levels. At the same time, PESHE/M customers increased the interior temperature at the peak hour by more than 2°.

Table 5.15. Water heating electricity load savings on *system peak day one, two, and three years after* weatherization

		LOAD SAVINGS[a,b,c]		
TIME	PRE-PROGRAM WATER HEATING	1985/86	1986/87	1987/88
1 am	0.29	0.03/10.3	0.13/44.8	0.10/34.5
2	0.23	0.04/17.4	0.03/13.0	0.00/00.0
3	0.19	0.05/26.3	0.02/10.5	0.04/21.1
4	0.21	0.04/19.0	0.03/14.3	-.02/-9.5
5	0.18	0.02/11.1	0.03/16.7	-.02/-11.
6	0.38	0.08/21.1	0.07/18.4	0.02/05.3
7	0.67	0.06/09.0	-.09/-13.	-.06/-9.0
8	**1.18**	**0.00/00.0**	**-.08/-6.8**	**-.10/-8.5**
9	1.09	0.07/06.4	-.05/-4.6	0.01/01.0
10	1.00	0.10/10.0	0.08/08.0	0.28/28.0
11	0.82	0.16/19.6	0.11/13.4	0.24/29.3
noon	0.70	-.01/-1.4	-.02/-2.9	0.13/18.6
1 pm	0.62	-.05/-8.1	-.03/-4.8	0.07/11.3
2	0.55	0.04/07.3	0.09/16.4	0.07/12.7
3	0.50	-.00/-0.0	-.01/-2.0	0.10/20.0
4	0.60	0.05/08.3	0.05/08.3	0.11/18.3
5	0.64	0.07/10.9	0.13/20.3	0.13/20.3
6	0.74	0.05/06.8	0.10/13.5	0.06/08.2
7	0.85	0.09/10.6	0.16/18.8	0.07/08.2
8	1.03	0.20/19.4	0.19/18.4	0.14/13.6
9	0.93	0.21/22.6	0.25/26.9	0.09/09.7
10	0.70	0.17/24.3	0.08/11.4	0.02/02.9
11	0.68	0.06/08.8	0.01/01.5	-.04/-5.9
12	0.44	0.09/20.5	0.03/06.8	0.11/25.0

[a]Value to the left of the "/" is the load savings in kW/house; value to the right of the "/" is the percentage change.

[b]Load savings are cumulative; that is, savings are calculated as follows: load savings = $load_{(base\ year,\ or\ pre\text{-}program\ year)} - load_{(current\ year)}$, so that a positive value indicates that load was reduced. Pre-retrofit community daily peak is represented in bold print.

[c](n_2, 145).

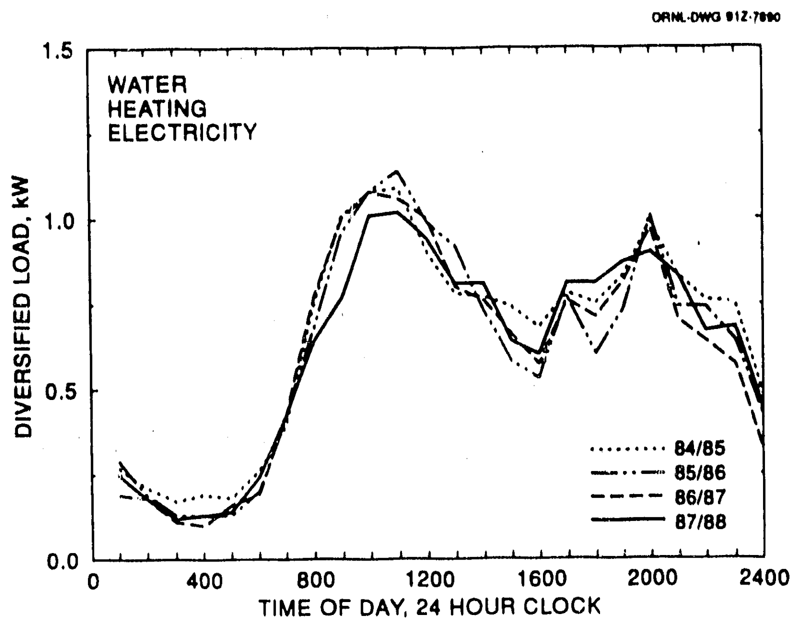

Fig. 5-17. Postretrofit diversified load profile--water-heating electricity--for PESHE/M sample 2 (n, 145), typical weekend day

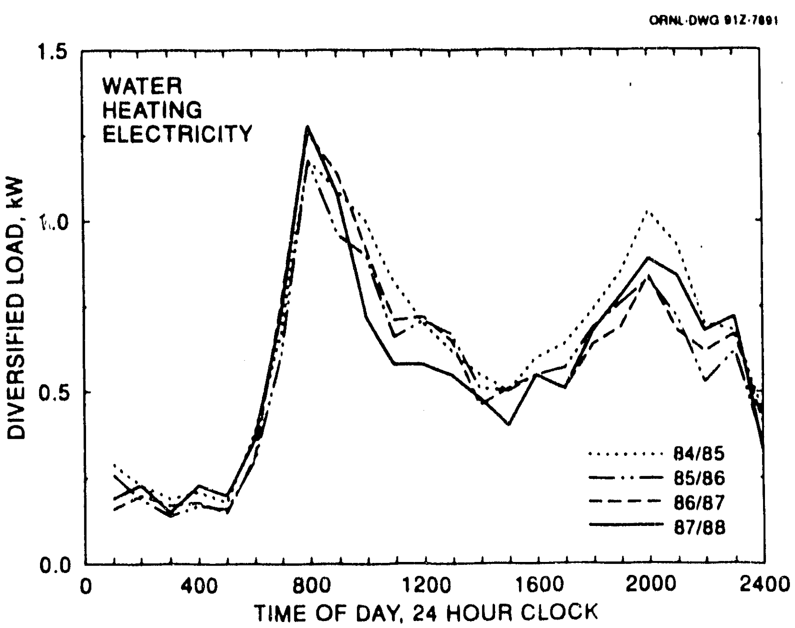

Fig. 5-18. Postretrofit diversified load profile--water-heating electricity--for PESHE/M sample 2 (n, 145), system peak day

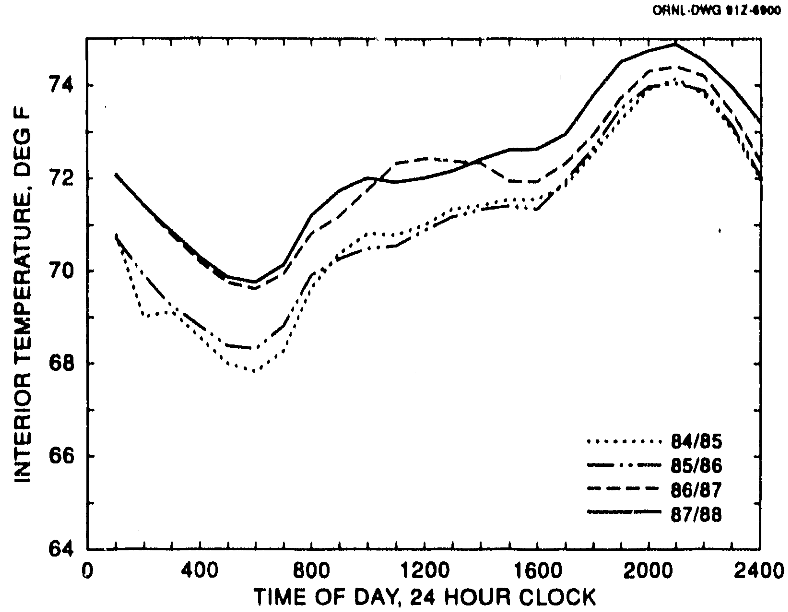

Fig. 5-19. Postretrofit profile of interior temperature for PESHE/M sample (n, 220), typical weekday

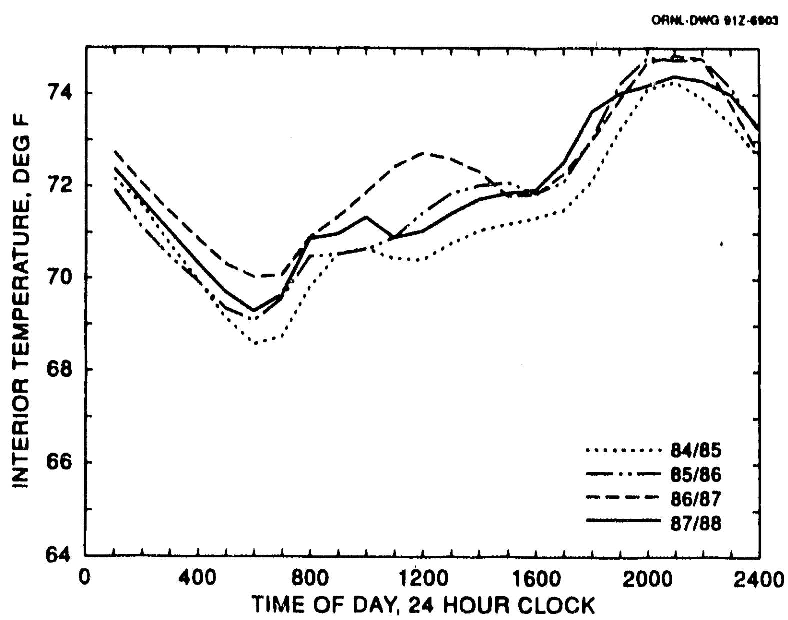

Fig. 5-20. Postretrofit profile of interior temperature for PESHE/W sample (n, 75), typical weekday

PESHE/W customers did not demonstrate the same systematic change in interior temperatures on weekend days (Fig. 5-22). Although PESHE/W customers did increase their interior temperatures by nearly 2° F. at the peak hour and by 0.5° on average between midnight and 8 AM, they also reduced interior temperatures by approximately 0.5° F. between 11 AM and midnight. It might have been that PESHE/W homes were "too warm" before weatherization.

On system peak days, PESHE/M and PESHE/W customers maintained the same pattern of interior temperatures that they exhibited before weatherization (Fig. 5-23 and Fig. 5-24). The PESHE/W houses were generally warmer both pre-retrofit and three years after weatherization, except during the daytime. Interestingly, both PESHE/M and PESHE/W customers increased their interior temperatures at 6 AM by approximately 3° F. three years after weatherization on system peak days.

The HRCP effectuated an improvement in comfort levels as indicated by the general increases in interior temperatures. Although it cannot be determined whether the improvement in comfort was attributable to customer response (i.e., takeback behavior) or an improvement in the thermal integrity of the houses, apparently PESHE/M customers received greater benefits in terms of greater warmth. Yet PESHE/W customers may have benefitted from lower (or more even) interior temperatures.

5.7. SUMMARY

In this chapter, load savings were examined one, two, and three years after weatherization.

During **weekdays**, the Hood River community residential peak occurred at 8 AM during the week. For the PESHE/M customers (Sample n_1, 220 houses), large load savings were obtained one year after weatherization at the residential peak hour; but, greater load savings were obtained during late morning and early afternoon. Apparently, PESHE/M customers became more conservationist--or they did not exercise "takeback" behaviors--or the thermal integrity of the house retained acceptable heat and comfort without occupants adjusting thermostats substantially.

In the first year after weatherization, peak whole-house electricity load for PESHE/M customers was reduced from 5.2 to 4.4 kW/house (or 109 MW savings for the Pacific Power

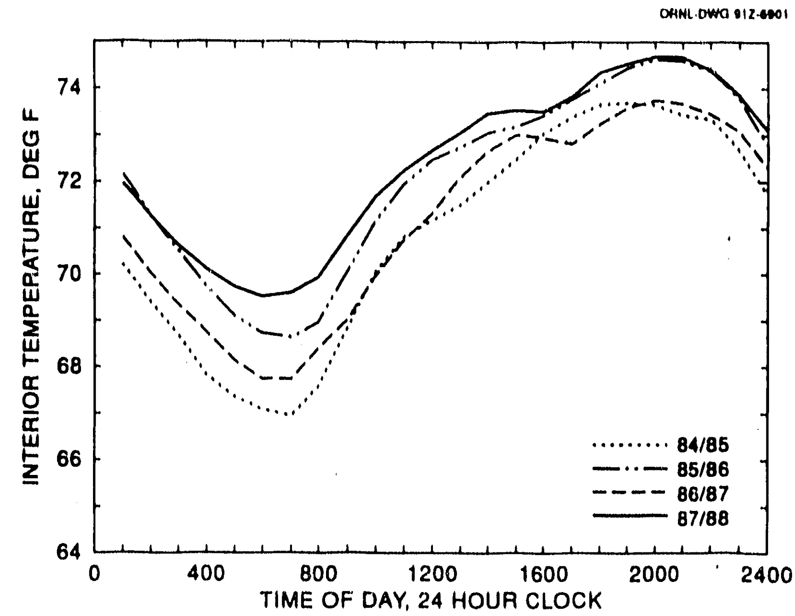

Fig. 5-21. Postretrofit profile of interior temperature for PESHE/M sample (n, 220), typical weekend day

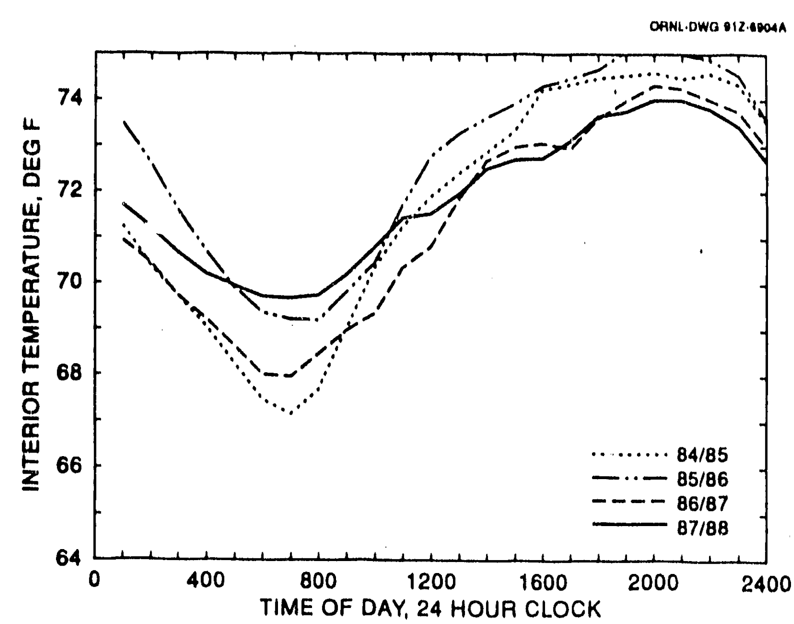

Fig. 5-22. Postretrofit profile of interior temperature for PESHE/W sample (n, 75), typical weekend day

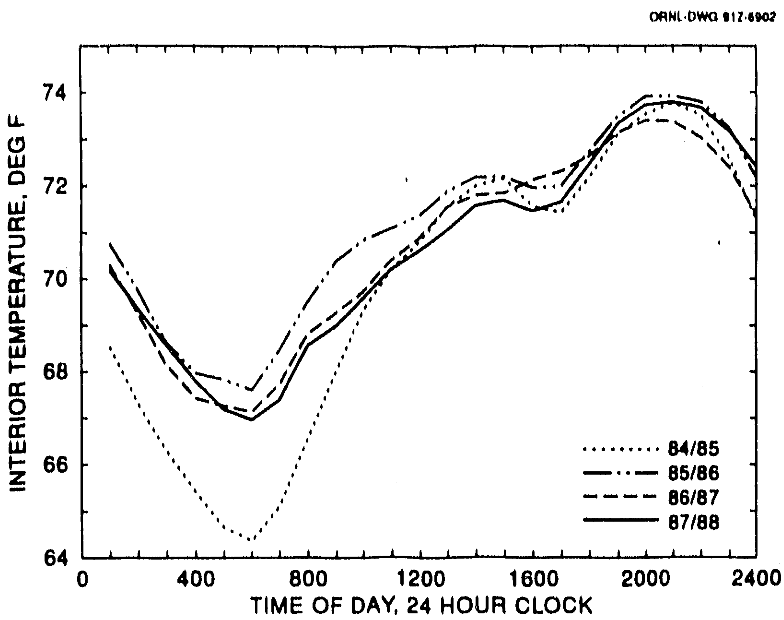

Fig. 5-23. Postretrofit profile of interior temperature for PESHE/M sample (n, 220), system peak day

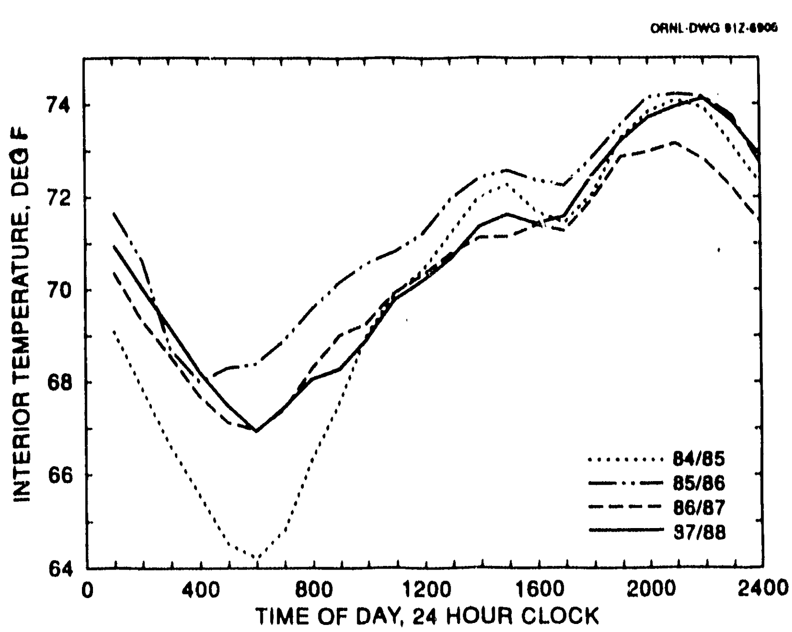

Fig. 5-24. Postretrofit profile of interior temperature for PESHE/W sample (n, 75), system peak day

system). Space heating electricity load was reduced from 2.7 to 1.9 Kw. At the peak hour, baseload electricity was virtually unchanged form the pre-retrofit year.

Whole-house electricity peak load can be significantly reduced--and it was--but weatherization will yield a lesser effect--and it did--on residential electricity load first thing in the morning and early in the evening at the time when the family reassembles after being dispersed for the day.

During **weekend days**, in the first year after weatherization, 1985/86, PESHE/M customers obtained the largest absolute load savings at 10 AM, a 25% reduction in whole-house electricity load that was equivalent to 1.4 kW/house (193 MW for the Pacific system). Larger "off-peak" load reductions suggested that PESHE/M customers improved their comfort through conservation--not by increasing their thermostat settings after weatherization--but through a general improvement in the thermal integrity of the house.

Space heating electricity load was reduced from the pre-retrofit peak of 2.8 kW/house to 1.7 kW/house, an absolute reduction of 1.1 kW, or 40% of pre-retrofit space heating electricity load, which is equivalent to 155 MW for the Pacific Power System.

On **peak days**, the first-year load savings was equivalent to 242 MW for the Pacific system. This load savings exceeds the load savings observed on typical winter weekdays and weekend days by 123% and 25%.

Space heating electricity load savings were also largest at the 8 AM community peak on Pacific Power System peak days. In the first postretrofit year, load was reduced by 1.68 kW/house, or 40% of pre-retrofit load.

During **weekdays**, the whole-house electricity peak load for PESHE/W customers was 4.7 kW/house, or 22% lower than the same load for PESHE/M customers. Pacific Power residential customers could have reduced whole-house electricity load by as much as 65 MW *without weatherization*, if they had used woodfuel in the same proportion as Hood River residents.[9]

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[9]Nearly three of four monitored Hood River homes had woodfuel space heating equipment (Tonn and White, 1987).

After weatherization, at the peak hour, whole-house electricity load for PESHE/W customers declined by 11%. Space heating electricity load declined by 36%. By comparison, the same loads for PESHE/M customers declined by 15% and 30% one year after weatherization.

During the first year after weatherization, 23% woodfuel load savings were obtained at the daily peak because customers elected to cut back on their use of wood burning equipment and use electricity to maintain warmth and comfort in their homes, and they still reduced electric space heating load.

During **weekend days**, the differences between PESHE/M and PESHE/W customers in the ways that electricity was used before weatherization were less distinct. However, one year after weatherization, the whole-house electricity load for PESHE/W declined by 2.1 kW/house and 1.7 kW/house at 10 AM and 11 AM on weekend days. The corresponding load for PESHE/M customers declined by 1.4 kW/house and 1.0 kW/house. The load reduction in PESHE/W houses was 57% greater than the load reduction in PESHE/M houses.

During system **peak days**, PESHE/W customers reduced whole-house electricity load at the peak hour by almost 2 kW/house after weatherization. Nearly all of this load savings was related to savings in space heating electricity (1.8 kW/house or 52% of pre-program load).

In general, load savings continued to accrue through the second postretrofit year. Then, in the third postretrofit year, levels for most of the loads either held the second-year levels or *increased* slightly. During **weekdays**, PESHE/M customers saved 0.8 kW/house (15%) three years after weatherization, virtually identical to the first year whole-house electricity savings. Like whole-house electricity load, space heating electricity load after three years was similar to the load after the first postretrofit year, at a reduction of 0.8 kW/house (30%) in pre-retrofit load.

Baseload electricity was virtually unchanged. No load savings were observed during the first two postretrofit years. In the third year after weatherization, baseload electricity *increased* by 6% over the pre-retrofit load.

Water heating electricity load savings were erratic for the three postretrofit years. In the first year, load declined by 3%, then *increased* in the second year by a little more than 3%. Three years after weatherization, water heating electricity load had *increased* by 10%.

PESHE/W customers saved 0.5 kW/house (11%) in whole-house electricity three years after weatherization. Savings of space heating electricity load for PESHE/W customers were, in one word, dramatic. Three years after weatherization, the cumulative change in load was a savings of 0.6 kW/house (28%).

Baseload electricity savings three years after weatherization were effectively zero. Year by year, the load changed by -8%, 9%, and 3%.

During **weekend days**, three years after weatherization, PESHE/M customers reduced the 10 AM load by 1.0 kW/house (18%) and the 11 AM load by 1.1 kW/house (21%).

The space heating electricity load peak actually shifted after weatherization from 9 AM to 11 AM. Space heating electricity load *increased* in year three by 32%, resulting in a cumulative load reduction from the pre-retrofit year to the third postretrofit year of 0.8 kW/house (27%).

Baseload electricity changed marginally three years after weatherization. The first-, second-, and third-year savings were 13%, -3%, and 3%, for a cumulative change of 0.2 kW/house (7%).

In the third year after weatherization, the water heating electricity load declined by 6%. At the same time, the water heating electricity load during the week *increased* three years after weatherization by 0.12 kW/house (10%).

During **weekend days**, the whole-house electricity load for PESHE/W customers peaked at 11 AM. Load savings at 10 AM--the new peak after weatherization--were 2.1 kW/house (41%), -0.2 kW/house (-5%), and -0.7 kW/house (-23%), for a cumulative three-year savings of 1.3 kW/house (24%). These savings resulted in a load reduction from 5.2 kW/house to 3.9 kW/house at 10 AM.

Weekend peak loads were apparently driven by baseload electricity, probably water heating and cooking. Baseload electricity and whole-house electricity both peaked at 11 AM. One-, two-, and three-year baseload electricity savings were 0.8 kW/house (23%), 0.2 kW/house (7%), and -0.2 kW/house (-8%), for a cumulative three-year savings of 0.8 kW/house (23%).

During system **peak days**, PESHE/M customers reduced whole-house electricity load after three years by 1.5 kW/house (21%) (207 MW systemwide). After three years, the space heating electricity load had declined by 1.3 kW/house (31%) (180 MW systemwide). Baseload electricity was virtually unchanged from year one to year three.

Three years after weatherization, water heating electricity load had *increased* by 0.1 kW/house (8%). Since weekday loads increased like peak day loads, and since weekend day loads declined three years after weatherization, there is strong support for the trend that occupants have shifted water heating electricity demand from weekends to weekdays.

The whole-house electricity load for PESHE/W customers declined by 1.6 kW/house (25%) three years after weatherization. PESHE/W customers reduced space heating electricity load at the peak hour on the Pacific Power System peak day by 1.8 kW/house (52%) in the first year after weatherization. In succeeding years, they *increased* this load by 0.3 kW/house (a -17% savings) and by 0.2 kW/house (-12%), for a cumulative three-year load reduction of 1.3 kW/house, 38% of pre-retrofit load at the peak hour on the system peak day.

Unlike PESHE/M customers, PESHE/W customers saved baseload electricity. The cumulative three-year baseload electricity savings was 0.3 kW/house (10%).

The HRCP effectuated an improvement in comfort levels as indicated by the general increases in interior temperatures. Although it cannot be determined whether the improvement in comfort was attributable to customer response (i.e., takeback behavior) or an improvement in the thermal integrity of the houses, it appeared that PESHE/M customers received greater benefits in terms of greater warmth while PESHE/W customers may have benefitted from lower interior temperatures.

6. INTERVENING EFFECTS OF FUEL SWITCHING ON SPACE HEATING LOADS

In this century, the use of wood in the U S. for residential wood combustion for space heating (RWC-h) declined due to competition from modern fuels such as coal, fuel oil, electricity, and natural gas, until the mid-1970s. Price increases and fuel shortages associated with the oil crises spurred a 130% increase in RWC-h between 1973 and 1980 and another 8% between 1980 and 1983. The U. S. Office of Technology Assessment (OTA) has forecast that RWC-h could triple by the year 2000, under conservative assumptions about price increases of competing fuels, and could increase sevenfold given significant increases in the prices of competing fuels. (See Tonn and White 1990.)

In areas such as the Pacific Northwest, it is important to document and understand RWC-h. Regional energy planners must understand how RWC-h complicates measurements of the cost-effectiveness of residential conservation programs designed to save electricity or reduce electric load. Utility demand-side planners need to develop profiles of wood users and explore their reasons for using wood. Utility supply-side planners must be aware of the potential for large swings in electricity demand, because households can readily switch from woodfuel to other fuels and *vice versa*. The potential for uncertainty among planners is magnified in the Pacific Northwest where 48% of households have the basic equipment for using wood as the primary space-heating fuel (Tonn and White 1986).

6.1. DECISION MODEL OF FUEL SWITCHING BEHAVIOR

A model of fuel switching may be defined as a logical decision process with 5 basic and highly integrative processes:

(1) Identify the decision alternatives;

(2) Identify goals to be satisfied by the decision;

(3) Identify factors influencing the decision;

(4) Identify beliefs that link (1) to (2) and (3) to (1) and (2); and

(5) Hypothesize how (1), (2), (3), and (4) are synthesized into a decision process.

The processes are numbered for ease of reference. However, the processes are not ordered by importance or sequence. In practice, the decision theoretic has no permanent entry point nor a concise exit. In other words, the decision theoretic is process- rather than outcome-based. The model and its application to fuel switching are summarized in Table 6.1.

Table 6.1. Theoretical decision model of fuel switching behavior

MODEL PROCESSES	DATA NEEDS
(1) Two (2) basic decisions: 1: whether or not to use an available fuel 2a: how much to use each chosen fuel, or 2b: alter lifestyle to incorporate selected fuel	Self-reports to direct questions
(2) Identify goals . trade-offs . relative importance	Self-reports with specific questions related to importance and trade-offs
(3) Identify factors influencing decisions	Time-series to control for exogenous factors
(4) Beliefs	Relationships among values, attitudes, intentions, behaviors
(5) Residential conservationist decision	Investigators are still in the exploratory stage

The database for the present study included limited information on fuel choices and the reason(s) for selecting certain fuels. Although the HRCP database was one of the richest databases ever assembled for an outcomes evaluation, the cumulative knowledge developed in decision modeling since 1983 when the HRCP was implemented has increased dramatically.

The sketch of the decision theoretic model presented in Table 6.1 was applied to the analysis of fuel switching in the present study within limitations. As noted above, fuel switching has been a significant practice in the Pacific Northwest.

6.2. FUEL SWITCHING IN THE HRCP

Nearly 28% of the submetered households reported that they switched primary space heating fuel at least one time between 1984 and 1989, either switching from electricity to woodfuel (22% overall) or woodfuel to electricity (6% overall). During the same six years, 47% of the households never switched from electricity and 25% never switched from woodfuel. Among the fuel switchers there were 26 different fuel selection paths between 1984 and 1989, where fuel was changed at least one time.

Tests of the difference between means of selected housing and household characteristics were conducted using SAS PROC GLM in order to understand the motivations for fuel switching. When only the primary fuel selection before weatherization is modeled without regard to a future fuel selection path, it was found that households that chose electricity were statistically different from woodusers in terms of the age of the household head (49 years to 44 years for woodusers); proportion of homeownership (0.93 to 0.83); and the number of rooms in the house (6.7 to 7.2). Although households that chose electricity earned $2,000 more annually than woodusers, the difference in income was not statistically significant.

The pre-retrofit primary fuel selection decision was modeled using SAS PROC CATMOD (Table 6.2). (See Appendix C.) Model results indicated that the choice between electricity and woodfuel for space heating was related to age of the household head, household income, homeownership, the number of rooms in the house, household size, and the household head's perception of the energy efficiency of the house. The categorical/logistic regression model had a R-squared analog of 0.149.

The fuel selection paths were compressed from 26 to 4 and modeled also using PROC CATMOD (Table 6.3). The most meaningful interpretation of the model indicated that the "propensity" to switch fuels was related to the age of the household head, the education level of the household head, household income, the number of rooms in the house, and the change in perceived comfort level due to the HRCP. This categorical/logistic regression model had an R-squared analog of 0.251.

Of course, these results are not conclusive. However, they do support previous research in fuel choice (especially between electricity and woodfuel) and fuel switching (Tonn and White

1987 and 1986). In short, fuel selection and fuel switching are conscious decisions and are influenced by energy-efficiency improvements in the house.

6.3. CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

It was shown in Chapter 5 that woodfuel use in the HRCP was comparable to a 65 MW displacement of electricity demand in the Pacific Power System. Since fuel switching has been prominent in the Pacific Northwest and was a significant activity during the four years of data collection in the HRCP and beyond, the study of fuel switching as a dynamic activity appears worthy of special attention.

The decision theoretic model presented in this chapter is a framework for developing a research plan. Survey instruments will need to be developed that ask valid questions about *residential conservationist goals* (if they exist) and acceptable trade-offs, factors that influence decisions, and belief-attitude-intention-behavior interaction. It can be argued that residential energy decisions are not independent of other household economic decisions and that they can be simultaneously influenced by community and other peer or authority figures. If this argument is substantively true, then the research plan should consider these interactions.

When more precise data are available then more sophisticated statistical models may be applied. More data and more models, however, do not assure that the best answers to the questions will be found. The research plan must control for the potential to make errors regarding causality, and for the temporal relationship between time of data collection (i.e., the moment of measurement) and the time of activity (i.e., the moment of decision implementation).

A better understanding of fuel selection and fuel switching will contribute to better marketability of residential energy conservation programs like the HRCP.

Table 6.2. Categorical data modeling results for pre-program fuel selection

Model: The choice of electricity or woodfuel as the primary space heating fuel is a function of . . .

ANALYSIS OF VARIANCE TABLE

SOURCE	DF	CHI-SQUARE	PROB
INTERCEPT	1	0.46	0.4964
Age of Household Head (years)	1	6.22	0.0127
Household Income (1984 $)	1	6.28	0.0122
Home Owner (0,1)	1	11.43	0.0007
Number of Rooms in House	1	1.99	0.1586
Household Size	1	1.83	0.1759
Energy Efficiency of House	1	3.87	0.0522
LIKELIHOOD RATIO	281	355.21	0.0018

ANALYSIS OF INDIVIDUAL PARAMETERS

EFFECT	PARAMETER	ESTIMATE	STANDARD ERROR	CHI-SQUARE	PROB
INTERCEPT	1	0.62181	0.914276	0.46	0.4964
Age of Household Head (years)	2	0.02572	0.010317	6.22	0.0127
Household Income (1984 $)	3	2.3E-05	9.3E-06	6.28	0.0122
Home Owner (0,1)	4	-1.6062	0.4752	11.43	0.0007
Number of Rooms in House	5	-0.1166	0.082717	1.99	0.1586
Household Size	6	-0.1519	0.112243	1.83	0.1759
Energy Efficiency of House	7	0.26478	0.136395	3.77	0.0522

R-SQUARED ANALOG = 0.149

Table 6.3. Categorical data modeling results for fuel selection path, 1984-1989

Model: The choice to retain the same primary space heating fuel over time, whether electricity or woodfuel, and the choice to switch from electricity to woodfuel or from woodfuel to electricity is a function of . . .

ANALYSIS OF VARIANCE TABLE

SOURCE	DF	CHI-SQUARE	PROB
INTERCEPT	3	8.84	0.0315
Age of Household Head (years)	3	18.40	0.0004
Education of the Hhd Head	3	6.70	0.0819
Household Income (1984 $)	3	8.35	0.0393
Number of Rooms in House	3	12.82	0.0050
Change in Comfort due to HRCP	3	9.47	0.02[illegible]6
LIKELIHOOD RATIO	858	641.90	1.0000

ANALYSIS OF INDIVIDUAL PARAMETERS

EFFECT	PARAMETER	ESTIMATE	STANDARD ERROR	CHI-SQUARE	PROB
INTERCEPT	1	-3.0224	1.96494	2.37	0.1240
	2	-4.865	2.05116	5.63	0.0177
	3	-1.5969	2.00986	0.63	0.4269
Age of Household Head (years)	4	0.06010	0.02037	8.70	0.0032
	5	0.04075	0.02113	3.72	0.0538
	6	0.01818	0.02149	0.72	0.3977
Education of the Hhd Head	7	0.11519	0.10799	1.14	0.2861
	8	0.16742	0.11090	2.28	0.1311
	9	0.00737	0.11093	0.00	0.9470
Household Income (1984 $)	10	2.0E-05	2.4E-05	0.71	0.3988
	11	2.4E-06	2.4E-05	0.01	0.9207
	12	3.6E-05	2.4E-05	2.26	0.1327
Number of Rooms in House	13	-0.1072	0.17871	0.36	0.5487
	14	0.21426	0.18358	1.36	0.2432
	15	0.13374	0.18501	0.52	0.4698
Change in Comfort due to HRCP	16	0.35815	0.17140	4.37	0.0367
	17	0.28172	0.17778	2.51	0.1130
	18	0.07745	0.17693	0.19	0.6616

R-SQUARED ANALOG = 0.251

7. SUMMARY AND CONCLUSIONS

7.1. LOAD SAVINGS

During typical weekdays at the peak hour, whole-house electricity load was reduced by 0.8 kW/house. Space heating electricity load was also reduced by 0.8 kW/house. Water heating electricity load *increased* by 10%. Baseload electricity was virtually unchanged. Woodfuel users saved 0.5 kW/house of whole-house electricity, 0.6 kW/house of space heating electricity, and practically no baseload.

During typical weekend days, whole-house electricity load was reduced by 1.0 kW/house. The space heating electricity load peak hour shifted from 9 AM to 11 AM, with a load savings of 0.8 kW/house. Baseload electricity was reduced by 7%. The water heating electricity load declined by 6%, in contrast to the weekday increase of 10%. Woodfuel users reduced whole-house electricity load by 1.3 kW/house. Approximately 0.5 kW/house of space heating electricity was saved. Baseload electricity was reduced by 0.8 kW/house.

During Pacific Power System peak days at the peak hour, whole-house electricity load was reduced by 1.5 kW/house (equivalent to 207 MW system-wide). Space heating electricity load comprised most of this savings (87%). Water heating electricity load *increased* by 0.1 kW/house (8%). Baseload electricity was virtually unchanged.

In general, evidence was found suggesting that water-heating electricity load and outdoor temperature are more correlated than has been usually hypothesized.

The HRCP effectuated an improvement in comfort as indicated by generally large increases in interior temperature, some as large as 3° F.

7.2. FUEL SWITCHING

Nearly 28% of the submetered homes reported that they switched primary space heating fuel at least one time between 1984 and 1989. During the same six years, 47% of the households never switched from electricity and 25% never switched from woodfuel.

Four fuel selection paths were modelled, indicating that the propensity to switch fuels was related to the age of the household head, the education level of the household head, household income, the number of rooms in the house, and the change in perceived comfort level due to the HRCP.

Woodfuel users demonstrated erratic responses to weatherization effects. The changes in their load profiles and interior temperature profiles indicated that the first and second postretrofit years were trials, and that woodfuel users did not adjust to the HRCP until the third postretrofit year. This observation suggests that woodburning is an integrated feature of a particular lifestyle that includes woodburning, and that altering the lifestyle is not automatic. HRCP participants that heated predominantly with electricity showed a less dramatic and more consistent response. Electricity loads are much more unpredictable in woodfuel houses.

7.3. CONCLUSIONS

The HRCP effectuated lower load profiles and sustained load savings for three postretrofit years, all at the same time that some participants were switching primary space heating fuels back and forth between electricity and woodfuel.

Virtually all of the load savings experienced by participants were space heating electricity reductions. Water-heating electricity load was unchanged after three postretrofit years. If space heating electricity load savings persist, baseload, including water-heating electricity, will become a more significant proportion of whole-house electricity load. Consequently, residential conservation efforts may need to be refocused on end-uses, rather than on the building envelope, in order to maximize load savings.

The reduction of water-heating electricity load during weekend days, coupled with the apparent shift of this load savings in the form of added load onto weekdays, implies that baseload could similarly shift. As a result, baseload margins would decline during the week and expand during weekends. Baseload electricity in general, and water-heating electricity load in particular, should be studied more directly by observing precise behaviors (e.g., dishwashing, the use of showers and baths, and cooking). This new examination may reveal benefits like the propensity of residential energy consumers to alter behavior in ways that are *consistent with but not expected by* residential conservation programs.

Although the evidence from the HRCP was not conclusive, there appeared to be a collective effort among participants to not take back load savings. The single, irrefutable demonstration of take-back was the transferring of woodfuel space heating load to electricity after weatherization.

Fuel switching activity was significant. More than one of four HRCP participants reported that they switched primary space heating fuel at least one time during the program. If they would switch to woodfuel "permanently" (and 70% of the fuel switchers did), then, hypothetically, more than half (53%) of the program participants would rely on woodfuel for their primary space heating needs. The issues to be resolved by utility load forecasters would become more complex, especially after consideration of the absence of a sufficiently strong explanation for switching fuels. A comprehensive study of woodfuel use should be conducted in conjunction with a study of the response of woodfuel users to programs like the HRCP in order to define the wooduser subculture.

Peak loads were reduced, and both electric space heating and woodfuel space heating participants improved comfort in terms of warmth. Interestingly, electric space heating customers benefitted from *warmer* interior temperatures three years after weatherization; woodfuel space heating participants benefitted from *lower* interior temperatures. It appears that different market segments can be targeted for the same residential energy conservation program, but that the different targets will respond in different ways.

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APPENDIX A

Sampling Bias

APPENDIX A: SAMPLING BIAS

The original sample of submetered houses was 320. Of these, 244 were single-family. After four years of submetered data had been collected, 22 of the 244 houses had been removed from the data collection process due to equipment failures, changes in occupancy, and other non-programmatic influences. Thus, 220 submetered, single-family houses (Sample n_1) were retained for this second load study, in which whole-house electricity and space heating electricity loads were monitored. Similarly, 145 of the original 160 single-family houses monitored for water heating electricity were retained, and 75 of the 83 single-family houses fitted with radiometers were retained for analysis.

Because data attrition was negligible--the number of houses removed from analysis was too small for statistical tests of the difference between means--bias tests were not conducted. These potential "horizontal" biases were assured to be small.

In this second load study, the "vertical" biases were expected. That is, since the houses submetered for water heating electricity and woodfuel space heating were mutually exclusive, it was expected that statistically significant differences would exist (*ed.* hopefully) between houses and households with woodstoves and those without. As indicated in Chapter 6, there were significant differences in terms of age of household head, household size, and other structural, demographic, attitudinal, and behavioral features that have become common distinctions between woodusers and those who do not burn wood. Thus, the vertical biases were artifacts of the population from which the samples (Sample n_2 and Sample n_3) were selected, and did not weaken the analysis.

APPENDIX B

Supplemental Illustrations

APPENDIX B: SUPPLEMENTAL ILLUSTRATIONS

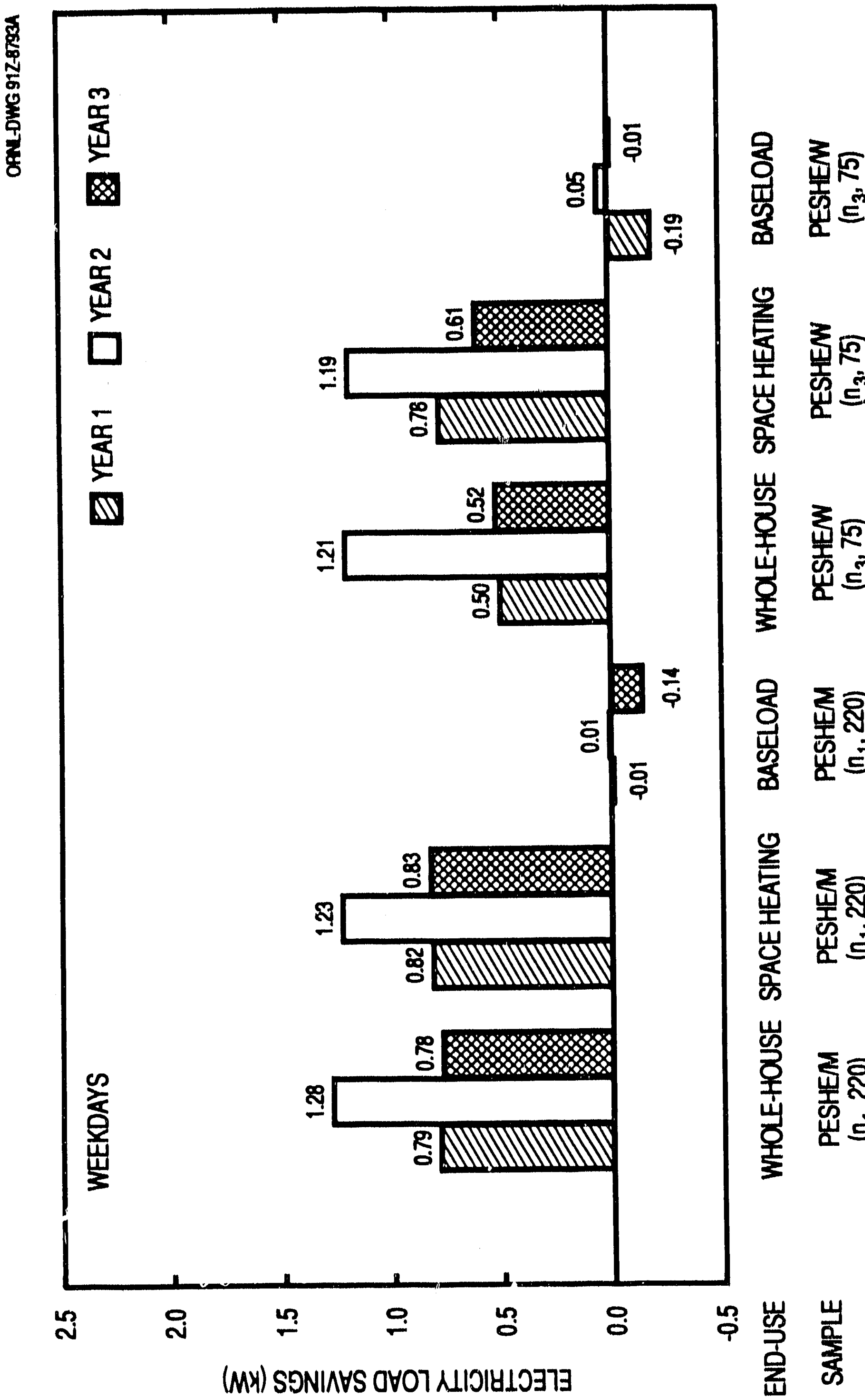

Fig. B-1. Electricity load savings by sample, by end-use, one, two, and three years after weatherization, week days.

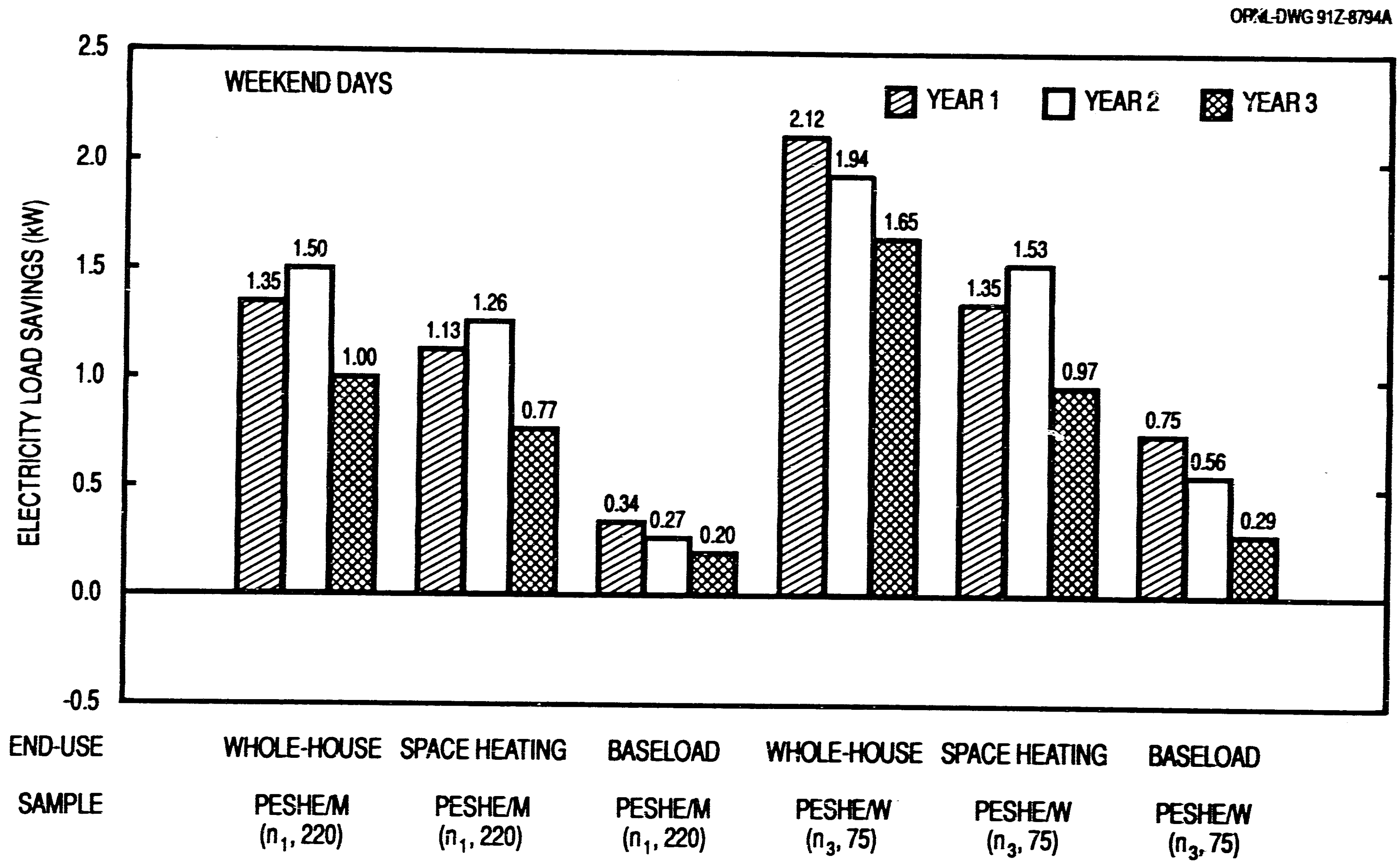

Fig. B-2. Electricity load savings by sample, by end-use, one, two, and three years after westherization, weekend days.

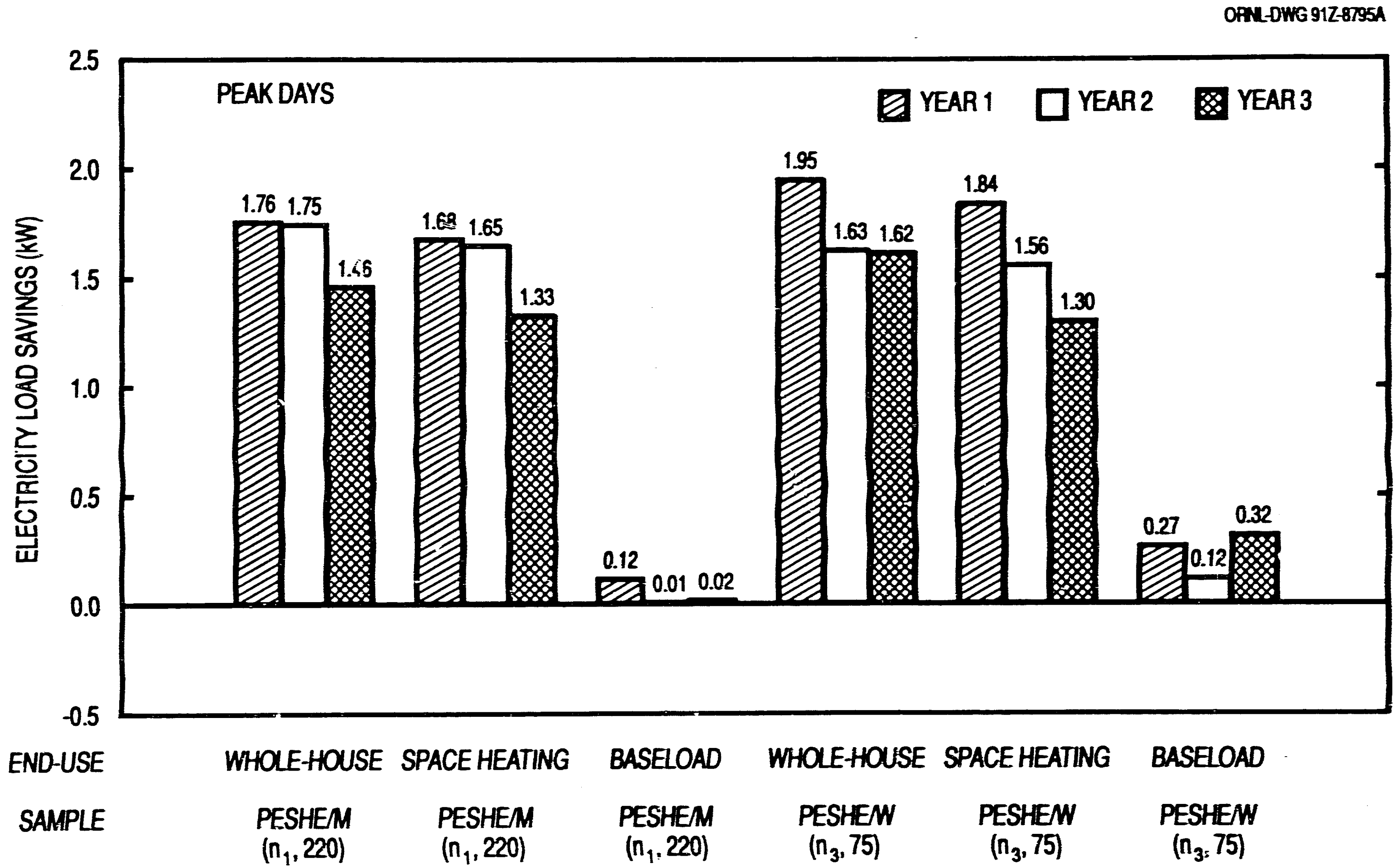

Fig. B-3. Electricity load savings by sample, by end-use, one, two, and three years after weatherization, system peak days.

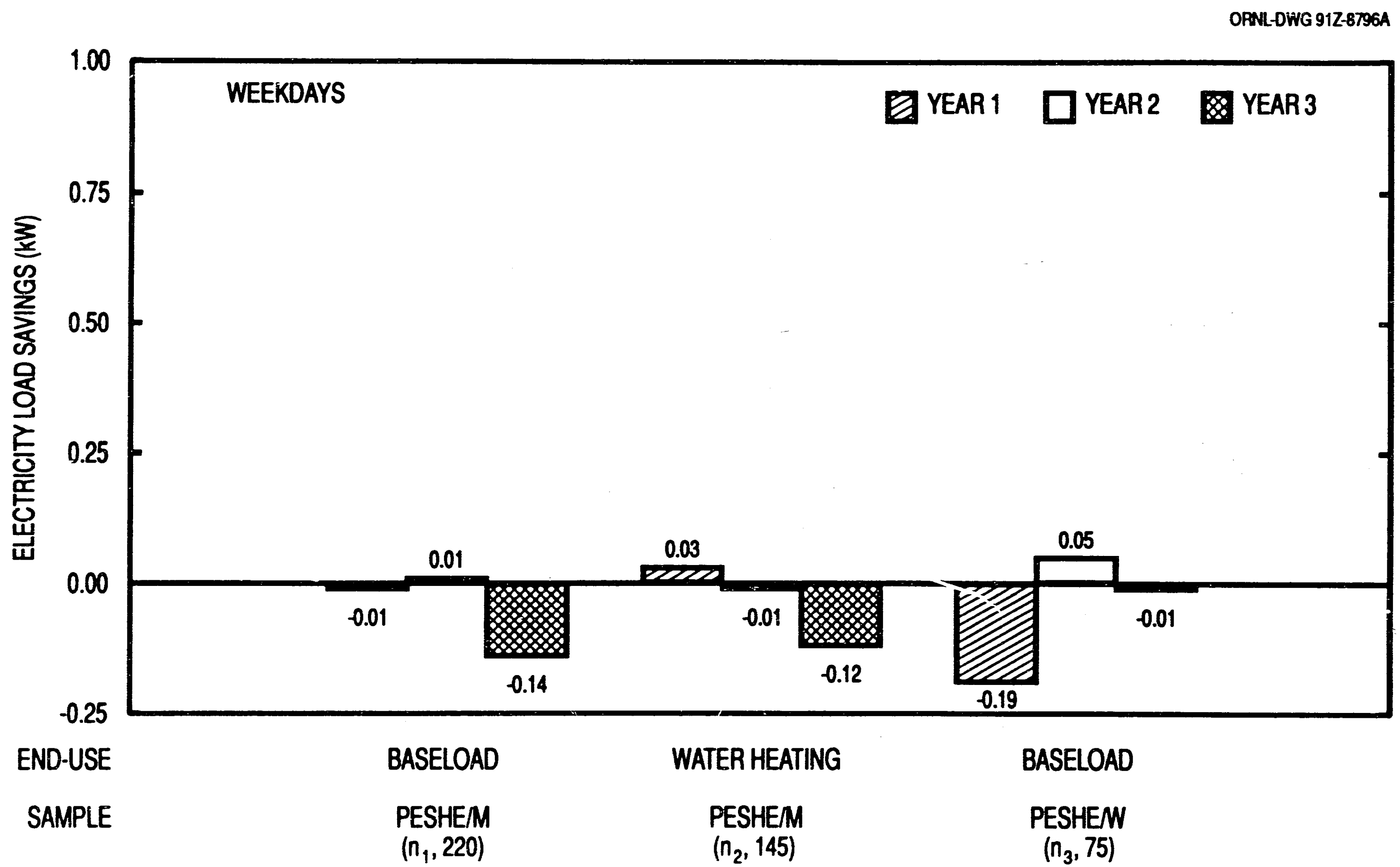

Fig. B-4. Baseload and water-heating electricity load savigs by sample, one, two, and three years after weatherization, weekdays.

ORNL-DWG 91Z-8797A

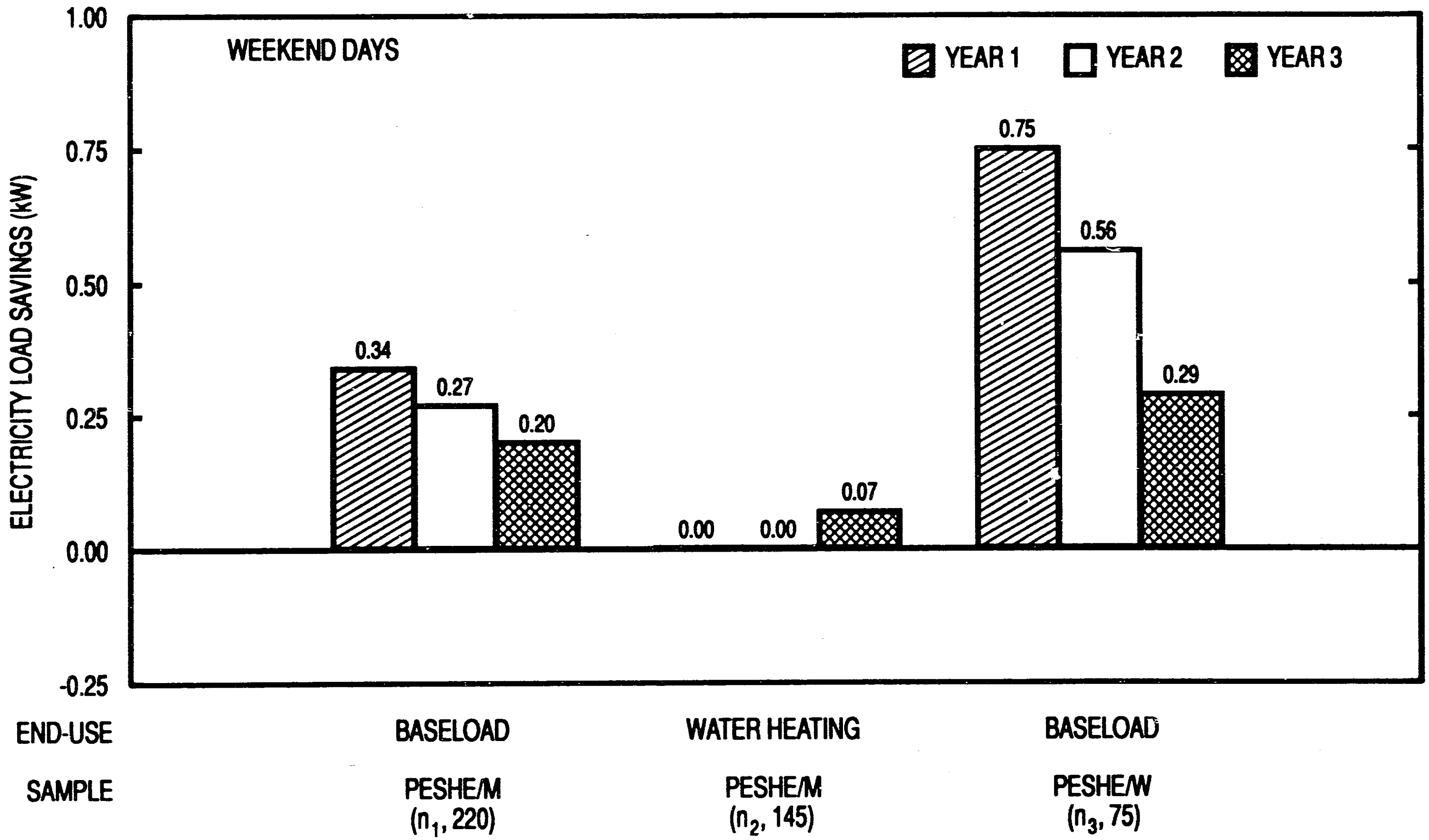

Fig. B-5. Baseload and water-heating electricity load savings by sample, one, two, and three years after weatherization, weekend days.

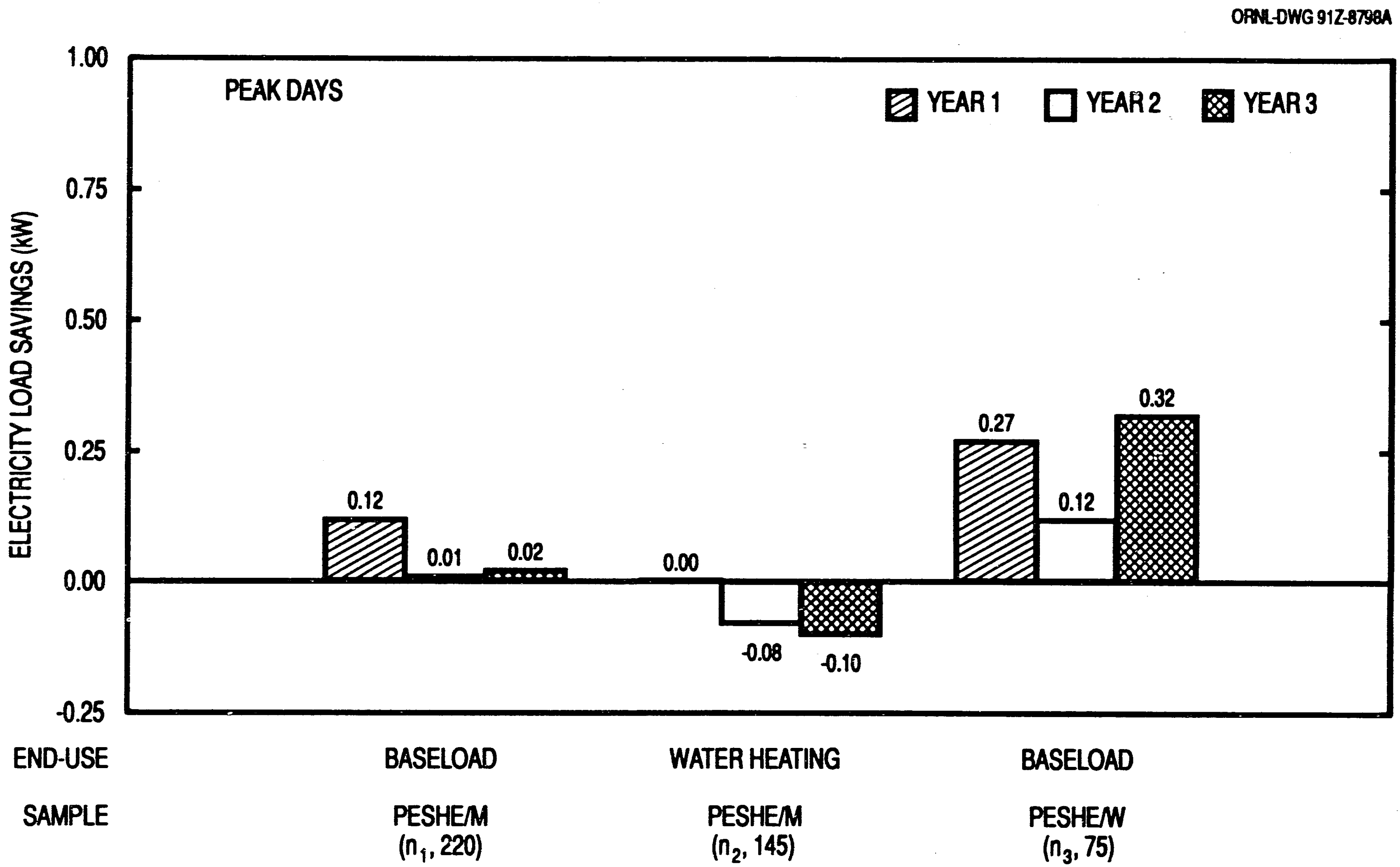

Fig. B-6. Baseload and water-heating electricity load savings by sample, one, two, and three years after weatherization, system peak days.

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