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Impact of the Hood River Conservation Project on Electricity Use for Residential Water Heating

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ENERGY DIVISION

IMPACT OF THE HOOD RIVER CONSERVATION PROJECT ON ELECTRICITY USE FOR RESIDENTIAL WATER HEATING

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EXECUTIVE SUMMARY

The Hood River Conservation Project (HRCP) was intended to test the reasonable upper limits of a residential retrofit program. It was proposed by the Natural Resources Defense Council, funded by the Bonneville Power Administration, and operated by Pacific Power and Light Company in the community of Hood River, Oregon. This three-year, $21M research and demonstration project installed as many cost-justified retrofit measures in as many electrically heated homes in Hood River as possible.

The retrofits were aimed at the building shell to reduce electricity use for space heating and at water-heater savings. Bonneville paid a vast majority of the total retrofit costs; 0.5% of this investment was for water-heater conservation. Three water-heater measures were installed based on auditor recommendations and the household's consent: water-heater wraps, five-foot pipe wraps, and low-flow showerheads. Some participants also had their hot-water temperatures lowered. No water-heater equipment was replaced.

This report evaluates the electricity savings and demand benefits of the HRCP water-heating retrofits. In addition, it attempts to estimate the benefits of each conservation measure and to assess the impact of varying household characteristics upon electricity savings.

Savings due to the water-heater retrofits are found to be both significant and consistent. Annual and daily water-heater usage curves after retrofit are consistently less than preretrofit usage. For the 182 households studied, the project resulted in first-year water-heater savings of 542 kWh or 8.4% of preretrofit usage. During typical winter days, daily water-heater energy requirements decreased by 1.9 kWh or 12.2%, significantly more than the average reduction for the rest of the year.

Fully one-fourth of the total electricity savings resulting from HRCP can be attributed to reductions in water-heater use. At the same time, the water-heater measures cost, on average, only $20 per household. Each kWh of water-heater savings during the first year after retrofit cost less than $0.04. This is less than the cost of purchasing one kWh of electricity from the utility, and therefore represents a payback period of less than one year.

Empirically estimated annual savings for each HRCP water-heater measure is compared in Table S-1 with predicted annual savings based on a review of the literature. Estimated annual savings of 714 kWh for each water-heater wrap, 232 kWh for each low-flow showerhead, and 0 kWh for pipe insulation suggest that savings were greater than expected for water-heater wraps, but less for the other two measures and for the package as a whole. Rewrapped water heaters were found to save as much electricity as the installation of water-heater wraps where no prior insulation existed.

Table S-1 Estimated and predicted annual water-heater energy savings, in kWh

	Estimated	Predicted[a]
Water-heater wrap	714	300-600
Low-flow showerhead	232	600-800
Pipe wrap	0	75
Total	946	975-1,475

[a]Based on a review of the literature.

A multiple regression model explained 44% of the household-by-household variation in annual water-heater savings. Savings were found to be greater for households with:

- greater preretrofit use of electricity for heating water;
- greater total electricity use;
- two or more showers;
- older water heaters;
- older homes;
- fewer household members;
- heavy wood use;
- higher incomes;
- mobile homes;
- higher preretrofit hot-water temperatures; and
- lower indoor temperatures after retrofit.

The winter load profile for water heating is characterized by a major peak in the morning (6:45 a.m. to 10:15 a.m.) and a minor peak in the early evening (7:00 p.m. to 10:00 p.m.). These peaks lag behind the space-heating and total household peaks in Hood River by 15 to 60 minutes. An extended quiescent period occurs between 1:30 a.m. and 5:00 a.m.

A duty cycle analysis based on 15-minute winter weekday data and the morning peak period defined as 6:45 a.m. through 10:15 a.m. provided insight into peak and off-peak savings. Before retrofit, the average customer's water heater was energized 14.5% of the time during winter; after retrofit the water heaters were energized only 13.1% of a typical winter weekday. During peak hours the duty cycle decreases from 23.7 to 21.6%, and during the quiescent period from 4.5 to 3.7%. Using the average water-heater size of 4.20 KW and the duty cycle savings, the following demand savings are estimated:

- .059 KW during average winter days;
- .088 KW on peak; and
- .034 KW during the quiescent period.

This represents a cost of $228 per KW which is significantly less than the capital costs associated with installing, transmitting, and distributing new generation. The estimate of .088 KW peak savings is corroborated by a comparison of load curves for winter (including weekends) and a peak of 8:00-9:00 a.m., which indicates peak savings of .061 KW at a cost of $329 per KW.

Duty cycle curves by conservation treatment showed that the largest savings are due to the water-heater wrap/low-flow showerhead combination, both on and off peak. This is followed by the water-heater wrap (with or without pipe insulation), then pipe insulation only, and lastly low-flow showerheads. Households with low-flow showerheads and no water-heater wrap actually increased their weekday usage during winter, suggesting that the showerheads were replaced or people took longer showers. The water-heater wrap, on the other hand, appears to save considerable energy on an annual basis (more than 700 kWh), and its savings on-peak (6:45 a.m to 10:15 a.m.) are greater than its savings off-peak (1:30 a.m. to 5:00 a.m.).

This report contributes significantly to assessing the demand and energy savings potential of water-heater retrofits. Not only does it detail the impacts of the water-heater conservation package as a whole, but it also estimates the conservation and demand benefits of specific retrofit measures, information that most program evaluations cannot offer. In particular, the report documents the cost effectiveness of water-heater wraps and the questionable effectiveness of low-flow showerheads and five-foot pipe wraps. It also identifies those segments of the customer population that contribute most to water-heater retrofit savings, and therefore provides insight for market segmentation strategies.

ABSTRACT

The Hood River Conservation Project (HRCP) was a two-year experiment in which residential customers were monitored for one year before and after the installation of conservation measures. Monitoring involved recording electricity use at 15-minute intervals for total consumption, space heat, and water heat. This report deals with the water-heater conservation results. The evaluation sought to: (1) determine electricity savings due to the installation of water-heater conservation measures; (2) quantify the savings attributable to each of the conservation measures (water-heater wrap, pipe wrap in the vicinity of the water heater, and low-flow showerheads); (3) quantify on- and off-peak savings; and (4) identify demographic and other determinants which correlate with savings.

Levels of pre- and postretrofit water-heater electricity use are compared on an annual, seasonal, daily, and time-of-day basis. Estimates of the peak and off-peak savings of individual conservation measures rely on a duty cycle analysis of the 15-minute monitored data. Survey information is used in a correlation and regression approach to relate savings to customer demographics. The principal findings are:

- Average annual electricity savings for water heating are 542 kWh during the first year after retrofit, or 8.4% of preretrofit water-heater use.
- Average winter electricity savings are 12.2% per household.
- One-fourth (26%) of the total electricity savings of HRCP are due to the water-heater conservation measures, while these measures cost only 0.5% ($20) of the average total cost per household.
- The cost for the water-heater savings is less than $0.04 per kWh, representing a payback period of less than one year.

- Water-heater demand decreased by .09 KW during winter weekdays; each KW of savings cost, on average, only $228.
- Most of the annual kWh savings are attributable to the water-heater wrap; it is estimated that each wrap saved, on average, 714 kWh.
- The best predictor of water-heater savings is the preretrofit level of water-heater electricity use.

1. INTRODUCTION AND BACKGROUND

1.1 OBJECTIVE

The objective of this report is to determine the level and type of impact that water-heater conservation measures have upon the electricity usage of households participating in the Hood River Conservation Project. In so doing, it seeks to quantify the electricity savings attributable to installation of the program's three water-heating conservation measures, estimate the load benefits of the measures, and identify demographic and other determinants of electricity use and savings.

Water heating is the second largest user of energy in the residential sector, estimated to account for almost 20% of total United States residential end-use energy consumption (EIA, 1985). Only space heating, which accounts for about half the total, consumes more energy.

Nationally, water heating is important to electric utilities for several reasons. First, a much larger percentage of residential customers use electricity for water heating than use electricity for space heating (32% vs 16% in 1982; EIA, 1984). Second, several low-cost measures are available to reduce energy usage for water heating. Third, because of their large storage capacity, residential water heaters are frequently the focus of utility load management programs.

Electric water heating is particularly important in the Pacific Northwest, where about 85% of the homes use electricity for water heating, and only 45% use electricity as the primary heating fuel (Bonneville, 1984). Analyses conducted by the Northwest Power Planning Council (NPPC, 1986) suggest that water heating accounted for 25% of total residential electricity usage in the Pacific Northwest during 1983, compared with 28% for space heating. The Council estimated the region-wide cost-effective potential to reduce electric power requirements for water heating at 514 MW. This represents 10% of the average residential electric load of 5,216 MW in 1983 and 39% of the 1,309 megawatts consumed for residential water heating. These savings estimates are based upon better-insulated water-heater tanks, pipe wraps (insulation on the hot and cold water pipes connected to the water heater), and more efficient appliances that use hot water. The Northwest Power Planning Council estimated that better-insulated water heaters, pipe wraps, and more efficient appliances that use hot water could save about 18% of water-heating loads in 2005 at a cost of 1.8 cents per kWh (NPPC, 1986, p. 6-6).

1.2 THE HOOD RIVER CONSERVATION PROJECT

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

The $20 million project 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 per first-year estimated kWh savings. Thus, HRCP offers the chance to examine levels of retrofit installation and subsequent energy savings when cost to the household and prior retrofit activities are largely removed as barriers. Additional information on the purposes, design, operation, and findings of HRCP are in the project's comprehensive final report (Hirst, 1987).

1.3 DETERMINANTS OF WATER-HEATING ELECTRICITY USAGE

Electricity is used for water heating in two ways: to heat water from its inlet temperature to the desired hot-water temperature for consumption (recovery) and to maintain the hot-water temperature at the desired level in the water-heater tank (standby losses). A. D. Little (1977) estimated that about 17% of the annual electricity use for residential water heating was to compensate for standby losses, implying an overall energy-efficiency of 83%. Hirst and Hoskins (1977) accounted for standby losses through distribution pipes and estimated an efficiency of 81% (14% lost through the jacket plus 5% through the pipes). Usibelli (1984) notes that the average efficiency of new electric water heaters remained nearly constant (at about 80%) between 1972 and 1980.

Electricity usage for hot-water consumption depends on the household's appliance holdings (e.g., clothes washer, dishwasher, and number of bathtubs vs showers), use of these appliances, and the difference between inlet and outlet water temperatures. Appliance holdings are influenced by household demographics including income and number of occupants. The design of appliances can also affect their hot-water consumption (e.g., water-saver cycles on washing machines, energy-efficient vs conventional water heaters). Appliance use (e.g., number of loads of laundry washed per week, showers per week, etc.) depends on season and on household characteristics, especially the number and ages of occupants. Finally, inlet water temperatures depend primarily on climate, while outlet temperatures are determined primarily by the household (through selection of the water-heater thermostat setting).

Standby losses depend on the physical characteristics of the water heater, its location, and the selected outlet temperature (which is also the "standby" temperature). A larger tank will increase the standby losses for a fixed level of insulation. More insulation on the tank and on the inlet and outlet pipes will reduce the standby losses. Standby losses are proportional to the difference between tank-water temperature and the ambient temperature around the water heater (which is a function of the water heater's location). Thus, tanks located in unheated basements, crawl spaces, or garages should have greater standby losses than similar tanks located in conditioned spaces inside the house.

1.4 PREVIOUS RESEARCH ON THE ENERGY-SAVINGS POTENTIAL OF CONSERVATION MEASURES FOR RESIDENTIAL WATER HEATING

Previous studies offer estimates of how much energy savings can be expected from the installation of electric water-heater wraps, pipe insulation, and low-flow showerheads--the three water-heater conservation measures installed as part of HRCP (Table 1.1). As this table illustrates, less performance information is available for pipe wraps and low-flow showerheads than for water-heater wraps.

The seven documents reviewed in Table 1.1 suggest that the annual kWh savings of water-heater wraps should be within the 300-600 range, while pipe wraps save considerably less--perhaps 75 kWh. Both the water-heater wrap and pipe wrap offer energy savings through reductions in standby losses. Assuming that 14% of the HRCP participant's annual electricity usage for residential water heating is lost through the water-heater jacket and 5% through the pipes, then 694 kWh and 248 kWh are the amounts lost by the Hood River sample, based on their consumption of 4,955 kWh for water heating during the preretrofit year. These values represent assumed maximum achievable electricity reductions.

Low-flow showerheads offer energy savings by reducing hot-water consumption and, therefore, recovery costs. If we assume that 81% of residential water-heating electricity use heats water for consumption, then 4,014 kWh is the average use for recovery purposes in the Hood River sample. Table 1.1

Table 1.1 Estimated annual savings for water-heating conservation measures, in kWh

	Water-heater wrap	Pipe wrap	Low-flow showerhead
Biemer[a]	574/192	69-78	--
Ek[b]	502-645	64-82	
	168-216	--	
Meier[c]	570	--	700
Perlman[d]	263-342	75	560
Philips et al.[e]	549	56	834
RCS model audit[f]	550	--	--
Usibelli[g]	460	--	--

[a]Biemer (1985). The upper estimate for the water-heater wrap assumes a conventional water heater, the lower estimate assumes an efficient water heater. The pipe wrap estimates are based on 15 feet of R-4 insulation wrapped around both the cold (inlet) and hot (outlet) pipes.

[b]Ek (1984). The upper range of estimates for the water-heater wraps refers to the average effect of an R-11 insulation blanket installed on a standard 52-gallon tank with temperature differentials of 70 and 90 degrees between the water and ambient air surrounding the tank. The lower range is for the wrap on an "energy-efficient" tank. The pipe wrap refers to 3/4-inch-thick tubular closed-cell insulation, and the range reflects the 70- to 90-degree differential.

[c]Meier (1986).

[d]Perlman (1987). The lower bound for the water-heater wrap assumes 50 mm of fiberglass on the sides and top. The upper bound assumes a thicker wrap of 75 mm. The pipe wrap is described as "short" lengths of fiberglass insulation. Perlman's estimates are based on an assumed annual water-heating energy consumption of 5,600 kWh per household.

[e]Philips, et al. (1987), p. 36.

[f]RCS assumes a 40-gallon tank.

[g]Usibelli (1984).

suggests that low-flow showerheads save anywhere from 600 to 800 kWh. This represents a significant portion of the total energy for recovery. These estimates are based primarily on assumptions about water temperatures and levels of water usage for showers. They are not derived from empirical data collected from a cross-section of households. Since the low-flow showerhead is highly vulnerable to tampering (i.e., removal) and behavioral "take back" effects (as when longer showers are taken to compensate for restricted water levels), the estimated savings presented in Table 1.1 are likely to be high.

Table 1.2 summarizes the estimated losses and savings discussed above. The savings are based on the assumption that each HRCP household had all three water-heater conservation measures installed, and that none of the households previously had any of the three measures. The total estimated savings is calculated by adding together the savings attributed to each of the three measures. The assumption of additivity is justifiable since the water-heater blanket and pipe wrap address different sources of standby losses, while the low-flow showerhead is supposed to reduce water usage and hence recovery costs. Altogether, the three measures are estimated to reduce the HRCP average water-heater usage of 4,955 kWh by 20 to 30%.

Table 1.2 Estimated energy losses and energy savings[a]

	Estimated losses	Estimated savings
Standby losses (19%)	941 kWh	
Water-heater jacket (14%)	694 kWh	300-600 kWh (6.1 - 12.1%)
Pipes (5%)	248 kWh	75 kWh (1.5%)
Consumption/recovery (81%) Low-flow showerhead	4014 kWh[b]	600-800 kWh (12.1-16.1%)
	Total:	975-1,475 kWh (19.7 - 29.7%)

[a]Based on the HRCP average water-heater usage of 4955 kWh. Numbers in parentheses are percentages of these averages.
[b]Electricity used for "recovery."

2. RESEARCH DESIGN

2.1 THE STUDY AREA

The town and county of Hood River, Oregon (plus the town of Mosier in Wasco County) were selected as the location for this "experiment" because the area is geographically delimited and diverse:

- it includes a diversified economy, population, and housing stock;
- the area is served by both public and private utilities [Hood River Electric Cooperative (HREC) and PP&L]; and
- it encompasses climate zones representative of the Pacific Northwest.

Hood River County has a population of about 15,000. Roughly two-thirds of the 6,200 residences are served by PP&L and the remainder by HREC. Hood River lies along the northern edge of Oregon by the Columbia River, 60 miles east of Portland.

2.2 THE HRCP WATER-HEATER CONSERVATION TREATMENT

As Table 2.1 illustrates, each of three water-heater conservation measures was installed in a majority of the households examined here. Compared with the HRCP homes as a whole, each was installed in a greater proportion of the monitored homes. In some instances, previously installed low-flow showerheads, shower restrictors, water-heater wraps, or pipe insulation were replaced with new materials.

In addition to these three measures, hot-water temperatures were also reduced in many homes. If a house contained a dishwasher, as was true for three-fourths of the monitored customers, hot-water temperatures were reduced to 140°F. Otherwise, temperatures were lowered to 120°F. This setback occurred at the same time that the other measures were installed. Based on hot-water temperatures and dishwashers owned at the time of the audit, 30% of the customers were eligible for a temperature setback. Unfortunately, records

Table 2.1 Frequency of installation of water-heating conservation measures

	Percent of submetered homes in which measure was installed[a]	Percent of audited homes for HRCP as a whole	Mean quantity per home	Mean cost per measure ($)
Water-heater wrap[b]	50	48	1.03[d]	20
Pipe wrap[c]	76	58	5.0 ft.	5
Low-flow showerhead	64	58	1.43[d]	9

[a]These percentages are based on a sample of 218 homes.
[b]Electric water-heater wrap (R-11).
[c]Five feet of inlet (cold) and outlet (hot) water pipes wrapped with R-3 insulation.
[d]Some houses have more than one water heater, and many have more than one shower. These are mean values for homes in which the measure was installed.

were not kept on exactly which households were both eligible and willing to have their hot-water temperatures set back. It is also not known how temperatures were adjusted (i.e., whether or not tap temperatures were checked to verify thermostat settings). Therefore, it is not possible to estimate the energy savings, if any, achieved by the setback.

All of the water-heater conservation measures are inexpensive, particularly compared with the average cost of installing other retrofit measures. The average cost of retrofitting an HRCP home was $3760. The mean cost per home for installing a water-heater wrap was $20, for installing pipe insulation it was $5, and for a low-flow showerhead it was $9. The temperature setback is considered to be cost free. The average cost of installing the water-heating conservation measures, per monitored household, was only $20.05.

The cost of the pipe wrap is low because it was placed on only the first five feet of inlet (cold) and outlet (hot) pipe. The wrap, therefore, can be viewed as an extension of the water-heater wrap, reducing conduction losses from the tank, rather than distribution losses.

The cost of the water-heater measures represents the incremental costs of installing the measures in a home that is participating in a larger conservation package. Costs would be greater if the entire expense of visiting a customer was attributed to the water-heater retrofit. Frequently the water-heater treatment does accompany an energy audit or other weatherization work. Thus, the $20.05 cost seems reasonable.

2.3 DATA SOURCES

Because HRCP was viewed primarily as a research and demonstration project, considerable time and attention were devoted to establishing extensive data collection systems.

The data available for analysis of HRCP include detailed information on participating households, including information on their homes and the appliances therein, demographic characteristics, the retrofit measures recommended and installed, and the dates of participation (audit, beginning of retrofit installation, completion of retrofits). The Appendix in Philips et al. (1987) includes the HRCP data collection forms.

Detailed electricity end-use data were obtained from 319 participant homes in Hood River. Information on total and space-heating electricity usage, as well as indoor temperatures, were collected at 15-minute intervals in these homes, from mid-1984 through mid-1986. Only 219 homes were metered with a water-heater channel.[1] Wood heat sensors were used in the remaining 100 homes.

Detailed weather data, including outdoor ambient temperatures (recorded at 15-minute intervals), were obtained from three weather stations in Hood River County. Ground temperatures at three depths: 4 inches, 20 inches, and 40 inches are available for only one of these stations. As a result, a decision was made to use both the outdoor and ground temperature data from that one weather station for the entire sample.

2.4 TIME-LINE OF THE EVALUATION

Each household that participated in HRCP received an energy audit before participation. This audit estimated savings for each of the eligible conservation measures. Some measures--including the low-cost, water-heating measures--were typically installed during the audit. However, 209 of the 219 households selected for submetering were scheduled for all retrofit work to be done during the summer of 1985 (Fig. 2.1), thereby providing HRCP evaluators with one year of preretrofit submetered data (July 1984 through June 1985) and one year of postretrofit submetered data (July 1985 through June 1986).

Information collected during the audit included demographic and structure characteristics and other variables, including reasons for participation and sources of information about HRCP. Follow-on inspections were conducted after retrofit work was completed, to collect information primarily about the measures installed.

Data from submetering/monitoring devices were collected from each of the 219 water-heating, load-metered households on a 15-minute basis for the period July 1984 through June 1986.

Each of the monitored homes also received the Pacific Northwest Residential Energy Survey administered during Spring 1984. Many demographic and housing questions asked by interviewers during this on-site survey paralleled questions asked by auditors. Consequently, missing data

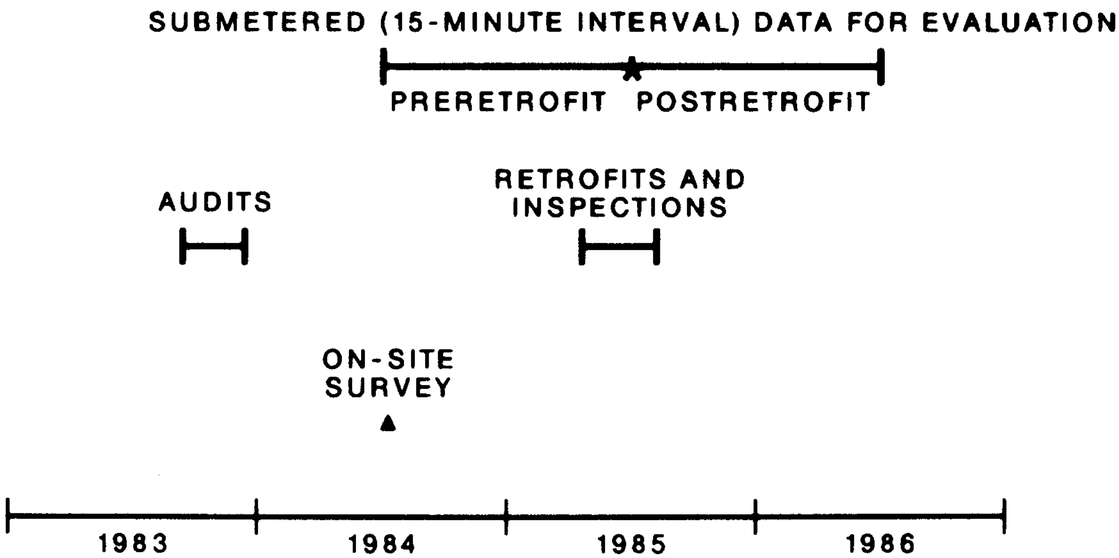

Fig. 2.1 Time-line of the HRCP water-heating evaluation.

values from one survey were frequently filled in by information from this second survey. [Tonn and White (1987) demonstrate that the quality of these complementary data sources supports the replacement of missing data values from one source with nonmissing data values from the other.]

2.5 THE SAMPLE

Only 182 of the 219 HRCP households with monitored water-heater usage are retained for analysis here. Table 2.2 lists the criteria for deletion that were applied to the monitored households. Households that had moved in or out since July 1984 or that had water-heating measures installed at the time of the audit were removed from the database. Data quality screening led to the removal of additional households for the following reasons:

- one or more years of monitored electricity data missing
- multiple water heaters, not all of which were submetered
- nonelectric water heating
- unclear assignment of electricity data associated with multi-metered accounts
- major remodelling of the house in addition to HRCP weatherization.

As a result, 37 of the 219 households are unavailable for the water-heating analysis.

Table 2.2 Summary of sample attrition

Reasons for attrition:	N of cases
Household moved since July 1984	15
Water-heating measures installed at time of audit (1983)	10[a]
One or more years of electricity data missing	6
Building with two water heaters, but only one is metered	2
Fuel oil or solar water heater	2
Multimetered building with unclear assignment of electricity data	1
Major remodelling during study period	1
Total	37

[a]In the duty cycle analysis (section 4.2), these households are included in the "no retrofit" group.

The 182 households retained for further analysis were compared with a random sample of 1,026 electric-space heating residents of Hood River (both PP&L and HREC customers) in order to evaluate their representativeness. The two samples are similar in most respects, but significant differences do exist. In particular, the 182 households:

- had more low-flow showerheads installed as part of HRCP (1.43 vs 1.31)
- are more frequently homeowners (88% vs 76%)
- have more showers (1.50 vs 1.36)
- have higher incomes ($25,800 vs $23,200)
- live in newer homes (20.7 vs 26.6 years)

These differences portray the 182 end-use metering participants as slightly more "up-scale" than the population of households from which they were selected. This difference is typical of conservation programs where "self selection" biases tend to result in more up-scale participants (Berry, 1986).

2.6 ANALYSIS PLAN

Several approaches are used to determine the impact of HRCP on the electricity used for water heating. First, correlates of electricity consumption before and after retrofit are identified. Second, correlates of electricity savings are analyzed to determine household variations in the program's impacts on conservation. Third, the magnitude and correlates of demand savings are examined. Thus, there are three types of dependent variables:

- pre- and postretrofit electricity consumption for water heating;
- water-heater electricity savings (preretrofit minus postretrofit consumption); and
- demand savings.

These dependent variables are analyzed at various time intervals: quarter-hour, hour, day, week, season, and year. The focus here is primarily on electricity savings and demand benefits, since Hirst, Goeltz, and Hubbard (1987) have previously examined energy consumption of the monitored HRCP households during the preretrofit period.

A variety of independent variables are examined as possible predictors of water-heating electricity usage and savings. These are grouped into four categories related to: (1) conservation treatment; (2) household appliance characteristics; (3) household and dwelling unit variables; and (4) relevant temperatures (Table 2.3).

These four categories are not mutually exclusive. For instance, a household's hot-water temperature at the time of the audit is classified as a temperature variable. Yet, it also can be seen as an appliance characteristic or a behavioral variable. The four categories are simply a convenient mode of examining four different types of influences upon water-heater electricity usage and savings.

Table 2.3 Explanatory variables

Water-heater conservation treatment:

- installation of a water-heater insulation blanket (0,1)
- installation of insulation on exposed pipe up to 5 ft. (0,1)
- installation of low-flow showerheads (number: 0,1,2,3) (number of low-flow showerheads installed/number of showers)
- number of water-heater conservation measures installed by HRCP (0,1,2,3)

Household appliance characteristics:

- number of showers in the home at time of audit
- low-flow showerheads/restrictors at time of audit (number: 0,1,2,3) (number of low-flow showerheads and restrictors/number of showers)
- dishwasher (0,1)
- washing machine (0,1)
- age of water heater, in years
- water-heater wrap already installed at time of audit (0,1)

Household and dwelling unit variables:

- preretrofit normalized annual consumption of electricity (NAC)
- home at least half-time during normal working hours (0,1)
- number of years in residence
- age of building in years
- number of household members, by age (years)
- combined 1982 income in 1982 dollars
- budget billing (0,1)
- education of respondent in years
- wood user (0,1)
- housing type (mobile home vs other)
- square feet of floor insulation added by HRCP
- estimated savings from HRCP floor insulation
- estimated/recommended savings from HRCP floor insulation
- house size (square feet of floor area)
- index reflecting the extent that the energy efficiency of the dwelling unit's shell was improved by HRCP[a]

Table 2.3 Explanatory variables (cont.)

Temperatures:

- water-heater location--unheated vs heated space
- hot-water temperature at time of audit (1)
- indoor temperature during peak hot-water use period (2)
- change in average indoor temperature[b]
- outdoor temperature during peak hot-water use period (3)[c]
- temperature gradient index[d]
- ground water temperatures at 4", 20", and 40" during peak hot-water use period[c]

[a]Index = $[(1-wxneed_{post}) - (1-wxneed_{pre})]/(1-wxneed_{pre})$ where:

$wxneed_{pre}$ is the amount of kWh savings achievable through weatherization at the time of the audit divided by the household's preretrofit NAC, and $wxneed_{post}$ is the amount of kWh savings still achievable after HRCP (based on audit recommendations that were not implemented) divided by the household's postretrofit NAC.

[b]Based upon daily mean values of measured, submetered data. Daily mean values were then averaged over the pre- and postretrofit years in order to obtain one value to reflect the average indoor temperature for 1984/86. Change is calculated by substracting the postretrofit value from the preretrofit value.

[c]Outdoor and ground water temperatures do not vary across households and are therefore not examined in relation to household variations in energy savings.

[d]If water heater is in a heated space,
Index = (1) - (2)

If water heater is in an unheated space,
Index = (1) - [(2) + (3)] / 2

3. COST EFFECTIVENESS: ELECTRICITY USE AND SAVINGS

3.1 COST EFFECTIVENESS OF THE WATER-HEATER CONSERVATION TREATMENT

The average annual electricity use for water heating among the 182 households studied here was 4,955 kWh before retrofit and 4,367 kWh afterwards (Table 3.1). In comparison, the average consumption for households in Bonneville's weather zones 1 and 2 is 4,750 and 5,450 kWh, respectively. Hood River's weather is comparable to these two zones as was its water-heater electricity usage before retrofit (Bamberger, et al., 1987).

Both before and after retrofit, water-heater usage represented approximately 24% of total electricity use for the 182 Hood River households. This share is similar to the 25% estimate for the Pacific Northwest as a whole (NPPC, 1986).

Table 3.1 Levels of annual electricity usage[a]

	1984/85		1985/86	
	Mean	Standard deviation	Mean	Standard deviation
Space heating	7,908	5,540	6,145	4,556
Water heating	4,955	2,279	4,367	2,096
Base load	7,753	3,559	7,805	1,731
Total	20,578	7,060	18,480	6,134

[a]Each of these mean values is based on the subset of the 182 households for which data are available. Since the sample sizes differ across the years, the savings estimates shown in Table 3.2 do not equal the differences between these pre- and postretrofit means. Also the total consumption is not simply the sum of the usage for the three separate end-uses.

The difference between pre- and postretrofit annual electricity usage for water heating is 542 kWh, or almost 8.4% of preretrofit use (Table 3.2). At the same time, space heating under HRCP was reduced by 1,752 kWh (or 23.9%), based on the "raw" consumption data. When pre- and postretrofit differences in weather are controlled through the PRISM model, space heat savings are estimated to be 2600 kWh or 15% (Hirst, 1987). Base-load usage essentially remained constant. (The increase of 82 kWh shown in Table 3.2 is not significant.)

Fully one-fourth of the total energy savings resulting from HRCP (542 of 2,105 kWh) can be attributed to reductions in water-heater electricity use. At the same time, the water-heater measures cost, on average, only $20 per household compared with the average cost of the total conservation package--$3760 ($4400 including administrative costs). Each kWh of water-heater savings during the first year after retrofit cost less than $0.04. This is less than the cost of purchasing one kWh of electricity from the utility, and therefore represents a payback period of less than one year.

Table 3.2 Levels of electricity savings[a,b]

	kWh savings		Percent savings		
	Mean	Standard error	Mean	Standard error	Retrofit costs
Space heating	1,752	235	23.9	5.7	$3740
Water heating	542	86	8.4	2.4	$20
Base load	-82	134	-3.2	1.7	0
Total	2,105	4,142	8.1	0.18	$3760

[a]Entries in this table are mean values of variables measured at the household level. For example, percent savings is the kWh savings divided by the preretrofit electricity usage, calculated for each household and then averaged. Thus, the values differ from aggregate calculations of percent savings based upon the mean kWh savings and the mean preretrofit use. Numbers of cases also vary across variables due to missing information.

[b]These estimates are actual meter readings without weather adjustment.

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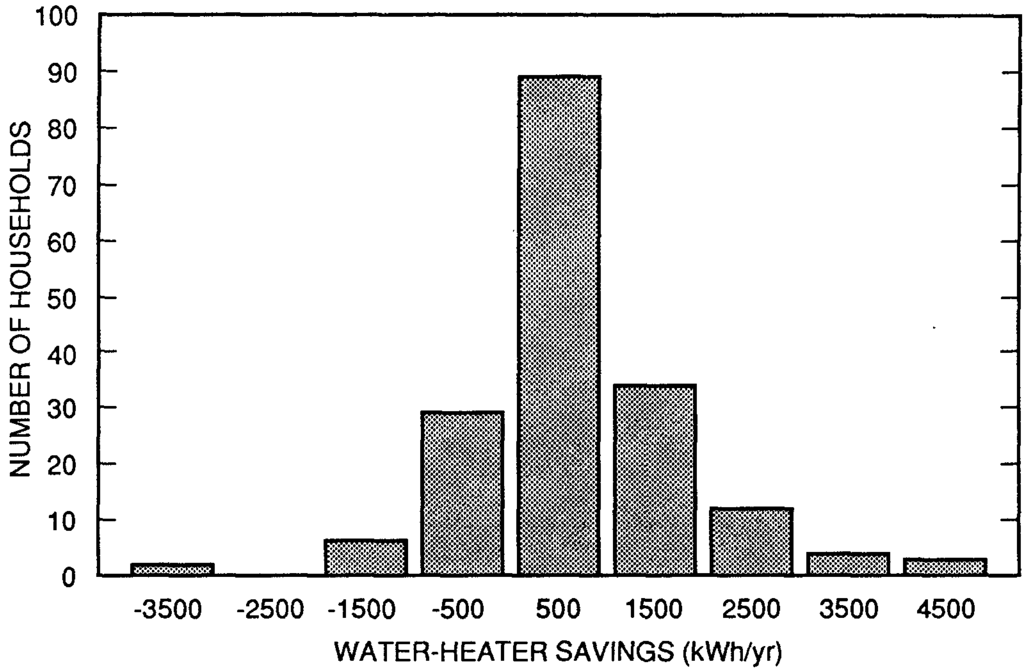

Fig. 3.1 Histogram of the distribution of water-heater savings among 182 HRCP homes.

There is widespread variation in the level of water-heating energy savings across the 182 households studied here (Figure 3.1) Sections 5 and 6 identify some of the variables which help explain this variation.

Analysis of the before and after daily load shapes indicates that water-heating demand (coincident with household peak) can be reduced during the winter by 0.06 KW (6.1%) by investing approximately $20.05 per household. The demand cost can alternatively be represented as $338/KW, which is less than capital costs associated with installing new generation. During typical winter days (see Section 3.3 for a discussion of the sampling of winter days), daily water-heater energy requirements can be reduced by 1.9 kWh, or 12.2% which is more than the 8.4% reduction achieved on average throughout the year.

3.2 SAVINGS ATTRIBUTABLE TO EACH WATER-HEATING CONSERVATION MEASURE

Table 3.3 breaks out the average water-heating electricity usage and savings according to the nature of the water-heater conservation treatment completed for each household. It suggests that installation of the full complement of water-heater conservation devices saves the household 935 kWh per year, or 17% of their water-heating electricity usage. This estimate is lower than the 20 to 30% range developed in Table 1.2 based on previous research.

Table 3.3 Water-heating electricity usage and savings, by type of conservation treatment[a]

	Electricity usage (kWh/year)		kWh	Percent
	1984/85	1985/86	change	change
Number of water-heating conservation measures installed by HRCP				
0 (N=17)	4,930**	4,701	229***	2.8**
1 or 2 (N=102)	4,422	4,053	300	3.9
3 (N=63)	5,830	4,782	935	17.2
Water-heater wrapped by HRCP				
0 (N=86)	4,486**	4,280	122***	0.0***
1 (N=95)	5,384	4,446	923	16.6
Pipes wrapped by HRCP				
0 (N=39)	4,810	4,476	149**	3.0*
1 (N=142)	4,995	4,338	649	9.9
Low-flow showerheads installed by HRCP				
0 (N=60)	4,424*	4,068	357	3.8
1 (N=121)	5,220	4,516	636	10.7

*Means are significantly different at $\alpha=.05$; ** at $\alpha=.01$; *** at $\alpha=.001$. Comparisons are made down each column (e.g., comparing "percent change" across 0, 1 or 2, and 3 measures).

[a]Entries in this table are mean values of variables measured at the household level. For example, percent change is the kWh change divided by the preretrofit electricity usage, calculated for each household and then averaged. Thus, the values differ from aggregate calculations of percent change based upon the mean kWh change and the mean preretrofit use. Numbers of cases also vary across variables due to missing information.

The 17 households that had no water-heater conservation measures installed also saved electricity for water heating--229 kWh or 3%. If these households were used as a control group, the estimate of 17% savings attributable to the three measures would have to be reduced to account for a general reduction of electricity use among the population at large. Due to the smallness of this "control group," however, and the fact that it was not randomly selected, such an adjustment was not made.

Since households frequently received more than one water-heater conservation measure through HRCP, the savings associated with each of the measures is not easily determined. The pipe wrap is particularly problematic because it was almost always installed in association with either the water-heater wrap or the low-flow showerhead (Table 3.4).

Table 3.4 Simple correlations between installation of the three water-heater conservation measures

	Water-heater wrap	Pipe wrap	Low-flow showerhead
Water-heater wrap	--	0.40***	0.05
Pipe wrap	0.40***	--	0.19**
Low-flow showerhead	0.05	0.19**	--

*, **, and *** indicate that correlation coefficients are significantly different from zero at the .05, .01, and .001 levels of confidence, respectively.

Table 3.5 documents the savings attributable to each of the various combinations of conservation measures. The three most common combinations are: (1) all three measures; (2) the water-heater and pipe wrap; and (3) the pipe wrap and low-flow showerhead. Using these three combinations in a simultaneous equations format results in the following:

Table 3.5 Water-heating electricity usage and savings, by type of conservation treatment[a]

Water-heater wrap	Pipe wrap	Low-flow shower-head		Electricity usage (kWh/year) 1984/85	1985/86	kWh change	Percent change
Yes	Yes	Yes	(N=63)	5,830	4,782	1,020	17.2
Yes	Yes	No	(N=26)	4,693	3,949	745	15.7
Yes	No	Yes	(N=3)	5,392	4,249	1,143	18.5
Yes	No	No	(N=3)	2,146	1,903	244	10.5
No	Yes	Yes	(N=39)	4,299	4,006	293	4.4
No	Yes	No	(N=14)	3,799	3,984	-184	-18.3
No	No	Yes	(N=17)	5,072	4,763	-160	-1.3
No	No	No	(N=17)	4,930	4,701	229	2.8

[a]Entries in this table are mean values of variables measured at the household level. For example, percent change is the kWh change divided by the preretrofit electricity usage, calculated for each household and then averaged. Thus, the values differ from aggregate calculations of percent change based upon the mean kWh change and the mean preretrofit use. Numbers of cases also vary across variables due to missing information.

$$A + B + C = 1{,}020 \text{ kWh}$$

$$A + B = 745 \text{ kWh}$$

$$B + C = 293 \text{ kWh}$$

where:

A = water-heater wrap;
B = pipe wrap; and
C = low-flow showerhead.

These equations solve with the following values:

A = 727 kWh;
B = 18 kWh; and
C = 275 kWh.

Thus, it appears as though the water-heater wrap saves considerably more than the low-flow showerhead, and that the pipe wrap saves very little. This assessment will be reexamined in Section 6 where the possible influences of other variables such as household size and appliance stock are taken into account.

In keeping with the HRCP goal to install conservation measures up to a generous cost-effectiveness limit of $1.15/first-year estimated kWh savings, many water-heating conservation measures which existed at the time of the audit were replaced by new measures as part of HRCP. This type of conservation treatment is referred to here as a "retrofit" to distinguish it from the installation of new measures where none previously existed. Data are available on the existence of water-heater insulation and low-flow showerheads/restrictors at the time of the audit. Thus, it is possible to determine whether or not these HRCP installations are retrofits or new installations. Information on the prior existence of pipe insulation is unknown. Presumably, some of the 40 households which did not have their pipes wrapped by HRCP already had pipe insulation, but we have no specific data to verify this.

Figure 3.2 presents the annual kWh savings for four categories of households based on: (1) whether or not they had a water-heater wrap at the time of the audit, and (2) whether or not they had a water-heater wrap installed by HRCP. It indicates that considerable savings might be achieved by replacing old water-heater insulation. The 19 households with water-heater wrap retrofits consumed 1,224 kWh less during the postretrofit year compared with the preretrofit year. The 76 households with new water-heater wraps saved slightly less--846 kWh per year, but the difference is not statistically significant. The retrofits may have been as effective as the new wraps for a number of reasons. First, water heaters with prior wraps were less frequently located in heated areas (32% compared to 61% without prior wraps). Second, 58% of the prior wraps were at least five years old at the time of HRCP retrofit.

It is suspected that insulation installed five years ago is less effective than the materials and techniques used today, and there may also have been some deterioration in the insulation's performance over time.

Not all of the savings shown in Figure 3.2 can be attributed to the water-heater wrap. The vast majority (94%) of those households whose water heaters were wrapped by HRCP also had pipe insulation installed as part of their conservation package, and there is a similar coincidence between low-flow showerheads and pipe insulation. This pattern of multiple incidence is similar for the retrofit and new water-heater wraps.

		Water heater wrapped at the time of the audit: No	Water heater wrapped at the time of the audit: Yes
Water heater wrapped by HRCP	No	-44 kWh (s.d.=1,141) N=47	327 kWh (s.d.=861) N=38
	Yes	846 kWh (s.d.=1,028) N=76	1,224 kWh (s.d.=1,423) N=19

Fig. 3.2 Average water-heating electricity savings of households with no water-heater wrap, old, new, and retrofit wraps. ("s.d." refers to standard deviation.)

4. DAILY LOAD PATTERNS AND DUTY CYCLE ANALYSIS

4.1 DAILY LOAD PATTERNS DURING WINTER

An analysis of daily load patterns was conducted to show the impacts of the HRCP conservation treatment on daily load profiles and to compare water-heater load curves with those of other end-uses. The analysis is not intended to be the authoritative work on total household or space-heating demand effects of HRCP, since this is analyzed elsewhere using the full sample of 320 monitored households (Stovall, 1987).

Our analysis of daily load patterns is based on the subset of 182 customers described in section 2.5, and the 28 similar winter days selected by Stovall (1987). Winter days are of interest because the Pacific Northwest is a winter-peaking region. These 28 days include weekdays and weekends over a range of temperatures that are representative of the entire winter season. The intent of the 28 similar winter days is to normalize the loads for temperature, thus removing temperature as a variable. The load shapes for each winter season can then be compared. The sampling also reduces the analysis to a more manageable scale compared with the formidable task of processing several winter months of hourly and 15-minute data for the two seasons.

Figure 4.1 displays the pre- and postretrofit diversified household load profiles, and the daily pattern of savings, for total, water-heating, space-heating, and base load usage. Pre- and postretrofit winter load shapes are shown to be very similar, increasing our confidence that the winter seasons have been normalized with respect to weather. Figure 4.1 shows how the various end-uses compare in terms of the coincidence of peak consumption and savings across end-uses. Of note is the fact that the water-heating peak

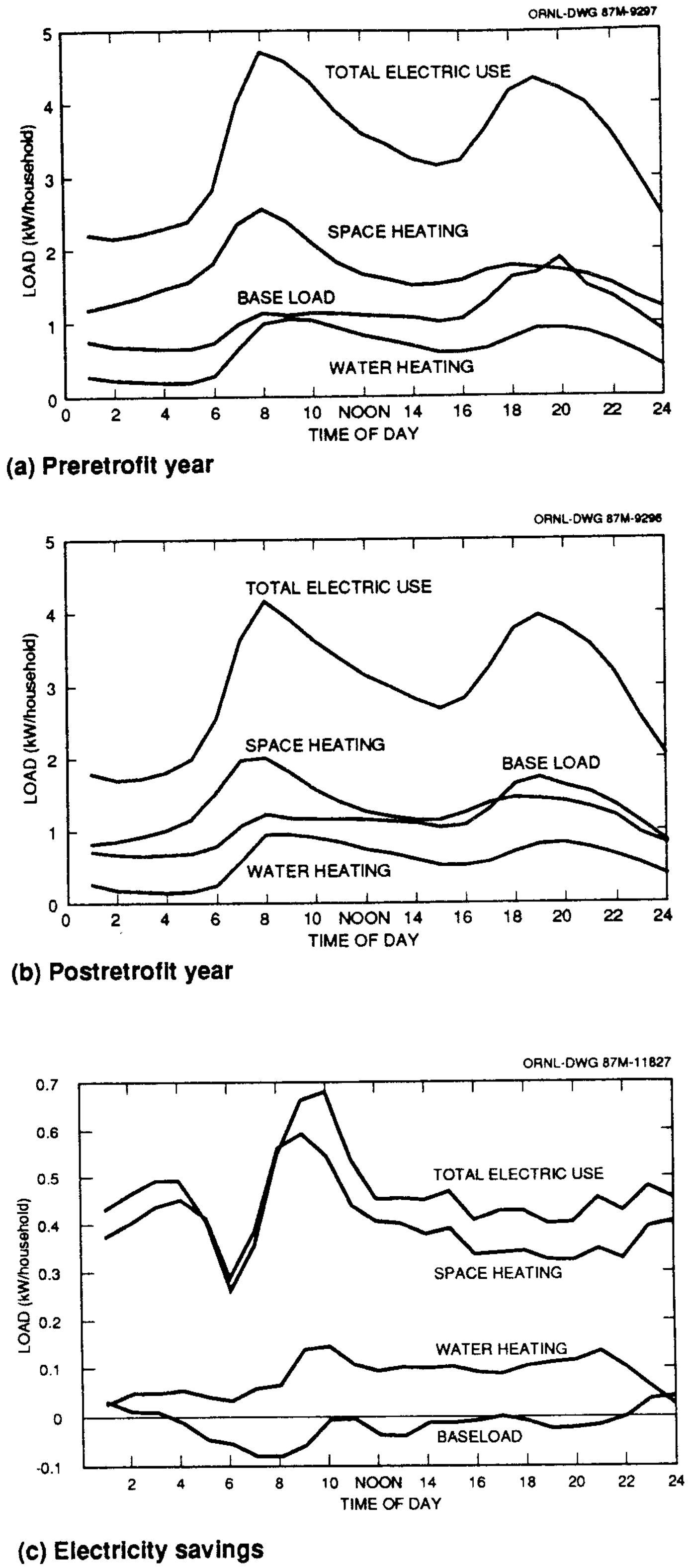

Fig. 4.1 Diversified household daily load shapes and savings, based on 28 similar winter days.

occurs 15 to 60 minutes after the space-heating and total residential peaks, reflecting the water heater's lagged response to usage. Space and water heating appear to drive the morning household peak whereas base load and, to a lesser extent, water and space heat drive the evening peak.

Figure 4.2 presents the water-heating electricity consumption before and after participation in HRCP. It also compares these with the diversified demand of water heaters during winter months in Wisconsin and North Carolina based on studies by Bischke and Sella (1985) and Lee and Wilkens (1983). All three curves indicate an early morning peak in diversified water-heater demand, and a secondary peak in the early evening. The Wisconsin study suggests a more gradual load buildup in the morning than is the case in Hood River or North Carolina. It also shows an evening peak of almost comparable magnitude to the morning peak. The North Carolina pattern, on the other hand, is almost identical to the diversified water-heater load for Hood River.

For the 182 customers examined here, HRCP resulted in an approximate residential peak reduction of .54 KW and an average hourly reduction of 0.46 KW per monitored water-heater customer. Savings are consistently positive and loosely track the residential load level for all but the base load end-use. The lowest KW savings occur at 6:00 a.m., when household members are waking--turning the heat up and taking showers (Fig. 4.1c). The highest KW savings occur 1 to 2 hours after the 8:00 a.m. residential peak.

The water-heater conservation measures generated a 6.1% (0.06 KW) residential peak demand savings, where the peak hour is defined as 8:00-9:00 a.m. (Table 4.1). On an average hourly basis the reduction is 0.08 KW per monitored customer. HRCP resulted in a much greater space-heating peak

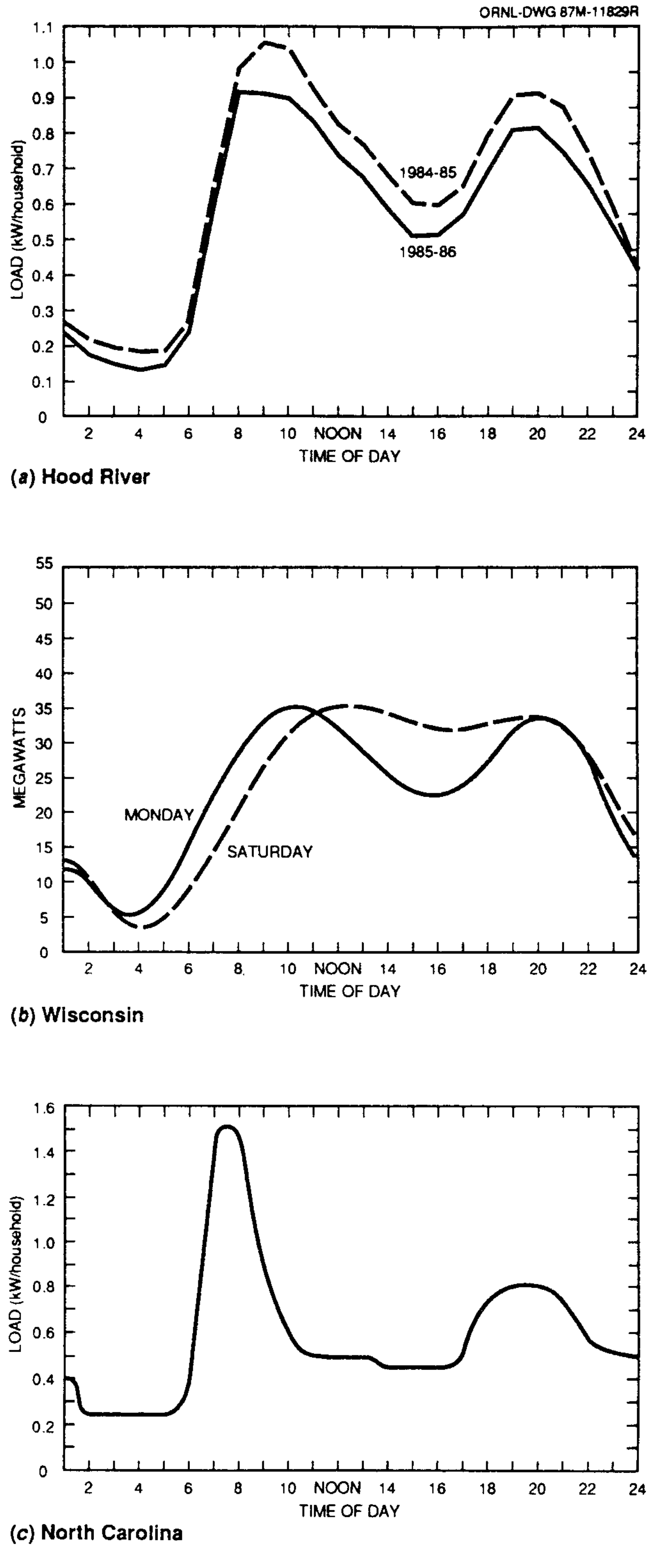

Fig. 4.2 Daily diversified water-heater demand in winter in Hood River, Wisconsin, and North Carolina.

Table 4.1 Demand and energy savings associated with 28 similar winter days

Average household load	Demand (KW)[a]				Daily energy (kWh)			
	Before[b]	After[c]	Savings	Percent savings	Before[a]	After[b]	Savings	Percent savings
Space heating	2.57	2.01	0.56	21.8	40.4	3.8	9.5	23.6
Water heating	0.99	0.93	0.06	6.1	15.3	13.4	1.9	12.2
Base load	1.14	1.22	-0.08	-7.0	25.9	26.4	-0.5	-1.8
Total	4.69	4.15	0.54	11.5	81.6	70.7	10.9	13.4

[a]The peak hour is defined to be 8:00 a.m.
[b]1984/85 winter.
[c]1985/86 winter.

reduction (0.56 KW) and an average hourly reduction of 0.40 KW per customer during the winter. The peak demand for base load is actually greater after participation in HRCP.

The water-heater conservation measures generated 12.2% energy savings per customer during winter (Table 4.1). This is slightly more than the 8.4% savings calculated on an annual basis (Table 3.2). Since space-heat savings are also much greater during winter, water-heater savings represent only 17% (1.9 of 10.9 kWh) of the winter-time daily savings for HRCP. Recall that on an annual basis, water-heater savings are 26% of the total savings.

Figure 4.3 provides histograms of percent energy savings for water heating, detailed by hour. For example, the percent saving for 8:00 a.m. is calculated as the savings of kWh during each one-hour period divided by the preretrofit usage for the same hour. It views the savings in terms of a behaviorally-driven pattern, where allowances are made for water-heater recovery:

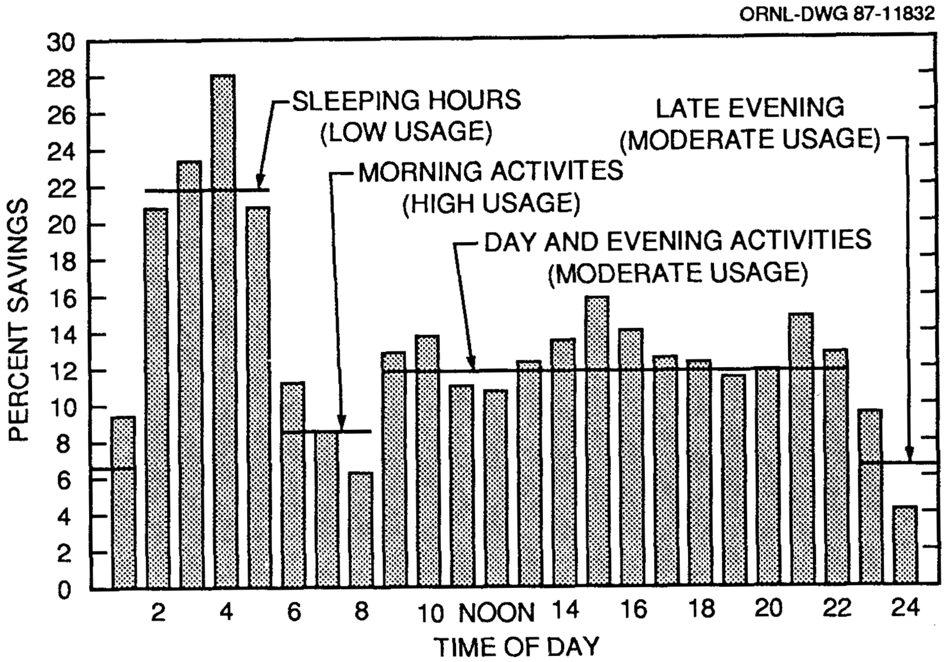

Fig. 4.3 Percent water-heater savings by hour, based on 28 similar winter days.

- Hours 2-5 represent sleeping hours during which percent savings are substantial presumably because of the installation of water heater and pipe wraps;
- Hours 6-8 represent normal morning activities (e.g., showering) resulting in high (coincident) usage and low percent savings;
- Hours 9-22 represent normal day and evening hours during which usage and savings are moderate; and
- Hours 23-24 and 1 represent late evening activities such as showers, dishwashers and water-heater recovery. Usage is moderate to low, as are savings.

4.2 DUTY CYCLE ANALYSIS

The duty cycle analysis is based on a different sample of customers than was used in the rest of the report, due to the finer level of data being employed (i.e., 15-minute data). The screening criteria are discussed in the Methodology section below. Additionally, only non-holiday weekdays are used, in order to focus more precisely on peak periods. This reduces the number of similar pairs of winter days from 28 to 17.

4.2.1 Methodology

For the duty cycle analysis, customers were divided into six categories (Table 4.2). "All customers," as the title implies, includes all customers without regard to conservation treatment. At the other extreme, the "no retrofit" group includes the 23 customers that did not have water-heater wraps, pipe wraps, or low-flow showerheads installed by HRCP. Earlier findings concluded that pipe wraps had little or no impact; thus, the groups between these extremes exemplify differences caused by the water-heater wrap and low-flow showerheads. For instance, among the 20 customers in the group labelled "water-heater wrap," there were no low-flow showerheads installed, but some customers had pipe wrap installed while others did not.

Table 4.2 Classification of households based on retrofit measures

		Definition of Groups		
Conservation classification	Sample size	Water-heater wrap	Pipe wrap	Low-flow showerhead
All customers	147	yes/no	yes/no	yes/no
Water-heater wrap and low-flow showerhead	54	yes	yes/no	yes
Water-heater wrap	20	yes	yes/no	no
Low-flow showerhead	40	no	yes/no	yes
Pipe wrap only	10	no	yes	no
No retrofit[a]	23	no	no	no

[a]Nine of these customers had retrofit measures installed at the time of the audit. Therefore, their 1984-85 (preretrofit) year of consumption was presumably reduced.

The sample for the duty cycle analysis was reduced from 219 to 147 customers to improve data quality for the 96 daily time periods. Customers were removed from the sample for any of the following four reasons:

- if 20% of a customer's data was missing in any year;
- if a customer appeared to have an abnormally large water heater (greater than 6.0 KW), based on the customer's maximum duty cycle values;
- if a customer's pre- and postretrofit maximum duty cycle values differed by more than 10%; or
- if a customer had more than one water heater.

All customers were screened individually using duty cycle frequency distribution data.

The daily duty cycle shape for "all customers" was used to define peak and quiescent time periods. The "peak" period is 6:45 a.m. through 10:15 a.m. This period is after the morning load build up and before the morning load decline and includes the sustained peak period. The peak period is critical because it impacts new generating requirements. The "quiescent" period is defined as the early morning period from 1:30 a.m. through 5:00 a.m., representing the sustained minimum load period. This period should show the impact of conservation on standby water-heater losses.

For the duty cycle analysis, 15-minute water-heater energy values were converted from kWh to percentages by dividing each data value by the maximum 15-minute usage and multiplying by 100. The maximum 15-minute value is customer-specific and represents the size of the water heater being energized. This yields a peak value of 100 for each customer. These values were then multiplied by .15 to indicate how many minutes the water heater was energized out of each 15-minute period. The duty cycle is then represented as a value between 0 and 15 minutes indicating the average energized time for a group of water heaters being energized, or as a percentage of the 15-minute period. In the following analysis both representations of the duty cycle are used.

4.2.2 Findings

The distribution of water-heater sizes used in this analysis is shown in Fig. 4.4. The water-heater size is determined by converting the maximum observed 15-minute values into KWs for each of the 147 customers in the duty cycle analysis. The majority of water heaters are between 4 and 5 KW, with a mean of 4.2 KW.

Utilities interested in controlling future demand and/or energy can use the water-heater duty cycle data (indicating the percentage of time the appliance is energized) and the water-heater size to calculate the impact of conservation measures on loads, utility peak demand requirements, and production cost. Utility system planners can thereby better integrate conservation options with future generating expansion alternatives. Expressing water-heater conservation savings in terms of duty cycle and water-heater size is particularly helpful when developing direct load control strategies.

Before retrofit, the average customer's water heater was energized 14.5% of the time during winter weekdays; after retrofit the duty cycle declined to 13.1%. During peak hours the duty cycle decreases from 23.7 to 21.6%, and during the quiescent period from 4.5 to 3.7%. Using the average water-heater size of 4.2 KW and the proportion savings, this results in the following approximate demand savings:

- .059 KW during average winter days (4.2 KW * .014);
- .088 KW on peak (4.2 KW * .021); and
- .034 KW during the quiescent period (4.2 KW * .008).

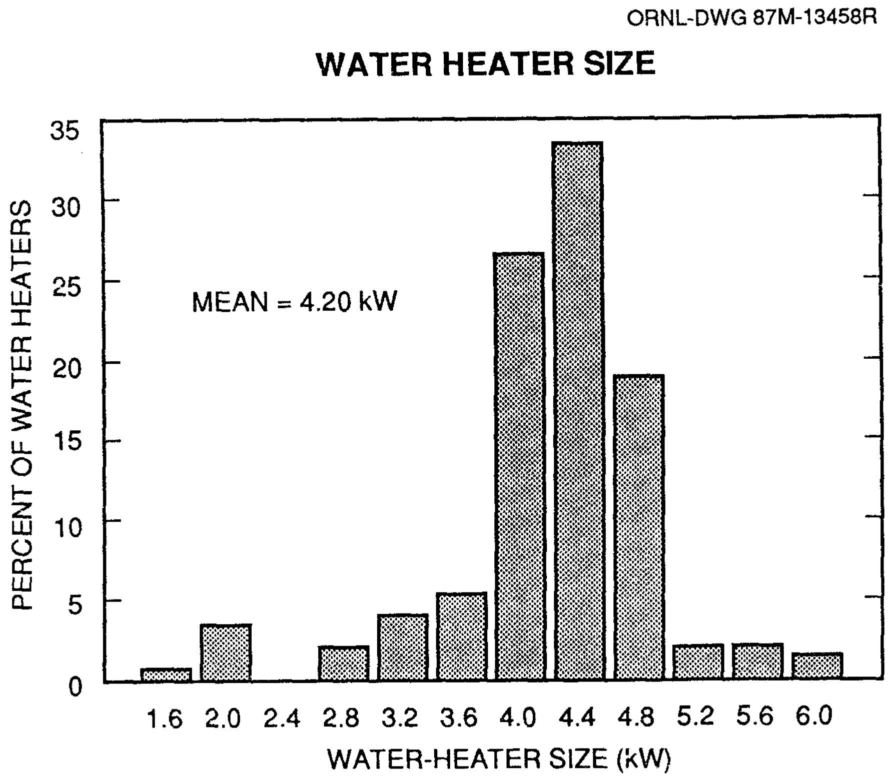

Fig. 4.4 Distribution of water-heater sizes (estimated by the maximum, customer-specific energy consumption during 15-minute intervals).

The .088 KW peak demand savings is greater than the .06 KW estimate presented in Table 4.1 (based on a comparison of pre- and postretrofit consumption between 8:00 a.m. and 9:00 a.m.). This is partly due to the use of two different sample sizes: 182 households when examining hourly load profiles and 147 households when explaining 15-minute data. Additionally, the peak period is defined as one hour for the 182 households and 3 1/2 hours for the 147 households.

Intuitively one would expect the data to show that water-heater insulation and pipe wraps are effective throughout the day, while low-flow showerheads are only effective during usage (which is largely coincident with the morning and evening peaks). That is, low-flow showerheads should contribute to peak load relief, and water-heater and pipe wraps to both peak and off-peak savings.

Duty cycle curves by conservation treatment are presented for the peak period in Fig. 4.5, and for the quiescent period in Fig. 4.6. For "all customers" they show savings both in the morning peak and in the quiescent time period. Water-heater wraps and low-flow showerhead installations, as expected, show similar, but slightly greater savings. Water-heater wraps show savings during the morning peak as well as during the quiescent period. The curve is not smooth because it represents only 20 customers. The low-flow showerhead produced an unexpected result: the morning peak shows negative savings. This suggests that either showerheads were replaced or people took longer showers with the low-flow showerheads. As anticipated, the quiescent time period did not show a significant difference in usage. The 11 customers that had pipe wraps installed show a small savings, but a clear visual separation between the before and after conservation years does not exist.

One would expect customers in the "no retrofit" group to display little savings, and this is generally the case except during the morning peak where the water heater was energized 26% of the time in 1984/85 and only 24% of the time in 1985/86. Recall that households with no HRCP water-heater measures were also found to reduce their annual usage of electricity for water heating by nearly 3% (Table 3.3). Table A-1 profiles the social and economic characteristics of households by conservation group in an attempt to explain the savings behavior of the "no retrofit" group. It indicates that the "no retrofit" households are poorer and less educated, live in older homes with older water heaters, had greater shell efficiency improvements through HRCP, and lowered their indoor temperatures more after HRCP. The last distinction, in particular, suggests a conservation orientation that might explain their

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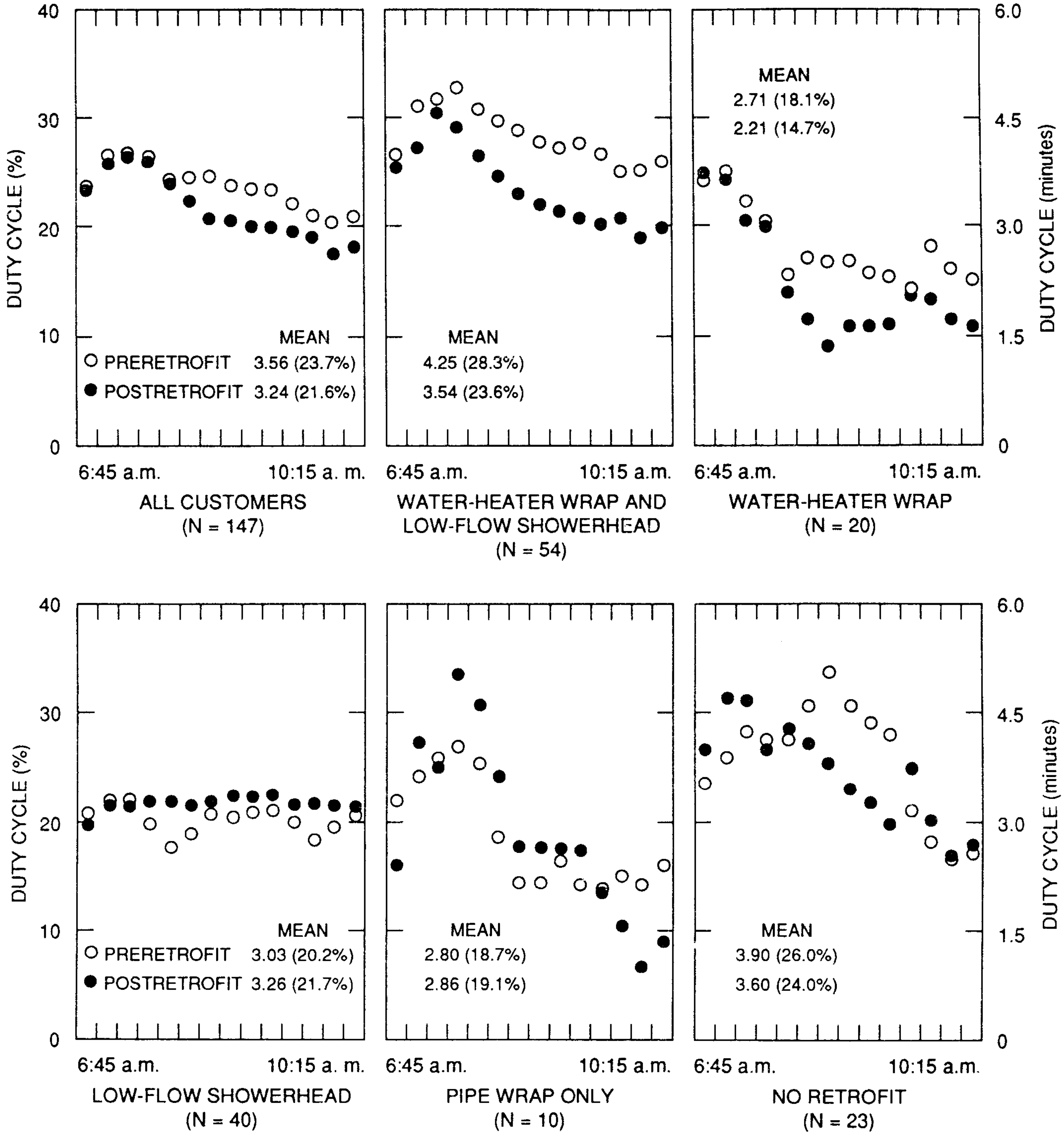

Fig. 4.5 Pre- and postretrofit duty cycles for water heating during peak hours, based on 17 pairs of similar weekdays in winter.

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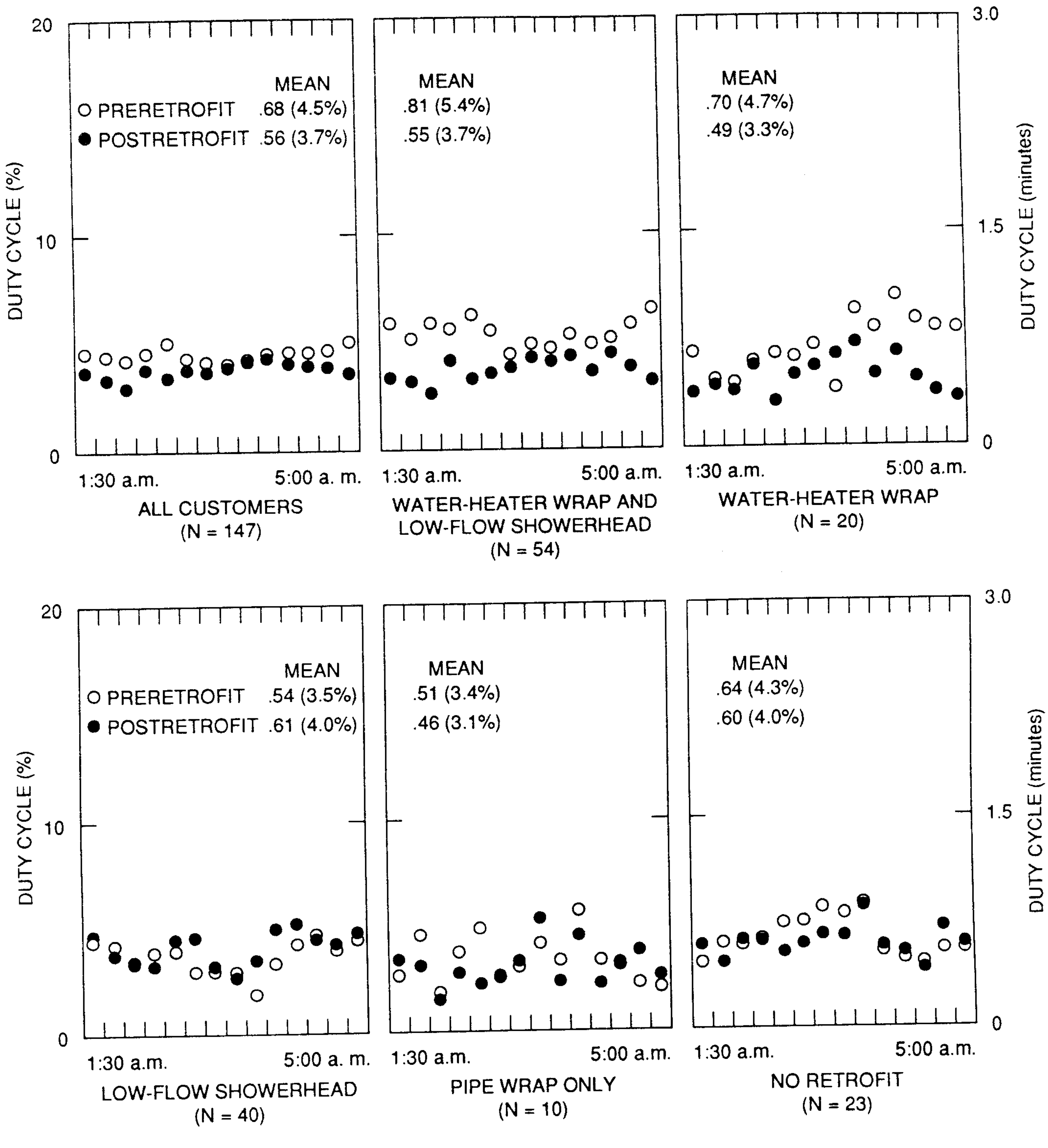

Fig. 4.6 Pre- and postretrofit duty cycles for water heating during quiescent hours, based on 17 pairs of similar weekdays in winter.

water-heater savings. In addition, some number of these customers had their hot-water temperatures reduced.

The daily, peak, and quiescent duty cycles (Figs. 4.7 and 4.8) show the same rank ordering of conservation treatments. The largest savings are consistently due to the water-heater wrap/low-flow showerhead combination, followed by the water-heater wrap, then pipe insulation, and lastly low-flow showerheads which actually showed increased usage.

The superior performance of water-heater wraps during these 17 matched winter weekdays is consistent with the analysis of annual electricity savings. Pipe wraps do not appear to contribute significantly to energy savings, a finding that is paralled in the analysis of annual savings. The low-flow showerhead was expected to save considerably on-peak, but it is associated with <u>increased</u> peak usage during winter weekdays. The analysis of annual savings suggested a small overall reduction.

The distribution of duty cycles is presented in Table 4.3 for daily, peak, and quiescent time periods. A comparison shows that the frequency of duty cycles that were less than one minute in duration increases after retrofit. Before retrofit, 74% of the water heaters for this sample of 147 households were not energized during a typical 15-minute winter weekday period. After retrofit this number increases to 76%. Before retrofit, 62% of the water heaters were not energized during a 15-minute interval during the peak period, and this was increased to 64% after retrofit. During the quiescent period there is an increase of only 1% from 89% to 90%.

At the other end of the scale, the proportion of 14- and 15-minute duty cycles was reduced considerably after retrofit. During the course of a typical winter weekday, 7% of the water heaters were energized for 14 or 15 minutes in any particular 15-minute interval. This was reduced to 6% after retrofit.

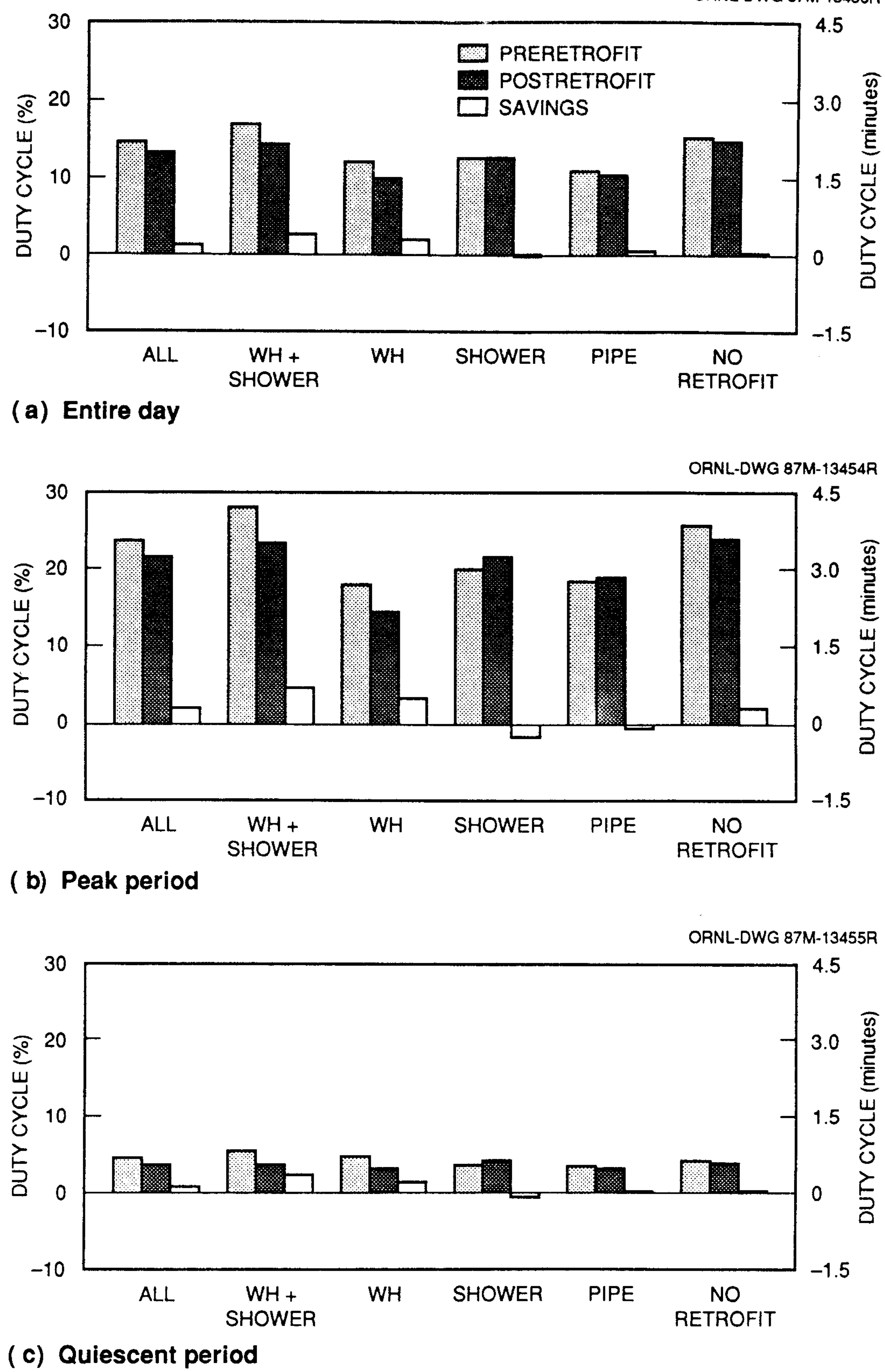

Fig. 4.7 Mean duty cycle values (preretrofit, postretrofit, and difference) for 17 pairs of similar weekdays in winter.

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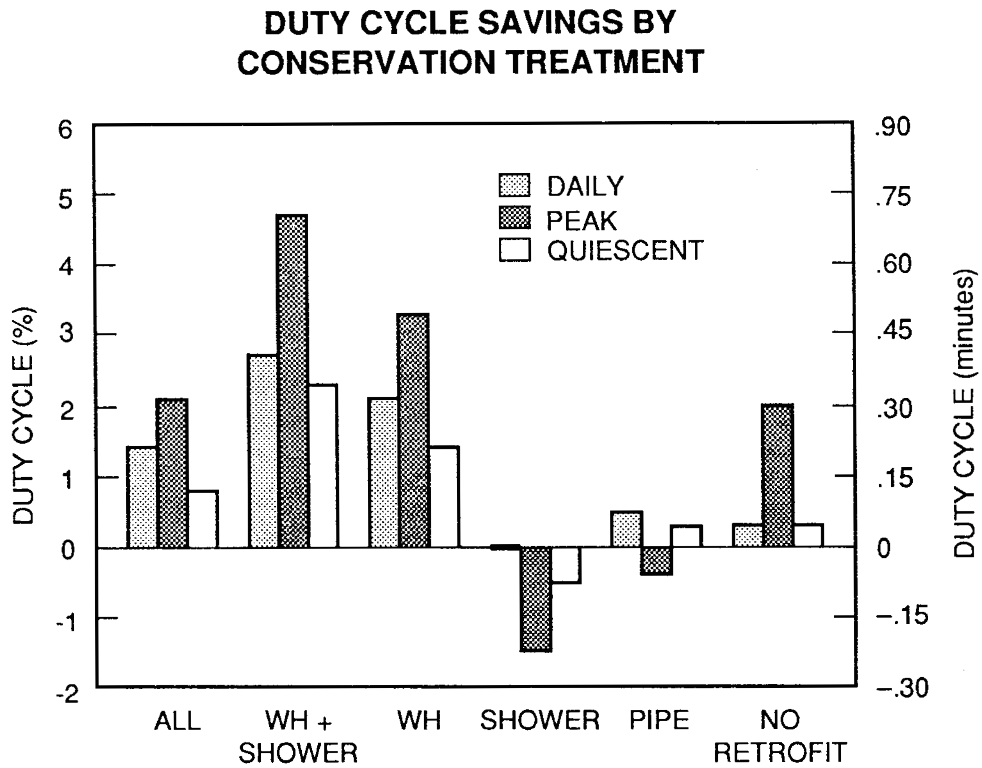

ALL = All customers

WH + SHOWER = Water-heater wrap and low-flow showerhead

WH = Water-heater wrap, but no low-flow showerhead

SHOWER = Low-flow showerhead, but no water-heater wrap

PIPE = Pipe wrap only

NO RETROFIT = No retrofit measures installed

Fig. 4.8 Percent duty cycle savings by conservation treatment, for 17 pairs of similar weekdays in winter.

During the peak period, the number of 14- or 15-minute duty cycles was reduced from 14% to 13%. There was essentially no such decrease during the quiescent period. Thus, during winter, the water-heater savings achieved by HRCP occur disproportionately during peak hours, making the conservation program that much more valuable.

Table 4.3 indicates that direct load control of water heaters during winter weekday peak periods would interrupt service for approximately 40% of Hood River's residential customers. The typical water heater that was interrupted would have otherwise been energized for about six minutes. Such calculations illustrate the potential value of the duty cycle methodology employed here.

Table 4.3 Percent duty cycle frequency distributions for 17 pairs of similar weekdays in winter

Duty cycle	Minutes on	Entire winter day		Peak period		Quiescent period	
		Before[a]	After[b]	Before[a]	After[b]	Before[a]	After[b]
0.0	0	74.0	75.9	61.7	64.3	88.7	90.1
6.7	1	1.6	1.5	1.8	1.8	1.1	0.9
13.3	2	1.6	1.6	1.9	1.7	1.0	1.0
20.0	3	1.7	1.6	2.1	1.9	1.0	1.0
26.7	4	1.8	1.8	2.0	2.2	1.2	1.1
33.3	5	2.1	2.1	2.6	3.0	1.4	1.2
40.0	6	2.2	2.2	2.8	2.6	1.4	1.5
46.7	7	2.1	2.0	2.9	2.7	1.1	0.9
53.3	8	1.6	1.3	2.1	1.9	0.7	0.5
60.0	9	1.0	0.9	1.5	1.4	0.4	0.4
66.7	10	1.0	0.9	1.3	1.2	0.4	0.3
73.3	11	0.8	0.6	1.1	0.9	0.3	0.2
80.0	12	0.6	0.5	1.1	0.8	0.2	0.1
86.7	13	0.7	0.6	1.1	1.0	0.2	0.1
93.3	14	3.5	3.7	6.9	6.6	0.5	0.4
100.0	15	3.7	2.7	7.0	6.1	0.3	0.2

[a] 1984/85 winter.
[b] 1985/86 winter.

5. CORRELATES OF WATER-HEATER USAGE AND SAVINGS

5.1 CORRELATION OF SAVINGS WITH PRERETROFIT ELECTRICITY USE

Previous studies have found that preretrofit energy use is a key determinant of postretrofit use and savings: households that are most energy intensive have the greatest potential for savings through retrofit investments (Hirst, et al., 1983; Goldberg, 1986; Hirst, White, and Goeltz, 1985; and Brown and White, 1987). The speculation might be made that a household's preretrofit electricity use for water heating would be a strong predictor of savings from installing water-heater conservation measures.

Table 5.1 shows that this is the case for the Hood River Conservation Project. Further, total preretrofit electricity use is a strong predictor of water-heater savings. On the other hand, preretrofit space heating and base load electricity use are only weakly correlated with water-heater savings. This is one of many indications that household behavior relative to the three end-uses studied here are quite distinct. Annual space heating electricity usage is unrelated to annual water-heater and base-load consumption, and annual base-load and water-heating usage are only moderately correlated.

Table 5.1 Simple correlations between preretrofit electricity use and savings

Preretrofit use	Postretrofit water-heating use	Water-heating savings
Water heating	0.86***	0.38***
Space heating	-0.12	0.19***
Base load	0.31***	0.15*
Total	0.33***	0.30***

*, **, and *** indicate that correlation coefficients are significantly different from zero at the .05, .01, and .001 levels of confidence, respectively.

5.2 HOUSEHOLD APPLIANCE CHARACTERISTICS

The household's stock of appliances prior to participation in HRCP has some bearing on pre- and postretrofit electricity usage (Table 5.2). Households with one shower or none consume less than average electricity for water heating both before and after retrofit than households with two or more showers. Similarly, households without dishwashers consume less than those with dishwashers. Number of showers and age of the water heater also correlate with electricity savings. Households with two or more showers save more electricity than households with only one, and households with water heaters that are six to twenty years old save more than households with newer water heaters.

5.3 HOUSEHOLD AND STRUCTURE VARIABLES

Water-heater electricity usage is behaviorally driven (Table 5.3). Usage is greater for households with fewer years in residence, more members, greater income, larger homes, and more formal education. Most of these relationships are quite strong. Several of these same variables are also correlated with savings, but the relationships are generally weaker. Water-heating savings are greater for higher-income households, mobile homes, and the smallest and largest homes in our sample.

It was anticipated that customers who had floor insulation installed by the Hood River Conservation Project might save on water heating since their pipes would generally be better insulated. Table 5.3 indicates that customers who benefitted from floor insulation did not save more. The same result occurred when other measures of floor insulation were tested, including:

- square feet of floor insulation added by HRCP;
- estimated savings from HRCP floor insulation, in kWh; and
- estimated/recommended savings from HRCP floor insulation.

Table 5.2 Water-heating electricity usage and savings, by type of conservation treatment[a]

	Electricity usage (kWh/year) 1984/85	1985/86	kWh change	Percent change
Number of showers				
0 (N=10)	3,876***	3,237**	639*	15.4
1 (N=86)	4,543	4,124	337	3.5
2 (N=78)	5,410	4,627	762	13.6
3+ (N=5)	8,097	6,783	1314	18.7
Number of low-flow shower-heads/restrictors at time of audit				
0 (N=101)	5,020	4,386	565	10.3
1 (N=39)	4,725	4,211	488	3.2
2+ (N=25)	5,789	4,910	879	14.4
Dishwasher				
yes (N=137)	5,238**	4,636**	551	7.6
no (N=45)	4,082	3,558	516	10.9
Age of water heater				
0 - 5 years (N=30)	5,192	4,796	320*	-5.0*
6 - 10 years (N=52	5,670	4,939	646	10.3
11 - 20 years (N=72)	4,820	4,271	731	14.6
21+ years (N=28)	3,743	3,548	164	1.9
Water-heater insulation at time of audit				
yes (N=58)	4,833	4,107	626	11.1
no (N=124)	5,013	4,487	503	7.1

*Multiple comparison ANOVA indicates means are significantly different at α=.05; ** at α=.01; *** at α=.001.

[a]Entries in this table are mean values of variables measured at the household level. For example, percent change is the kWh change divided by the preretrofit electricity usage, calculated for each household and then averaged. Thus, the values differ from aggregate calculations of percent change based upon the mean kWh change and the mean preretrofit use. Numbers of cases also vary across variables due to missing information.

Table 5.3 Water-heating electricity usage and savings, by household and structure variables[a]

	Electricity usage (kWh/year) 1984/85	1985/86	kWh change	Percent change
Home at least half-time from 9:00 a.m.- 5:00 p.m.				
yes (N=129)	5,003	4,338	611	9.8
no (N=49)	4,929	4,450	453	6.9
Number of years in residence				
0 - 4 years (N=44)	5,281**	4,600**	649	11.0
5 - 14 years(N=88)	5,181	4,583	536	10.0
15 - high (N=44)	3,873	3,512	354	1.9
Household size				
1 member (N=25)	2,843***	2,611***	232*	7.1
2 members (N=78)	4,173	3,750	406	5.2
3 members (N=26)	5,756	4,821	935	15.9
4 members (N=35)	6,253	5,192	935	15.4
5 members (N=9)	7,582	7,351	231	3.5
6+ members (N=6)	9,504	8,639	864	7.5
Combined 1982 income				
low - $13,000 (N=40)	4,043**	3,806*	222*	1.7
$13,001 - 32,500 (N=87)	5,248	4,617	550	7.9
$32,501 - high(N=41)	5,454	4,608	846	14.8
Budget billing				
yes (N=11)	4,581	4,364	217	4.8
no (N=165)	4,988	4,366	572	9.0
Housing type				
single-family (N=135)	5,004	4,477	517	6.7*
mobile home (N=41)	4,811	4,010	634	14.4
Age of building				
0-9 years (N=44)	5,766**	5,031**	413	7.1
10-20 years (N=85)	4,992	4,510	678	12.5
20+ years (N=51)	4,147	3,726	413	3.1
Square feet of floor area				
low - 1041 (N=45)	4,038**	3,466**	566*	11.7
1042 - 1651 (N=90)	4,973	4,584	372	3.7
1652 - high (N=45)	5,744	4,790	845	14.3

Table 5.3 Water-heating electricity usage and savings, by household and structure variables[a] (cont.)

	Electricity usage (kWh/year)		kWh change	Percent change
	1984/85	1985/86		
Education of respondent				
less than 12 years (N=33)	4,399	3,652*	529	9.8
12 - 14 years (N=116)	5,116	4,550	554	7.6
15 years or more (N=30)	5,096	4,433	663	13.5
Wood user				
yes (N=115)	5,291**	4,557	663	9.6
no (N=66)	4,375	4,038	337	6.4
Floor insulation by HRCP				
0 (N=79)	5,188	4,558	561	10.1
1 (N=103)	4,773	4,222	528	7.1

*Multiple comparison ANOVA indicates means are significantly different at α=.05; ** at α=.01; *** at α=.001.

[a]Entries in this table are mean values of variables measured at the household level. For example, percent change is the kWh change divided by the preretrofit electricity usage, calculated for each household and then averaged. Thus, the values differ from aggregate calculations of percent change based upon the mean kWh change and the mean preretrofit use. Numbers of cases also vary across variables due to missing information.

5.4 AMBIENT, GROUND, AND INDOOR TEMPERATURES

Electricity use for water heating varies considerably over the course of the year (Fig. 5.3). Mean weekly electricity use in the winter is roughly 50% higher than in summer. This temporal variation is assumed to occur for two reasons:

1. households use more hot water in winter than in summer (which is partially caused by the cold-water temperatures being lower, so that "warm" water for showers and baths requires more hot water than in summer), and

2. inlet water temperatures are lower in winter (which requires more energy for the water heater to heat) (Fig. 5.4).

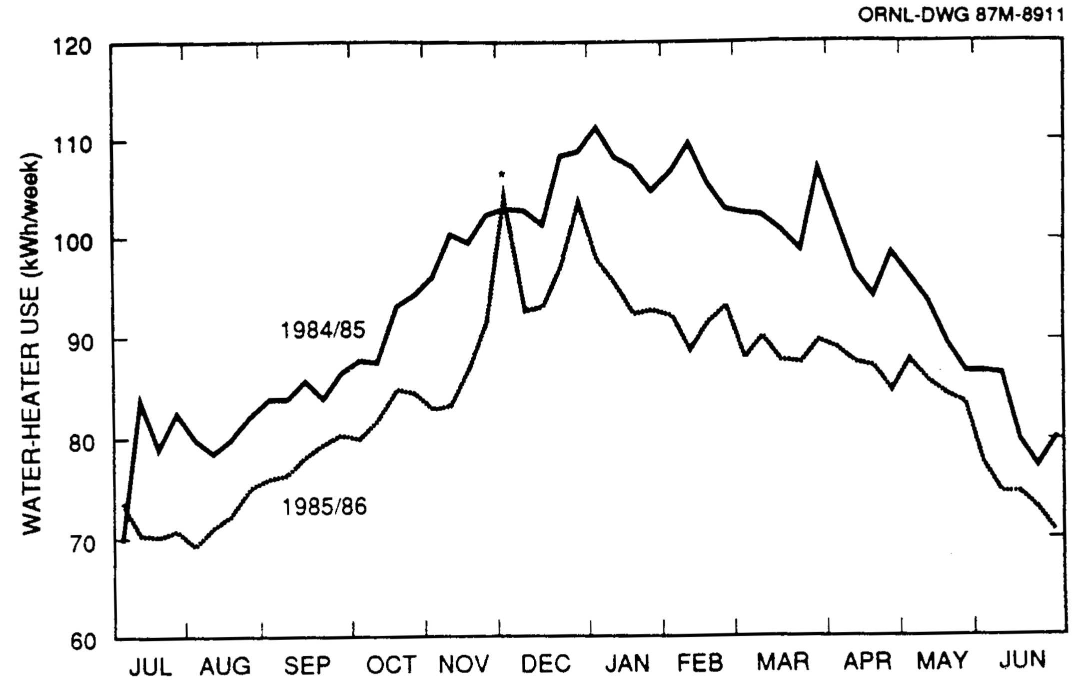

Fig. 5.3 Seasonal variation in the pre- and postretrofit consumption of electricity for water heating. (*November, 1985 was the coldest November in 100 years in Hood River.)

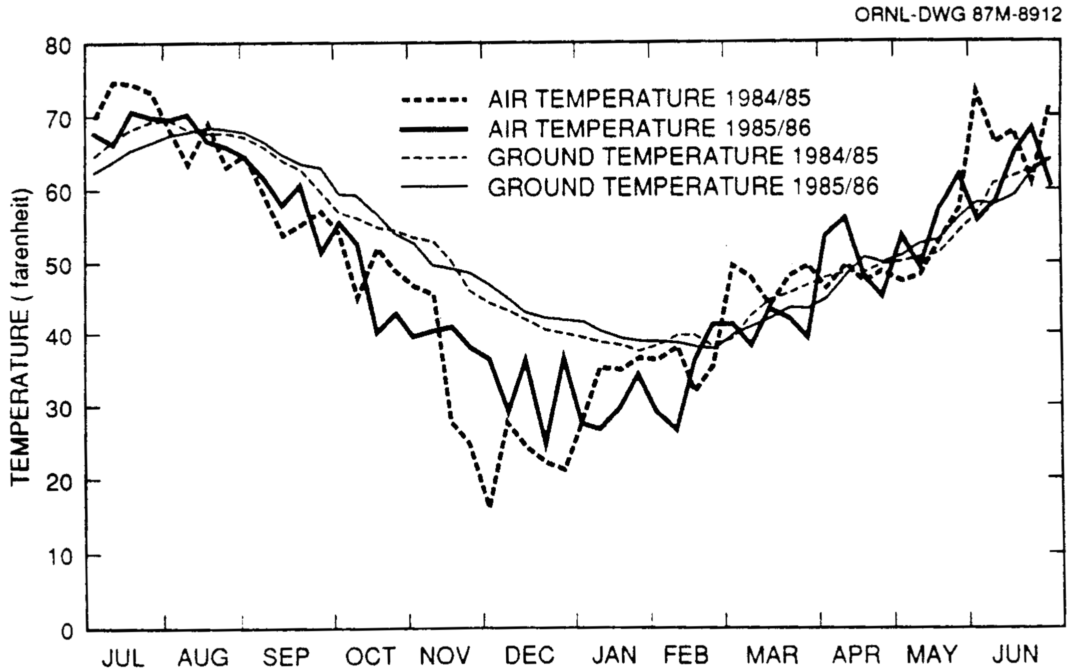

Fig. 5.4 Seasonal variation in the pre- and postretrofit air and ground temperatures. (Ground temperatures were measured at a depth of 40 inches.)

Thus, the dynamics of water-heater electricity use depend on both seasonal behavior and weather. Information collected by Gilbert Associates (1985) from 11 utilities showed average daily hot-water consumption per household of 70 gallons in January, compared with 57 gallons in July. In addition, electricity use per gallon of hot water consumed was almost 50% higher in January than July. Inlet water temperatures reached their minima in February and their maxima in August, roughly one month after the associated extremes for air temperature. A strong lag between air and ground temperatures is also apparent for the HRCP data (Fig. 5.4).

Table 5.4 presents simple correlations between water-heating electricity usage and outdoor and ground temperatures for the pre- and postretrofit years analyzed separately. Three different levels of aggregation are employed: the week, day, and hour.

At the weekly and daily levels of aggregation, there is a strong linear relationship between electricity use and each of the four temperature predictors. No single predictor is markedly superior, suggesting that there is no need to collect ground temperature data when examining water-heater electricity usage, as long as outdoor temperatures (which are less expensive to collect) are available. Since each of the 182 households receives its water from a local water system rather than private wells, ground temperatures at 40 inches would appear to be the best of the three depths for representing inlet water temperatures. Perhaps the behavioral component is more closely tied to outdoor temperatures, causing the more shallow ground temperatures, which fluctuate more closely with outdoor temperatures, to be the better predictors.

When each household is examined individually, there is only a weak relationship between electricity usage and outdoor and ground temperatures. An examination of plots of weekly usage for each of the 182 households reveals many different patterns. For example, some homes show multiweek periods of near-zero use, perhaps while the family is on vacation. Some homes show a few weeks (not necessarily contemporaneous) with very high electricity use, perhaps while friends or relatives are visiting. Other homes show very little seasonal variation.

Mean hourly data do not perform as well as the mean weekly and daily data (Table 5.4). Variations in usage across hours of the day are caused by strong behavioral patterns that are largely independent of inlet water or outdoor temperatures.

Table 5.4 Simple correlations between water-heating electricity usage and outdoor and ground temperatures

	Outdoor temperature	Ground temperature at 4 inches	Ground temperature at 20 inches	Ground temperature at 40 inches
Using mean values for the 52 weeks of 1984/85	-.93***	-.95***	-.95***	-.92***
Using mean values for the 52 weeks of 1985/86	-.92***	-.93***	-.94***	-.93***
Using mean daily data for 1984/85	-.89***	-.90***	-.91***	-.88***
Using mean daily data for 1985/86	-.86***	-.88***	-.87***	-.84***
Using mean hourly data for 1984/85	-.18*	-.19*	-.19*	-.18*
Using mean hourly data for 1985/86	-.18*	-.18*	-.18*	-.18*

* and *** indicate that the simple correlation is significantly different from zero at the .05 and .001 levels of confidence, respectively.

In addition to outdoor and ground temperatures, the temperature of a household's hot water at the time of the survey is strongly related to both the pre- and postretrofit electricity usage for water heating. Neither the location of the water heater nor any of the other temperature variables shown in Table 5.5 are related to usage, however.

Only one of the temperature variables shown in Table 5.5 is significantly correlated with savings: change in indoor temperature. As household indoor temperatures increase, so does the electricity consumed for water heating. This correlation indicates the existence of a tendency on the part of some households to try to conserve electricity in a variety of ways over the 1984 through 1986 period, while other households became generally less conserving. That is, conservation behaviors tend to evolve and change in consistent patterns.

Section 6 attempts to develop a comprehensive model of energy savings. In so doing, it places the role of the conservation treatment into a larger context of evolving behaviors, some of which may in fact be in response to the Hood River Conservation Project.

Table 5.5 Water-heating electricity usage and savings, by temperature variables[a]

	Electricity usage (kWh/year)		kWh change	Percent change
	1984/85	1985/86		
Water-heater location				
heated area (N=92)	4,853	4,286	554	9.8
unheated (N=86)	5,120	4,458	583	8.2
Hot-water temperature at time of audit				
low - 120°F (N=33)	4,145*	3,705	424*	3.5
121 - 139°F (N=112)	5,029	4,480	500	8.3
140 - high°F (N=33)	5,672	4,664	957	17.0
Indoor temperature[b]				
low - 70.90°F (N=46)	5,259	4,449	664	11.8
70.91 - 74.01°F (N=92)	4,628	4,236	523	7.4
74.02° - high°F (N=44)	5,322	4,485	489	7.6
Change in average indoor temperature				
Up 2+°F (N=22)	4,260	4,403	-144**	-2.9***
Up 0 - 2°F (N=104)	4,965	4,447	518	9.3
Down 0+°F (N=56)	5,053	4,204	849	16.1
Temperature gradient index				
less than 60 (N=42)	4,414	4,072	513	10.7
60-80 (N=95)	5,038	4,296	575	8.4
80+ (N=40)	5,494	4,754	604	8.9

*Multiple comparison ANOVA indicates means are significantly different at $\alpha=.05$; ** at $\alpha=.01$; *** at $\alpha=.001$.

[a]Entries in this table are mean values of variables measured at the household level. For example, percent change is the kWh change divided by the preretrofit electricity usage, calculated for each household and then averaged. Thus, the values differ from aggregate calculations of percent change based upon the mean kWh change and the mean preretrofit use. Numbers of cases also vary across variables due to missing information.

[b]Values are based on the year(s) under consideration.

6. REGRESSION ANALYSIS OF WATER-HEATER SAVINGS

6.1 EXPLAINING SAVINGS IN TERMS OF THE CONSERVATION TREATMENT

In order to estimate the independent effects of the HRCP water-heater conservation treatment and each of the water-heater measures, a multiple regression analysis of annual kWh of water-heater savings was completed using three predictors: number of water heaters wrapped by HRCP; water pipes wrapped by HRCP (0,1); and number of low-flow showerheads installed by HRCP.

Table 6.1 presents the results. In contrast to the lower estimates of potential savings shown in Table 2.2, the water-heater wrap has the highest regression coefficient, indicating that 714 kWh are saved each time a water-heater wrap is installed. The analysis indicates that only 232 kWh are saved for each low-flow showerhead installation. Pipe wraps do not enter into the model, indicating that their impact on annual savings is insignificant.

Altogether, these two variables explain only 14% of the variation in savings across households. Other variables must be considered in order to gain a fuller portrayal of households that have saved a lot of energy and those that have saved little.

6.2 EXPLAINING SAVINGS USING ALL PREDICTORS

This section presents the best regression model of water-heater savings based on all of the predictors available for inclusion (Table 6.2). The model is able to explain 44% of the variation in savings--much more than the prior model based solely on characteristics of the conservation treatment.

The variables in Table 6.2 are ordered according to when they entered the regression model. Thus, the most significant single predictor of water-heater savings is the change in average interior temperature: those

Table 6.1 Regression analysis of water-heater savings based on the type of conservation treatment

Predictor	Regression coefficient	Standard error
Intercept	-45	
Number of water-heater wraps installed by HRCP	714***	152
Number of low-flow showerheads installed by HRCP	232*	100
Coefficient of determination (R^2)	0.143***	

* and *** indicate that regression coefficients are significantly different from zero at the .05 and .001 levels of significance, respectively.

households that had warmer interior temperatures after retrofit also used more electricity for water heating after retrofit. Over the two-year study period, indoor temperatures rose by approximately 0.6° Fahrenheit, indicating a general tendency for greater comfort after retrofit and a "takeback" of potential space-heating savings that is paralleled by a loss in potential water-heating savings (Dinan, 1987). This variable suggests consistent conservation behavior patterns for both space and water heating.

Homes with greater improvements in the energy efficiency of their shell tended to be occupied by households with less water-heater savings (Table 6.2). This provides further evidence of a "takeback" effect, whereby those households with more efficient homes elect more energy-intensive lifestyles.

Other predictors of larger savings are: older homes, smaller households, day-time occupants, water-heater wraps installed by HRCP, more preretrofit water-heating electricity usage, a higher proportion of actual to recommended floor insulation savings, and wood users.

The coefficient for the number of water-heater wraps installed by HRCP indicates that each wrap saved 611 kWh, slightly less than in the prior model (Table 6.1). The number of low-flow showerheads installed by HRCP does not emerge as a significant predictor, even though it did enter into the previous model. This is because it is significantly (and positively) correlated with preretrofit water-heater electricity use which does enter the model as a strong predictor. Once again, pipe insulation appears to have no measurable impact on postretrofit electricity use for water heating.

Table 6.2 Full regression analysis of water-heater savings

Predictor	Regression coefficient	Standard error
Intercept	-738	
Change in average interior temperature	205***	42
Improvement in energy efficiency of dwelling unit shell	-205*	140
Age of building (in years)	12.9**	5.2
Household size	-216**	81
Home at least half-time during the days	283	164
Number of water-heater wraps installed by HRCP	640***	144
Preretrofit water-heater electricity usage	0.225***	0.047
Actual/recommended floor insulation savings	132**	50
Wood user (0,1)	334*	163
Coefficient of determination (R^2)	0.443***	

*, **, and *** indicate that regression coefficients are significantly different from zero at the .05, .01, and .001 levels of significance, respectively.

This model suggests that water-heating electricity savings are greater for more "up-scale" households. Since the 182 households were found to be slightly wealthier than other households served by HREC and PP&L, this suggests that the savings estimated here are somewhat greater than for a more representative sample.

7. SUMMARY AND CONCLUSIONS

7.1 SUMMARY

Savings due to the installation and retrofit of water-heater conservation measures in the Hood River Conservation Project have been shown to be both significant and consistent. Annual and daily water-heater usage curves after retrofit are consistently less than preretrofit usage. For the 182 households studied, the project resulted in first-year water-heating electricity savings of 542 kWh or 8.4%. During typical winter days, daily water-heater energy requirements were reduced by 1.9 kWh or 12.2%--more than the average daily reduction during the rest of the year.

Fully one-fourth of the total energy savings resulting from HRCP can be attributed to reductions in water-heater electricity use. At the same time, the water-heater measures cost, on average, only $20 (or 0.5%) of the average cost of the total conservation package--$3760. The cost for each first-year kWh savings for water heating in these 182 homes is less than $0.04--a cost than can be repaid in less than one year through avoided costs to the consumer.

A comparison of estimated and predicted annual savings for each HRCP water-heating conservation measure is summarized below in Table 7.1. Estimated annual savings of 714 kWh for each water-heater wrap, 0 kWh for pipe insulation, and 232 kWh for each low-flow showerhead suggest that savings were greater than expected for water-heater wraps, but less for the other two measures and for the package as a whole.

Contrary to expectations, rewrapped water heaters were found to produce as much electricity savings as the installation of water-heater wraps where no prior insulation existed. This "counterintuitive finding" is attributed to three factors:

Table 7.1 Estimated and predicted annual water-heater energy savings, in kWh

	Estimated	Predicted[a]
Water-heater wrap	714	300-600
Low-flow showerhead	232	600-800
Pipe wrap	0	75
Total	946	975-1,475

[a]Based on a review of the literature.

- water heaters with prior wraps tended to be located in unheated spaces;
- they were wrapped, on average, five years ago when water-heater insulation is suspected to have been less effective; and
- there may have been some deterioration in the performance of the insulation over time.

There are many significant predictors of water-heater savings. Preretrofit water-heater electricity use strongly correlates with savings--households with greater usage, saved more. This same pattern holds for total electricity use as a predictor of water-heater savings. Household appliance stock is also important. Households with two or more showers and with older water heaters saved more than average.

Water-heating savings are greater for higher-income households, mobile homes, and small and large homes. Further, households with higher preretrofit hot-water temperatures saved more, as did those who lowered their indoor temperatures after participating in the program.

A multiple regression model containing many of these variables was able to explain 44% of the total variation in the amount of electricity saved for water heating.

The winter load profile for water heating is characterized by a major peak in the morning (6:45 a.m. to 10:15 a.m.) and a minor peak in the early evening (7:00 p.m. to 10:00 p.m.). In both instances these peaks lag behind the space-heating and total household peaks by 15 to 60 minutes.

An analysis of pre- and postretrofit winter consumption from 8:00 a.m. to 9:00 a.m. (the household peak), showed that water-heater demand decreased by 0.06 KW (6.1%). This represents a demand savings of $329/KW which is less than the capital costs associated with installing, transmitting, and distributing new generation.

A duty cycle analysis based on 15-minute data and a peak period defined as 6:45 a.m. through 10:15 a.m. provided additional insight into peak and off-peak savings. Before retrofit, the average customer's water heater was energized 15% of the time during winter; after retrofit the water heaters were energized only 13%. During peak hours the duty cycle decreases from 24 to 22%, and during the quiescent period from 5 to 4%. Using the average water-heater size of 4.20 KW and the savings in terms of percent reduction, this results in the following approximate demand savings per household:

- .059 KW during average winter days;
- .088 KW on peak; and
- .034 KW during the quiescent period.

The .088 KW reduction suggests a cost of $228 per KW.

Duty cycle curves by conservation treatment showed that the rank ordering of conservation treatments in terms of average savings during a typical winter day, peak periods, and quiescent periods is identical. The largest savings are consistently due to the water-heater wrap/low-flow showerhead combination, followed by the water-heater wrap, then pipe insulation, and lastly low-flow showerheads. The "no retrofit" group also reduced their consumption, particularly during on-peak hours.

The low-flow showerhead was expected to save considerably on-peak, but savings are disappointing, and during the quiescent period, this measure is associated with negative savings. The water-heater wrap on the other hand, appears to save considerable energy on an annual basis (more than 700 kWh), and its savings on-peak (6:45 a.m to 10:15 a.m.) are greater than its savings off-peak (1:30 a.m. to 5:00 a.m.).

This report has contributed significantly to assessing the demand and energy savings potentials of water-heater retrofits. It has documented the cost effectiveness of water-heater wraps and the questionable effectiveness of low-flow showerheads, and it has identified those segments of the customer population that contribute most to retrofit savings.

7.2 FUTURE RESEARCH

Despite the wealth of data and extensive analysis described in this report, several key questions remain unanswered. These are proposed as directions for future research:

- *Identify market segments with peak consumption patterns that respond differentially to water-heater conservation measures.* What types of households most dramatically reduce their on-peak consumption as the result of water-heater retrofit measures? Do the same demographic predictors of water-heater savings identified in this report apply to peak savings?

- *Analyze savings during summer.* Many utilities are summer peaking and would be interested in the impact of water-heater measures during this season.

- *Investigate further the impact of the thermostat setback, since it is a natural component of a water-heater retrofit program.* An evaluation of this measure requires better data than is available from HRCP. Precise setback measurements must be available along with pre- and postretrofit electicity consumption data.

- *Conduct an additional survey and an on-site audit in order to explain the poor performance of the low-flow showerhead.* Do customers replace their energy-saving showerheads? Do the low-flow showerheads operate properly over extended periods of time? Is there a "takeback" effect in terms of longer showers after retrofit?

- *Collect and analyze detailed data on hot-water usage.* It would be valuable to have 15-minute data on hot-water use in order to better understand water-heater retrofit impacts on electricity use for recovery vs standby losses.

The first two areas of investigation could be pursued by further examination of existing HRCP data. The remaining areas of inquiry require data that go beyond the Hood River experiment.

8. FOOTNOTES

[1]One of 220 accounts with water-heater submeters was a nonresidential customer.

[2]Stepwise ordinary least squares regression was used (as is the case in the rest of this report). Variables were entered into the regression model one step at a time based on their partial F-statistics, until the .10 level of significance was surpassed.

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APPENDIX A

HOUSEHOLD CHARACTERISTICS BY RETROFIT CATEGORY

Table A-1. Household characteristics by water-heating retrofit category

	Overall (N=147)	Water-heater wrap and low-flow showerhead (N=54)	Water-heater wrap, no low-flow showerhead (N=20)	Low-flow showerhead, no water-heater wrap (N=40)	Pipe wrap only (N=10)	No retrofit (N=14)	Prior water-heating retrofit (N=9)	Failed to meet screening criteria (N=35)
Preretrofit water heat (kWh)[a]	4,923	5,827	4,377	4,309	3,997	4,951	4,532	4,564
Water-heater savings (kWh)	563	1,001	972	146	151	78	97	248
Water-heater savings (%)	10.0	16.5	21.4	1.8	3.8	1.0	2.7	-1.1
Age of head	50.9	47.9	54.7	54.3	46.6	53.6	46.0	52.0
Education of head	12.8	12.7	12.9	13.4	12.8	11.9	11.5	12.6
Income ($, 1982)	26,500	29,296	24,921	28,333	16,350	22,375	23,750	25,424
Length of residence	11.2	9.1	15.7	12.7	8.3	12.9	7.6	12.0
Household size[a]	2.6	2.9	2.2	2.5	2.2	2.7	2.6	2.8
Age of house (years)[a]	22.3	17.2	25.0	23.3	23.7	29.3	30.3	22.9
House size (sq. feet)	1,381	1,415	1,209	1,581	1,152	1,260	1,122	1,278
Age of water-heater system (years)	13.5	12.1	15.8	14.0	8.9	16.6	14.4	15.8
Age of heating system	11.1	9.4	12.7	11.5	7.3	13.2	18.7	13.4
Hot-water temperature	131.2	133.1	128.8	129.9	129.6	130.8	132.9	129.5
Change in indoor temperature[a]	-0.43	-0.18	-0.66	-0.53	-0.35	-1.77	1.00	-0.08
Improvement in shell efficiency[a]	0.58	0.42	0.59	0.66	0.46	0.77	1.01	0.66
Home during day (%)[a]	70.8	79.6	60.0	64.1	70.0	92.3	37.5	76.5
Number of water heaters wrapped (%)[a]	51.0	100.0	100.0	0.0	0.0	0.0	11.1	42.9
Retrofit savings/ audit estimate (%)[a]	84.6	74.1	101.6	102.3	36.1	102.1	57.1	101.8
Burns wood (%)[a]	59.2	61.1	60.0	70.0	50.0	50.0	22.2	65.7

[a]Indicates statistically significant predictor of water-heater savings (see Table 6.2).

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