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Electricity Use and Savings in the Hood River Conservation Project

Eric Hirst
Richard Goeltz
David Trumble

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ENERGY DIVISION

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April 1987

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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 & Light Company in the community of Hood River, Oregon. This three-year, $21 million 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 heating retrofits; no heating or water heating equipment was replaced.

This report discusses methods and results related to actual electricity use and savings produced by HRCP. Our approach first analyzes monthly billing data to produce estimates of weather-adjusted (normalized) annual electricity use. The weather-adjustment method used to convert raw electricity bills into useful estimates of annual electricity use is the Princeton Scorekeeping Method (PRISM). PRISM is applied to data from individual households and to aggregate data (all HRCP participants, and households in Hood River and the two comparison communities - Grants Pass and Pendleton, OR). These estimates of annual electricity use are then used as inputs to pooled time-series/cross-sectional models. These multivariate regression models explain variations in annual electricity use and savings across households and years. Models are developed for both program participants and households in the three communities. The primary purposes of these models are to identify the net (as well as total) electricity savings attributable to HRCP and to quantify the effects of various factors (including participation in HRCP) on electricity use and savings.

The major findings are:

1. Postretrofit electricity use (1985/86) among HRCP participants was remarkably low, averaging 16,000 kWh/year, of which space heating accounted for less than 5000 kWh. Even in single-family homes that used electricity as their primary heating fuel (i.e., used little wood), total and space-heating electricity uses averaged 20,000 and 7000 kWh, respectively. The space-heating use of 7000 kWh is equivalent to 4.2 kWh/ft^2, substantially less than the 5.6 kWh/ft^2 observed in recently constructed single-family homes in the same climate zone, and close to the 3.3 kWh/ft^2 observed in homes that meet the region's Model Conservation Standards. The low levels of post-HRCP electricity use were caused by a combination of low levels of pre-HRCP electricity use and the HRCP retrofits. On a climate-adjusted basis, the HRCP homes achieved levels of post-retrofit space-heating electricity use lower than that recorded for any other retrofit program in the U.S.

2. Electricity use among HRCP participants before the Project began (1982/83) was less than 19,000 kWh/year, far below typical levels observed throughout the Pacific Northwest at that time. For example, single-family homes used about 20,000 kWh/year in Hood

River, compared with almost 25,000 kWh throughout the region. Similarly, pre-HRCP space heating electricity use averaged less than 8,000 kWh/year, much less than the almost 12,000 kWh observed throughout the region.

3. These low levels of electricity use among HRCP participants were probably caused primarily by dramatic increases in electricity prices; during the two years preceding HRCP, real (corrected for inflation) electricity prices rose by 40% in Hood River. In addition, growing public knowledge of energy conservation options, increases in unemployment, and participation in prior conservation programs all contributed to lower electricity use. Finally, almost two-thirds of the participants used wood as their primary or supplemental heating fuel, probably because of increases in electricity prices and unemployment; use of wood reduced annual electricity use by as much as 6000 kWh per wood-burning home.

   Many of the household actions contributing to lower electricity use could be reversed if electricity prices or household incomes change. The effects of such behavioral changes on electricity use would be substantially greater in nonretrofit homes than in homes with HRCP measures installed. Thus, the HRCP retrofits provide, in addition to immediate savings, "insurance" against rapid long-term load growth

4. The reduction in electricity use (pre-HRCP minus post-HRCP; 1982/83 minus 1985/86) in homes retrofit by HRCP averaged 2600 kWh/year, almost entirely because of reductions in space heating. The savings in multifamily homes and mobile homes and in single-family homes that used electricity as their secondary heating fuel saved less than the average. On the other hand, savings in single-family homes that used electricity as their primary heating fuel and that had not participated in earlier retrofit programs averaged 4500 kWh, consistent with that observed in other Pacific Northwest utility residential retrofit programs (2000 to 5000 kWh). HRCP's 15% savings relative to preretrofit consumption were comparable to that observed in other programs.

5. The most important determinant of HRCP's small savings was probably the low level of pre-HRCP electricity use. Had electricity use averaged 25,000 kWh in 1982/83 rather than 19,000 kWh, the savings would have been about 4,000 kWh. For example, the savings for single-family homes served by the Hood River Electric Cooperative were double that for comparable homes served by PP&L (4000 vs 2000 kWh/year); Coop homes also used much more electricity before HRCP than did PP&L homes (23,000 vs 18,000 kWh).

6. Other factors also contributed to the small electricity savings. Households took the efficiency improvements provided by HRCP retrofits in terms of both reduced electricity bills and increases in comfort and convenience. For example, reductions in wood use (pre- vs post-retrofit) cut electricity savings by roughly 300 kWh. Indoor temperatures increased slightly between 1984/85 and 1985/86 for homes retrofit in mid-1985, by an average of 0.6^{o}F, which cut

electricity savings by about 300 kWh/year.

The Project's focus on 100% participation led to inclusion of some homes with only small potentials for cost-effective conservation; the actual savings experienced in these homes reduced the average. For example, HRCP succeeded in gaining participation from multifamily buildings, while most other retrofit programs serve primarily single-family units. The average HRCP savings among multifamily units were only half that for single-family units (1600 vs 2900 kWh/year).

7. The net savings (the portion of total savings that can be attributed directly to HRCP rather than to market forces) were 2300 kWh. For homes that used electricity as their primary heating fuel, the net savings averaged 2700 kWh, compared with 1600 for homes in which electricity was a supplemental heating fuel.

These results (and comparisons with those from earlier studies) show how dynamic the electricity demand situation was in the Pacific Northwest between the late 1970s and mid-1980s. The dramatic increases in electricity prices followed by stability during the mid-1980s, the economic downturn followed by modest recovery, the initiation of utility and government residential conservation programs, and the increase and subsequent stabilization of wood use all complicate analysis of a particular conservation program.

HRCP demonstrated electricity savings that averaged 2600 kWh per retrofit home in a climate with 5600 heating degree days (65^{o}F base). Savings varied considerably as functions of house type and age, use of wood, participation in prior retrofit programs, and electricity-price histories (i.e., savings were much higher among HREC customers than among PP&L customers because prices increased less rapidly and began at a lower level for HREC customers). Single-family homes experienced higher savings, averaging 2900 kWh, and single-family homes that relied primarily on electricity as their heating fuel saved 4000 kWh. On the other hand, multifamily and mobile homes and homes that relied heavily on wood saved less electricity.

The Project also showed the feasibility of reducing electricity use to very low levels. Specifically, post-HRCP consumption averaged 16,000 kWh, of which space heating accounted for only 5000 kWh. Post-HRCP levels of space-heating electricity use were lower than those in typical new homes constructed during the early 1980s and far below levels obtained in other retrofit programs throughout the U.S.

The savings averaged only 43% of that predicted during energy audits of these homes (6100 kWh, on average). About 40% of the difference can be attributed to typical discrepancies between actual and predicted savings, about 40% was caused by pre-HRCP reductions in electricity use, and the remainder was caused by post-HRCP changes in energy-related behaviors (e.g., higher indoor temperatures and less use of wood).

LIST OF ACRONYMS

AO	Homes that received an audit, but no retrofit from HRCP (audit only)
BPA	Bonneville Power Administration
Council	Northwest Power Planning Council
DNAC	Change in NAC from one year to another
EUM	End-use monitored homes
HDD	Heating degree days
HRCP	Hood River Conservation Project
HREC	Hood River Electric Cooperative
NAC	Normalized Annual Consumption (kWh/year)
NOAA	National Oceanic and Atmospheric Administration
NP	Eligible nonparticipant in HRCP
ORNL	Oak Ridge National Laboratory
OSU	Oregon State University
PNW	Pacific Northwest region
PP&L	Pacific Power & Light Company
PRISM	Princeton Scorekeeping Method
RWP	Residential Weatherization Program
SH	Space heating
UO	University of Oregon
WX	House weatherized (retrofit) by HRCP

1. BACKGROUND

THE HOOD RIVER CONSERVATION PROJECT

The Hood River Conservation Project (HRCP) was a major residential retrofit demonstration project, initially suggested by the Natural Resources Defense Council, operated by Pacific Power & Light Company (PP&L) and funded by the Bonneville Power Administration (BPA). The Project sought to install as many cost-justified retrofit measures in as many electrically heated homes as possible in Hood River, Oregon. The retrofits were aimed at the building shell to reduce electricity use for space heating and at water heating retrofits; no heating or water heating equipment was replaced. Energy audits were conducted and retrofit measures were installed by HRCP between fall 1983 and the end of 1985. Data collection and analysis began in spring 1983 and continued through early 1987.

The $21 million Project involved higher levels of conventional retrofit measures than generally offered in weatherization programs in the Pacific Northwest [e.g., R-49 ceiling insulation rather than the R-38 generally recommended in the BPA Residential Weatherization Program (RWP); see BPA (1982)]. In addition, BPA paid for installation of these measures up to a limit of $1.15/first-year estimated kWh saved, almost four times the limit in the BPA RWP. Thus, HRCP offers the chance to examine retrofit installation and subsequent energy savings when cost to the household and prior retrofit activities are largely removed as barriers.

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; includes a diversified economy, population, and housing stock; is served by both public and private utilities (Hood River Electric Cooperative, HREC, and PP&L); and includes climate zones representative of the Pacific Northwest. Hood River lies along the northern edge of Oregon by the Columbia River, 60 miles east of Portland. 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.

The contract between BPA and PP&L to initiate this Project was signed in May 1983, after more than a year of planning. Energy audits were first offered in Fall 1983, and installation of retrofit measures began in early 1984. Roughly 15% of the retrofit installations were completed in 1984, with the remainder done in 1985. All Hood River households were eligible for a free home energy audit. However, the Project paid for installation of retrofit measures only in homes with permanently installed (before March 1983) electric space heating equipment. Of the roughly 3500 eligible households, 2988 (85%) received one or more HRCP-financed major retrofit measures. An additional 201 homes (6%) received an energy audit only.

Additional information on the purposes, design and operation of HRCP can be found in Oliver et al. (1984 and 1986), PP&L (1982 and 1983), Peach et al. (1984), Brown (1986), Philips et al. (1986a and b), and French et al. (1985).

PURPOSE OF THIS ANALYSIS

The success of a conservation program depends on the product of three factors: the number of eligible customers who participate in the program, the number of recommended conservation actions adopted by participants, and the actual energy savings achieved by the adopted actions. Earlier reports from ORNL (Hirst and Goeltz 1986b; Goeltz and Hirst 1986) dealt with the first two of these three issues. In addition, program success can be measured in terms of reduced postprogram electricity use because the levels of electricity use (rather than savings) determine the need for additional power plants.

The purpose of this report is to examine actual electricity use and savings. This analysis is especially important for HRCP, given its intention to reduce residential electricity use (especially for space heating) to very low levels. Two groups of households are examined in these analyses. The first includes eligible (i.e., electrically heated) homes in Hood River: those who received HRCP-financed retrofits, those who received only an audit, and eligible nonparticipants (WX, AO, and NP, respectively). The second group includes random samples of households from Hood River and the two comparison communities: Grants Pass and Pendleton, Oregon. Electricity use and savings are examined for the four years from 1982/83 through 1985/86.

The following section discusses the methods used to analyze electricity use and savings. Section 3 describes the data available from HRCP for analysis of household and community electricity use and savings. Readers interested primarily in findings should skip to Sections 4 and 5, which present results based on analysis of HRCP participants and of electrically heated homes in Hood River, Grants Pass, and Pendleton. The last section summarizes the findings and limitations in the present analysis.

2. METHODS USED TO ANALYZE ELECTRICITY USE

Accurate analysis of residential electricity use and of changes in electricity use is complicated. Electricity use is a function of the structure, its energy-using equipment (space heating systems, water heater, and appliances), the occupants (number and ages), the economic environment (electricity prices and household income), weather conditions, and participation in conservation programs (including HRCP).

Sorting out the influences of these disparate factors is difficult. Therefore, we developed and tested several methods and data sets to estimate electricity use and savings produced by HRCP. We think that such "triangulation" among alternative approaches lends confidence to the results obtained.

The analyses treat two different measures of program performance: total and net electricity savings. Total savings are the reduction in annual electricity use experienced by HRCP participants. Net savings are that portion of the total that can be directly attributed to HRCP. Thus, net savings are the difference between total savings and the savings that HRCP participants would have achieved on their own had HRCP not existed. Data from the two comparison communities are used to infer the no-program savings for participants.

We analyze electricity savings in a two-stage process. The first stage uses monthly billing and daily outdoor temperature data to compute weather-adjusted (normalized) annual electricity use. The output of this process (in kWh/year) is then used as an input to the second stage, cross-sectional models that analyze annual electricity use as functions of the factors listed above.

PRINCETON SCOREKEEPING METHOD

The first stage relies on the Princeton Scorekeeping Method (PRISM) developed by Fels (1984 and 1986). This weather-normalization method recognizes that electricity use is the sum of consumption for the various end-uses (e.g., space heating, water heating, air conditioning). Because space heating is generally the major energy end-user (accounting for about 40% of total electricity use for the households in this analysis) and because space heating is strongly temperature-dependent, PRISM defines household electricity use as:

$$E_{it} = a_i + b_i x HDD_{it}(Tref_i) , \quad (1)$$

where the unit of analysis is one year of billing data, called a household-year. E is the average daily energy use for household i during monthly billing period t. Electricity-billing and heating-degree-day (HDD) data are normalized by the number of days in each billing cycle to correct for differences (across households and utilities) in the number of days per cycle. The coefficient a_i reflects household use of energy for nonspace-heating purposes, and the coefficient b_i reflects use of energy for space heating (more accurately nonweather- and weather-sensitive consumption, respectively).

HDD is the number of heating degree days per day (to reference temperature Tref) for the same time period as the utility bill. HDD is defined as maximum (0, Tref - average daily temperature); daily HDD values are summed to obtain monthly or annual values. Daily temperature data are from a National Oceanic and Atmospheric Administration weather station near the household (e.g., NOAA 1984).

The reference temperature (Tref) is defined as the temperature that yields the highest explanatory power (R^2) in the above model; we restrict Tref to integers in the range 10 to 90°F. Physically, Tref is the outdoor temperature below which the heating system must operate to maintain the desired indoor air temperature; no heating is required at higher temperatures.

The parameters a_i, b_i, and $Tref_i$ are estimated for each household for each of the four years 1982/83 (pre-HRCP), 1983/84, 1984/85, and 1985/86 (post-HRCP). They are used to define Normalized Annual Consumption (NAC)[1] for household i and year j (Fig. 1):

$$NAC_{ij} = 365 x a_{ij} + b_{ij} x \overline{HDD}(Tref_{ij}) \, , \tag{2}$$

where $\overline{HDD}$ is the long-run normal (30-year average) HDD at base Tref for household i (NOAA 1982). A year is defined as the meter-reading dates from July 1 through June 30. The NAC formula "corrects" household energy consumption for year-to-year changes in winter severity and for temporal misalignment across households in fuel bills (e.g., some records begin on July 1 and others on July 23; some histories are for 320 days and others for 375 days).

Electricity use for air conditioning is ignored in these analyses because suitable techniques to normalize air-conditioning electricity use have not yet been fully developed. This approach is justified because the HRCP measures have much larger effects on space heating than on air conditioning, air conditioning loads are quite low in Oregon, and only 20% of the HRCP participants have air conditioners.

The second term in eq. (2) is generally referred to as space heating electricity use. However, this term includes all electricity

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1. The NAC estimate is the most stable and robust output from PRISM. Estimates of baseload and heating consumption and of Tref are much more uncertain.

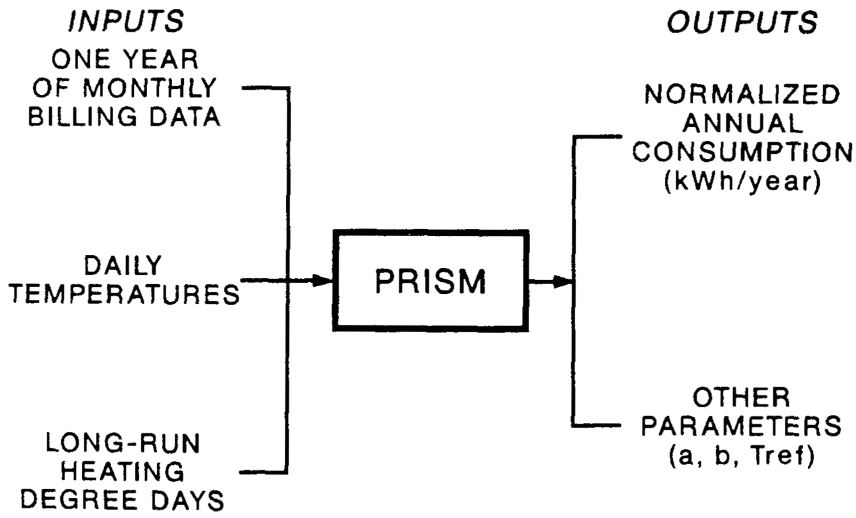

Fig. 1. Schematic diagram showing inputs to, and outputs from, PRISM.

uses that depend on outside temperature and/or that vary seasonally (Burnett and Lesser 1986; Fels 1986; Hirst and Goeltz 1986a). For example, water heating electricity use is generally higher in the winter than in the summer, both because households use more hot water in the winter and because inlet water temperatures are lower in the winter. Electricity use for lighting varies seasonally (as a function of the amount of daylight) but not with outdoor temperature. Electricity use for refrigerators is related to kitchen temperatures and is therefore generally higher in the summer than in the winter.

We used the HRCP load research data to compare PRISM estimates of space-heat use [the second term in eq. (2)] with actual electricity use for space heating as determined from annual totals of the space-heat channel (Hirst and Goeltz 1986a). That analysis showed that the discrepancy between PRISM's estimate and the end-use data depended primarily on the extent to which the household used other fuels (generally wood) for heating; PRISM generally underestimates base use [the first term in eq. (2)] by about 10%. This factor is used to adjust all the PRISM estimates of space heating use developed for this analysis downward to reflect PRISM's upward bias.

In addition to using PRISM with data for individual households, we estimated PRISM models for aggregates of households. We developed aggregate models for (1) respondents to the February 1986 posttest survey in each community that reported use of electricity as a heating fuel; and (2) HRCP participants.

Analysis of aggregate data has advantages and disadvantages compared with analysis of individual household data. Use of aggregate data permits one to ignore problems associated with master meters (multiple dwelling units on a single electricity meter) and household moves. PRISM models developed for individual households are meaningful only if the household/ housing unit combination is unchanged for the full heating season (e.g., July 1983 through June 1984). Changes in occupancy affect PRISM results in two ways. First, a typical move involves one or more months of non- or partial occupancy of the house. Second, the old and new households may differ in composition and in their energy-management practices.

Both factors render estimation and interpretation of household level PRISM models problematic. If movers and stayers differ in their energy-use patterns, results obtained with only stayers will not adequately reflect actual HRCP energy savings. For example, movers are more likely to be renters than homeowners and more likely to live in multifamily units than in single-family homes. Roughly 19% of the housing units retrofit by HRCP experienced a change in occupancy between mid-1983 and the end of 1985. Only 12% of the owner-occupied, single-family homes had a change in occupancy, while 38% of the dwelling units in multifamily buildings had such a change during this 30-month period (Hirst and Goeltz 1986b).

Use of individual household PRISM results to analyze changes in electricity use requires that the data be "balanced." That is, the same households must be used for the two periods (pre- and post-retrofit). Because some households move each year, this requirement reduces the number of observations available for analysis.

Use of aggregate data obviates the need to drop households that moved during either the pre- or post-retrofit time period. Data across housing units are aggregated for each month to produce one monthly bill that reflects average electricity use over all the housing units (both occupied and unoccupied) in the sample. Twelve such average monthly bills are used to estimate eq. (1), the output of which is a NAC estimate for the aggregate as a whole. The average of the meter-reading dates was used to define the appropriate period for computation of HDD.

The major disadvantage of using aggregate data is the loss of information on variation across homes in electricity use and savings. Therefore, the second stage of our approach cannot be implemented with these aggregate models. In addition, use of aggregate data makes it difficult to identify and correct outliers among the individual monthly bills (see Section 3).

CROSS-SECTIONAL MODELS

We assume that the first-stage NAC estimation removes the effects of changing weather and of all other short-run time influences from annual electricity consumption. Cross-sectional variations in NAC are modeled as functions of household characteristics, electricity price, and the serving utility. Time-series variations are modeled as functions of retrofit measures and changes in electricity price, number of household members, and wood use.

In stage two, we pool the data over the four years and across households to analyze NAC as a function of these cross-sectional/ time-series factors:

$$NAC_{ij} = c_o + \sum_k c_k x Z_{ik} \ , \qquad (3)$$

where Z_{ik} is a vector of k demographic and dwelling-unit characteristics (e.g., income, number of household members, floor area of home, age of dwelling unit, type of heating equipment, appliance holdings, participation in HRCP). The c_k coefficients quantify the effects of these factors on weather-adjusted energy consumption. Thus, PRISM computes overall mean values of NAC, while the second-stage models estimate variations in NAC across households and over time.

Information on the Z_{ik} was obtained from the 1986 posttest survey, conducted among random samples of households in the three communities. Data on HRCP participants were also obtained from the Project data base. Because these sources included information on structure and demographic characteristics at only one time, we assumed that these factors remained constant over the four-year period of analysis. Only electricity prices, installation of HRCP measures, and weather varied over time. The 1986 wood-use survey provided additional information on changes in wood use from 1984/85 to 1985/86 for a sample of HRCP participants.

Several diagnostic tests were used to identify problems associated with model misspecification, simultaneity bias and heteroscedasticity. Four tests were used in this model-building process:

Chow (1960) test for parameter consistency,
Lagrange multiplier tests for omitted variables and serial correlation (Godfrey 1978, Engle 1982),
Lagrange multiplier tests for constancy of error variance (Breusch and Pagan 1980, White 1980), and
Hausman (1978) test of random- and fixed-effects specifications.

Results of these tests were used to develop improved models by including more terms in Z, specifying a more realistic error structure, and treating wood use as endogenous.

Our analysis showed that the variance of the household error term was strongly correlated with factors such as income and household appliance holdings, for all specifications of Z. The diagnostic tests also showed that the within-household error covariance was nonzero, suggesting the use of either fixed-effects or random-effects models. These alternative specifications yield more efficient estimates than those obtained with ordinary least squares. Random-effects and fixed-effects specifications, both of which permit the intercept to vary across households, were tested; results of the random-effects models are presented in Sections 4 and 5.

The fixed-effects model examines differences over time for households, by assuming that the mean NAC for each household is a constant. The random-effects model simultaneously analyzes variations across households and time and therefore yields additional information.

An alternative to our two-stage approach is to analyze energy demand in a single-stage model of monthly electricity use that includes all explanatory variables, both HDD and the Z [see Parti and Parti (1980) and Lawrence and Parti (1984) for examples]. We prefer the two-stage approach because it reduces problems of multicolinearity and it yields results that are easier to interpret (i.e., the PRISM results are of interest in their own right, not just as inputs to the second stage). Also, the present approach is computationally simpler because the daily temperature and monthly billing data are used only once, in estimation of eq. (1). Finally, the PRISM weather normalization is more robust than that in the conditional demand approach, in part because the conditional demand method imposes the same reference temperature on each household over the entire analysis period.

Proponents of the conditional demand approach note that our two-stage method aggregates over a great deal of potentially useful information. That is, estimation of the PRISM model collapses the information in 12 electricity bills into NAC and its three components. Use of the original monthly data in a conditional demand model might yield additional insights into household electricity use and savings.

3. HRCP EVALUATION DATA BASE

DATA RESOURCES

Because HRCP was viewed primarily as a research and demonstration project, considerable time and attention were devoted to collecting the data needed to identify and quantify the operation and performance of HRCP. To ensure that the needed data would be available, a detailed plan for data collection, analysis, and evaluation was written about a year before the Project began (PP&L 1982 and 1983).

These data (see Table 1, Fig. 2, and Hirst and Goeltz 1985) include information on participant homes and the appliances therein; demographic characteristics of the household; the retrofit measures recommended and installed; cost of the installed measures; and the dates of audit, beginning of retrofit installation, and completion of retrofits. The Appendix in Philips et al. (1986a) includes the 19 HRCP data-collection forms.

The primary data sets used to analyze changes in electricity use are monthly household electricity bills from PP&L and HREC, and daily temperature data from the NOAA weather station in Hood River, all available from 1980 through June 1986. We use 1982/83 as the preparticipation period and 1985/86 as the postparticipation period. Interpretation of results for 1983/84 and 1984/85 is confounded by the occurrence of retrofits during that time. About 85% of the retrofit jobs were completed in 1985, the vast majority before the 1985/86 heating season began.

Detailed electricity end-use data were obtained from 319 participant homes in Hood River. Information on total, space heating,

Table 1. Data used in evaluation of HRCP

Data	Source	Description
Pretest (1983) mail survey	Oregon State University	Random samples of households in Hood River, Grants Pass, Pendleton, and Pacific Northwest region
Household monthly electricity bills and rate schedules	PP&L and HREC	Households in Hood River, Grants Pass, and Pendleton
Detailed and daily weather data	NOAA, Univ. of Oregon	NOAA weather stations in 3 communities, 3 detailed weather stations in Hood River
End-use load data	PP&L	319 homes in Hood River; 15-minute data on total, space-heat, and water-heat electricity use, and indoor temperatures; wood heat sensors replace water-heater load in 100 homes
On-site home interview	Bardsley & Haslacher	319 load-metered homes, conducted in July 1984
Load monitors on one feeder line	PP&L	
Project data	PP&L	Households that participated in HRCP Marketing questionnaire Demographics and appliance data Energy audits Barriers to retrofit measures Water heating measures installed Cost-effectiveness results Postinstallation inspection
Nonparticipant survey	Bardsley & Haslacher	Telephone interviews in late 1985 with eligible households that did not participate in HRCP
Wood-heat survey	Columbia Research & PP&L	Mail survey in mid-1986 to determine ownership of wood burning equipment and wood use for space heating
Posttest (1986) mail survey	OSU and PP&L	Random samples of households in Hood River, Grants Pass, Pendleton, and Pacific Northwest region

and water heating electricity use as well as on indoor temperatures were collected at 15-minute intervals in these end-use monitored (EUM) homes from mid-1984 through mid-1986. (As part of a followup project, PP&L will continue to collect this load data through mid-1988.) Sensors that monitored the output of wood stoves were used in place of the water heating electricity use monitors in 100 homes. Detailed weather data (also recorded at 15-minute intervals) were obtained from three weather stations in Hood River County. Because the EUM homes were all retrofit in mid-1985, a full year of preretrofit and a full year of postretrofit load data are available for analysis (Stovall 1987).

In addition, information on random samples of households in Hood River and the two comparison communities (Fig. 3) is available. Data for households with permanently installed electric heating equipment in the two comparison communities are used to assess the net electricity savings produced by HRCP. These communities were chosen because they are served by PP&L, pay the same electricity rates as do PP&L customers in Hood River, and are far enough from Hood River to be unaffected by knowledge of HRCP (French et al. 1985). The data include monthly billing data for all households in the three communities. Billing data from PP&L for their customers in the three communities are available from 1977 through mid-1986. Billing data from HREC, which serves about one-third of the households in Hood River, are available from 1980.

NOAA weather stations provide daily temperature data for locations in each of the three communities: Hood River Experiment Station in Hood River, Cave Junction near Grants Pass, and Pendleton Station in Pendleton.

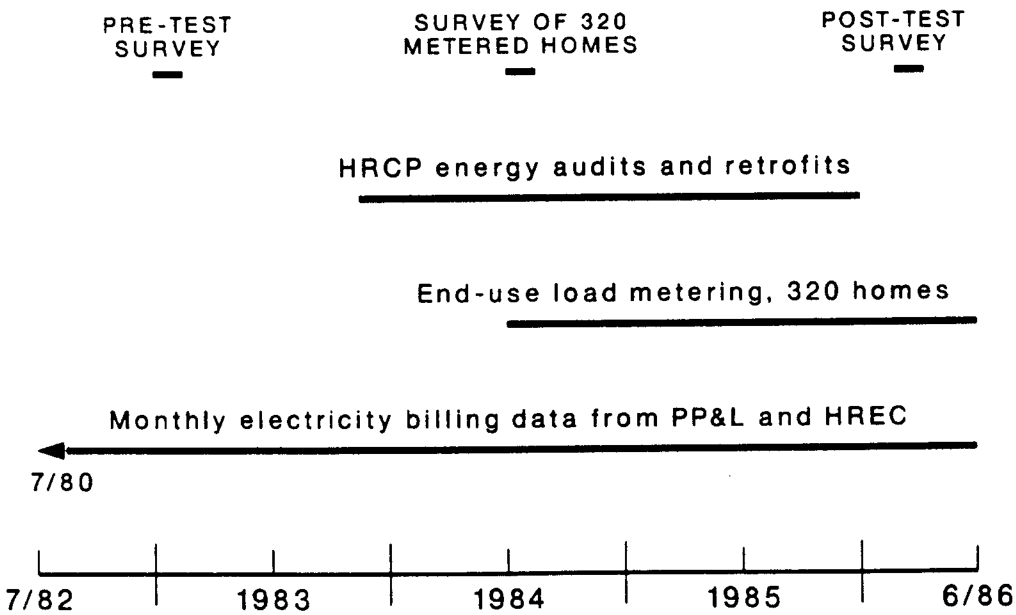

Fig. 2. Timelines of HRCP and its data.

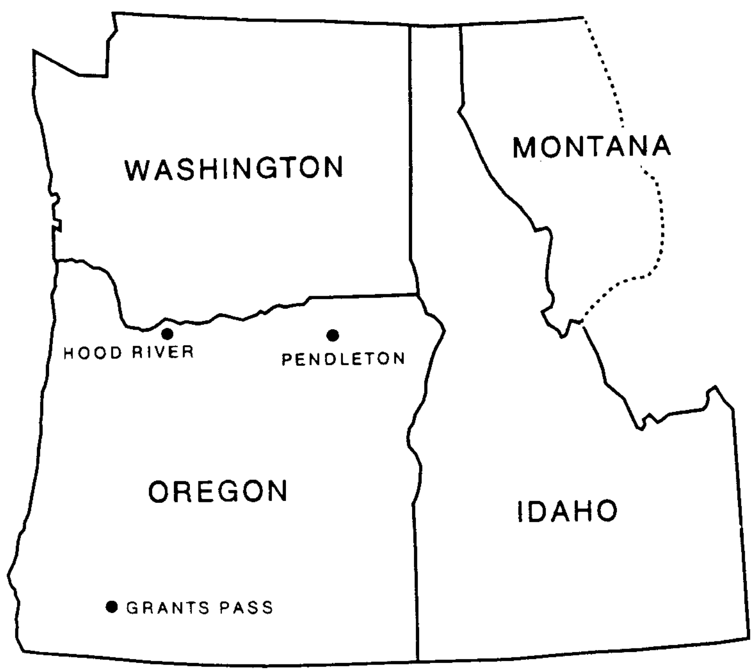

Fig. 3. Map of the Pacific Northwest showing the location of Hood River and the two comparison communities (Pendleton and Grants Pass).

Additional data on household characteristics, household attitudes, dwelling unit characteristics, retrofit measures installed, residential electricity prices, and other factors were obtained from the early 1983 pretest survey and the early 1986 posttest survey (Berg and Bodenroeder 1983 and 1986). The posttest survey is used in the cross-section analysis discussed in Section 5 because the 1983 survey does not include enough questions on the type of electric heating equipment to determine whether respondents met the HRCP eligibility requirements.

DATA QUALITY AND REPRESENTATIVENESS

A crucial consideration in analysis of monthly electricity data is data quality. As with any real-world data set, household billing histories are subject to error (e.g., broken or inaccurate meters and meter-reading errors) and to unusual occurrences (e.g., an occasional long vacation away from home, a broken heating system that is not repaired for several days, or a malfunctioning thermostat). Clearly, these problems have much larger effects on models of individual households than on aggregate models.

Another concern is the use of electricity for space heating. This issue arose because HRCP is focused on electrically heated homes; it purchased "conservation electricity resources" from these homes primarily by installing measures that reduce space heating electricity use. Analysis of homes that do not use electricity for space heating would yield results that are uninformative at best and misleading at worst. Complications occur with homes that use both electricity and another fuel (generally wood) for space heating. As discussed later, roughly 60% of the homes included in these analyses used wood as either their primary or their supplemental heating fuel.

Other data-quality complications concern housing type and movers. While most of the HRCP participants did not move into or out of their homes during the analysis period, enough (19%) moved to complicate the use of individual household/dwelling unit data. As expected, a much larger fraction of multifamily unit occupants than of single-family-unit occupants moved each year.

Careful examination and analysis of individual billing histories can help identify anomalous monthly bills that might be errors and overall patterns that suggest use of nonelectric fuels for some or all the home's space heating needs (Hirst, Goeltz, and White 1984; Fels et al. 1984). We explored several ways to categorize individual household billing histories for accuracy and intensity of electricity use for space heating. After considerable experimentation, we decided on a primary data set and one subset for use in analysis of individual household PRISM results.

The primary data set (called Somefit4) excludes all master-metered dwellings and includes all remaining household-years of billing histories with four or more bills that cover 270 or more days; the norm, of course, is 12 bills covering about 365 days. We used a very conservative approach to the deletion of outliers that might be errors. Households for which the year-to-year change in electricity use exceeded 80% of the prior year's consumption were dropped from the analysis data set. We considered application of additional tests to delete homes with very large NAC and/or DNAC (NAC_i - NAC_1, where i refers to years 2, 3, or 4) values. For example, about 1% of the HRCP participants used less than 4000 kWh/year, and another 1% used more than 45,000 kWh/year. Although some of these "outlier" values may be incorrect, we chose to leave them in the data set. Essentially, we opted for a representative data set, rather than a "clean" one. About 80% of the households in the Project data base are included in Somefit4 (Table 2).

The second analysis data set (called Goodfit4) is a subset of Somefit4. It includes only households whose electricity billing data closely fit the PRISM model - R^2 greater than 0.75, a and b coefficients statistically significant at the 10% level or better, Tref less than the maximum daily outdoor temperature for the entire year (from NOAA data), and Tref standard error less than 20°F - for <u>each</u> year of analysis. Households whose billing histories met these criteria almost surely used electricity for most or all of their space heating needs. These households comprise only small samples (26% of the total) of the HRCP participants (Table 2).

Analysis of electricity use for the three communities, based on household responses to the posttest survey, raises additional problems (Tables 3 and 4). Because we focus on homes that are "eligible" for participation in HRCP, the posttest survey included several questions

Table 2. Disposition of households from the HRCP Project data base

	Number of households, by group		
	Weatherized	Audit only	Nonparticipant[a]
Total	2988	201	311
Somefit4	2362	144	133
Goodfit4	615	57	25

[a]Of the 311 (estimated) nonparticipants, 60 are in the Project data base and 111 are in the Nonparticipant Survey. Attrition is high for this group because 45% of the population are not included in our data bases.

Table 3. Disposition of households from the posttest survey

	Number of households, by community		
	Hood River	Grants Pass	Pendleton
Respondents to survey	570	489	482
"Eligible" for HRCP[a]			
Electricity is:			
primary heating fuel	192	141	108
supplemental heating fuel	129	126	93
Somefit4	281[b]	188	162
Goodfit4	71	45	42

[a]These households reported, in the posttest survey, ownership of electric heating equipment permanently installed before 1983.

[b]Of these 281 Hood River respondents, 216 (77%) were retrofit by HRCP according to the Project data base. This is a much smaller percentage than for the population as a whole (85%).

Table 4. Relationship between household reports of electric heating equipment in the posttest survey and the HRCP data base

Response to posttest survey	In HRCP Project data base? Yes	No
Permanently-installed electric heating equipment is:		
Primary heating source	167	25[a](13%)
Supplemental heating source	85	44[a](34%)
Electricity not used for heating	15[a](8%)	184

[a]The household self-report and the HRCP data base are in conflict for these 84 households, 16% of the 520 survey respondents. The numbers in parentheses are the percentages of discrepancies in each row. For those whose responses to the posttest survey indicate eligibility for HRCP, 21% disagree with the HRCP data base.

concerning the household's "main" and "additional" sources of heating fuels and the type of electric heating equipment (permanently installed or portable) in the house.

Unfortunately, household self-reports were often inconsistent with the HRCP data base (Table 4). Fewer Hood River survey respondents reported participation in HRCP than expected. The Project data base includes more than 90% of the eligible Hood River homes, but the fractions of households that reported use of permanently installed electric heating equipment not in the Project data base are much larger: 13% for those who reported electricity as the primary heating fuel and 34% who reported electricity as their supplemental heating fuel. (On the other hand, 7% of those who said they do not use electricity for heating are in the HRCP data base.) These inconsistencies make it difficult to define an appropriate sample of households for analysis of electricity use. Inclusion of all households that reported use of electricity for heating will underestimate HRCP effects. On the other hand, reliance on the HRCP data base to classify households will bias results because we have no independent confirmation of space heating equipment for the two comparison communities.

For the sake of completeness, we present results in Section 5 for all the households that reported use of electricity as either their primary or supplemental heating fuel. But we rely on only the results from the primary users in our analysis and interpretations.

Our analysis of aggregate data involves only one restriction. We include in the aggregates only households that reported use of electricity as their primary or supplemental heating fuel.

4. ELECTRICITY USE AND SAVINGS: HRCP

SCOREKEEPING RESULTS (STAGE ONE)

Pre-HRCP Electricity Use. PRISM results (Table 5) show that total weather-adjusted electricity use before HRCP was less than 20,000 kWh/year for all three groups - participants (WX), audit only (AO) homes, and eligible nonparticipants (NP). Electricity use for space heating was also quite low, less than 8000 kWh for each of the three groups.

Total and space heating uses averaged 21,000 and 10,000 kWh/year, respectively, for single-family homes that had not participated in prior retrofit programs. These consumption levels continue trends observed historically. For example, participants in BPA's pilot Residential Weatherization Program (RWP) used almost 30,000 kWh/year preretrofit (1980/81). Participants in the BPA regionwide RWP, one and two years later, used 25,000 kWh/year preretrofit (Hirst and Keating 1987); and those that participated in 1985 used 24,000 kWh the year before participation (Bronfman and Lerman 1987).

Watson (1986) observed similar declines over time for space-heating electricity use. BPA's estimates of space-heating use for 1979 and 1980, for example, averaged almost 14,000 kWh. Participants in BPA's pilot program used an average of 14,500 in 1980/81 and participants in the regionwide program used 10,800 a year or two later (Hirst, White, and Goeltz 1985; Goeltz, Hirst, and Trumble 1986). Watson notes that estimates of space-heat use for 1985 were around 11,000 to 12,000 kWh with the "low end of the plausible range" at 6200 kWh.

Table 5. Electricity use and savings for homes that met the eligibility requirements of the Hood River Conservation Program: mean values of PRISM results[a]

	Group		
	Weatherized	Audit only	Nonparticipant
Electricity use (kWh/yr)[b]			
Total NAC			
1982/83	18,600	19,100	17,800
1983/84	18,100	18,400	18,000
1984/85	17,000	18,100	17,300
1985/86	16,000	17,500	17,600
Space heating[c]			
1982/83	7,500	5,300	6,000
1983/84	6,800	5,400	5,500
1984/85	5,500	5,100	4,900
1985/86	4,800	4,600	5,500
Total savings			
1982/83 - 83/84	500	700	-200
1982/83 - 84/85	1,600	1,000	500
1982/83 - 85/86	2,600	1,600	200
Model R^2	0.76	0.79	0.70
Number of households[d]	2362	144	133

[a]These results are based on PRISM models developed for each household in the HRCP data base that met the Somefit4 criteria.

[b]NAC is the sum of baseload and heating components. The heating component is computed on the basis of long-run HDD for each household at its Tref, with different values of the PRISM coefficients for each year.

[c]These numbers have been adjusted to correct for the upward bias in PRISM estimates of space heating electricity use. The formula used is: $SH_{reported} = 1.111 x SH_{PRISM} - 0.111 x NAC$.

[d]The total population includes 2988 weatherized, 201 audit only, and 311 nonparticipant households.

Thus, one important finding concerning HRCP is that residential electricity use in homes nominally heated with electricity was much lower in 1982/83 (and substantially lower still in 1985/86) than most energy planners in the Northwest anticipated. These low levels of consumption before HRCP began were caused by several factors. Inclusion of all housing types in HRCP, rather than primarily single-family homes as in other programs, is one major factor. The dramatic increase in electricity prices during the late 1970s and early 1980s (Table 6) had a substantial effect on household electricity use. During the two years before HRCP began, real (adjusted for inflation) prices increased by 40%.[2]

The importance of electricity prices is clearly shown by the much higher pre-HRCP electricity use for households served by HREC vs those served by PP&L (22,500 vs 16,200 kWh/year; Table 7). The 6300 kWh difference is related to differences in housing types (75% of the HREC participants lived in single-family homes, compared with 60% for the PP&L participants; Table 8), as well as the much lower electricity price paid by HREC customers.

Other forces affecting electricity use were at work during this period. Considerable public awareness of energy issues, knowledge of the potential for saving money through adoption of energy-conservation practices and measures, changes in household income and in the local economy, and the existence of prior utility and government conservation programs all affected household electricity use. For example, almost 10% of the homes retrofit by HRCP had participated in earlier conservation programs operated by PP&L or HREC. As a result, pre-HRCP electricity use was 1500 kWh higher for single-family homes that had not

2. Assuming an own-price elasticity of demand of -0.4 [based on the -0.2 short-run and -0.7 long-run estimates suggested by Bohi and Zimmerman (1984)] yields a 14% decrease in electricity use due to the 40% electricity-price increase from 1980 through 1982. The price-induced decline in electricity use was surely greater, because of pre-1980 price increases (see Schoch, Khawaja, and Peach, 1986).

Table 6. Electricity prices, heating degree days, and unemployment rates in Hood River, Grants Pass, and Pendleton

	Hood River		Grants Pass	Pendleton
	HREC	PP&L		
Electricity prices[a] (1982-¢/kWh)				
1980/81	1.8	3.3		
1981/82	2.2	3.9		
1982/83	2.5	4.7		
1983/84	2.4	4.8		
1984/85	2.3	4.8		
1985/86	2.2	4.7		
Heating degree days (60°F)				
1982/83	3930		3320	3680
1983/84	4310		3180	4220
1984/85	4470		3480	4540
1985/86	4650		3180	4810
long-run[b]	4130		3060	3940
Unemployment rate (%)				
1980/81	11.0		13.6	8.3
1981/82	13.7		14.9	10.4
1982/83	14.2		14.3	11.8
1983/84	13.2		12.7	11.7
1984/85	13.1		11.2	11.6
1985/86	13.1		10.3	11.4

[a]These are the marginal prices charged by the two utilities as of January 1 for each year, normalized by the Consumer Price Index for Portland and Seattle. HREC's monthly customer charge increased sharply during this period, from $3.10 in year 1, to $4.16 in year 2, $5.10 in year 3, $7.30 in year 4, and $8.00 in years 5 and 6; PP&L's monthly charge remained constant at $3 during this period. PP&L prices apply to Grants Pass and Pendleton as well as to their Hood River customers.

[b]For the BPA region as a whole, the long-run HDD is 3730, based on analysis of BPA's Residential Weatherization Program (Hirst et al. 1985a). Values of long-run HDD at a 65°F base are 5570 for Hood River, 4330 for Grants Pass, and 5260 for Pendleton.

participated in a prior program than for those that had participated in earlier PP&L or HREC retrofit programs. Also, the use of wood (probably stimulated by the rapid increases in electricity price and high unemployment) was a major factor in Hood River, as discussed below.

Table 7. Electricity use and savings (kWh/year) for homes retrofit by HRCP, by utility: mean values of PRISM results

	All homes		Single-family		Other types	
	HREC	PP&L	HREC	PP&L	HREC	PP&L
Total NAC						
1982/83	22,500	16,200	23,000	18,000	21,000	13,500
1985/86	18,600	14,400	19,000	16,000	17,400	12,000
Total savings						
1982/83 - 1985/86	3,900	1,800	4,000	2,000	3,600	1,500
Number of households	872	1,490	653	892	219	598

Table 8. Electricity use and savings for homes retrofit by HRCP, by housing type: mean values of PRISM results

	Housing type		
	Single-family	Multi-family	Mobile home
Electricity use (kWh/yr)			
Total NAC			
1982/83	20,400	10,700	19,200
1985/86	17,500	9,200	16,700
Space heating			
1982/83	7,600	5,700	8,500
1985/86	4,600	3,700	6,300
Total savings			
1982/83-85/86	2,900	1,600	2,500
Floor area (ft^2)	1,560	800	1,090
Pre-HRCP Electricity use/ft^2	14.7	13.6	19.2
Total savings/ft^2	2.1	2.1	2.5
Retrofit cost ($)	5,420	2,150	2,350
Number of households	1545	396	421

Unemployment rates (State of Oregon 1986) increased between 1980 and 1983 in all three communities and then declined during the next three years (Table 6). These rates were much higher than for Oregon as a whole. For example, in 1985/86 the 13% unemployment level in Hood River was four percentage points higher than the state average. These high (and during the early 1980s, increasing) unemployment rates affected household use of both electricity and wood, decreasing the former and increasing the latter.

Preprogram electricity use was higher for the WX and AO households than for the nonparticipants. The retrofit homes had the highest level of space-heating electricity use, 40% of total electricity use, compared with about 30% for the two other groups.

Electricity Savings. The overall three-year reduction (1982/83 minus 1985/86) in electricity use was much higher for the WX households than for the other groups, 2600 kWh compared with 1600 for the AO and 200 for the NP households (Fig. 4). In addition to differences among groups by participation, substantial differences occur across households in both pre-HRCP electricity use and savings (Fig. 5). As expected, the reduction in space-heat electricity use was especially dramatic for the participants; the share of total electricity used for space heating declined from 40% in 1982/83 to only 30% in 1985/86; reference temperatures declined by almost 3^{o}F. For the other two groups, the percentage declined much less. These space-heating reductions are consistent with the types of measures installed by HRCP. Although some water-heating measures were installed (see Brown, White, and Purucker 1987), the primary retrofit efforts and, therefore, effects of HRCP related to space-heating electricity use.

The savings for HREC homes retrofit by HRCP were roughly double that for PP&L homes (3900 vs 1800 kWh/year; Table 7), roughly consistent across housing types. This difference is probably primarily

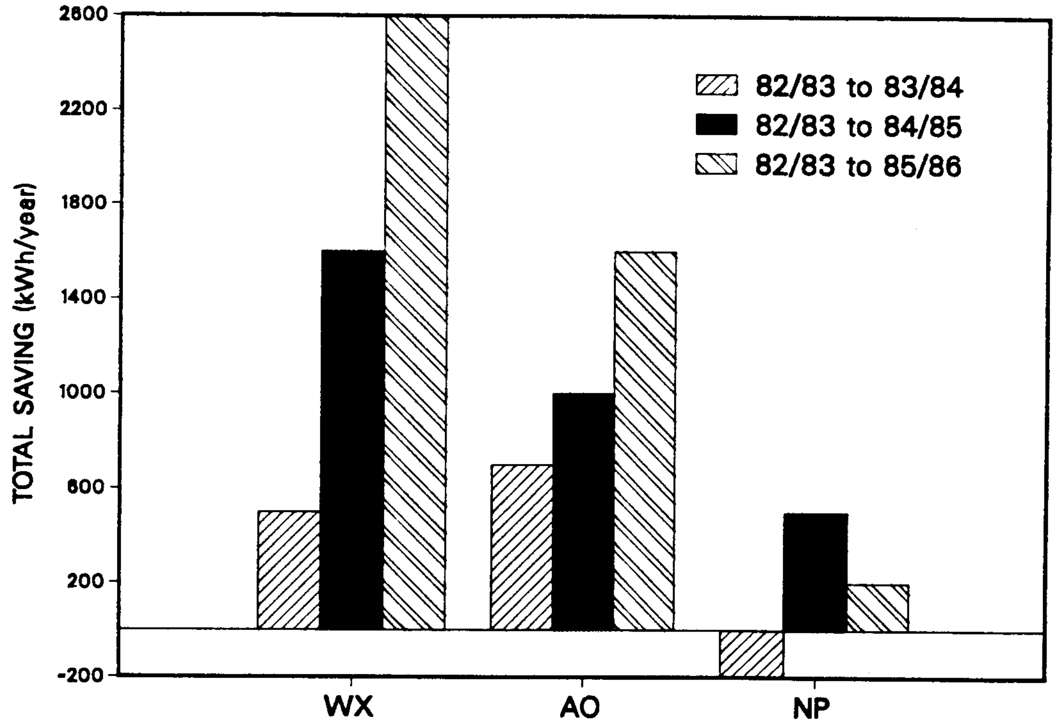

Fig. 4. Electricity savings relative to 1982/83 (pre-HRCP) in the first, second, and third years after HRCP began, by group.

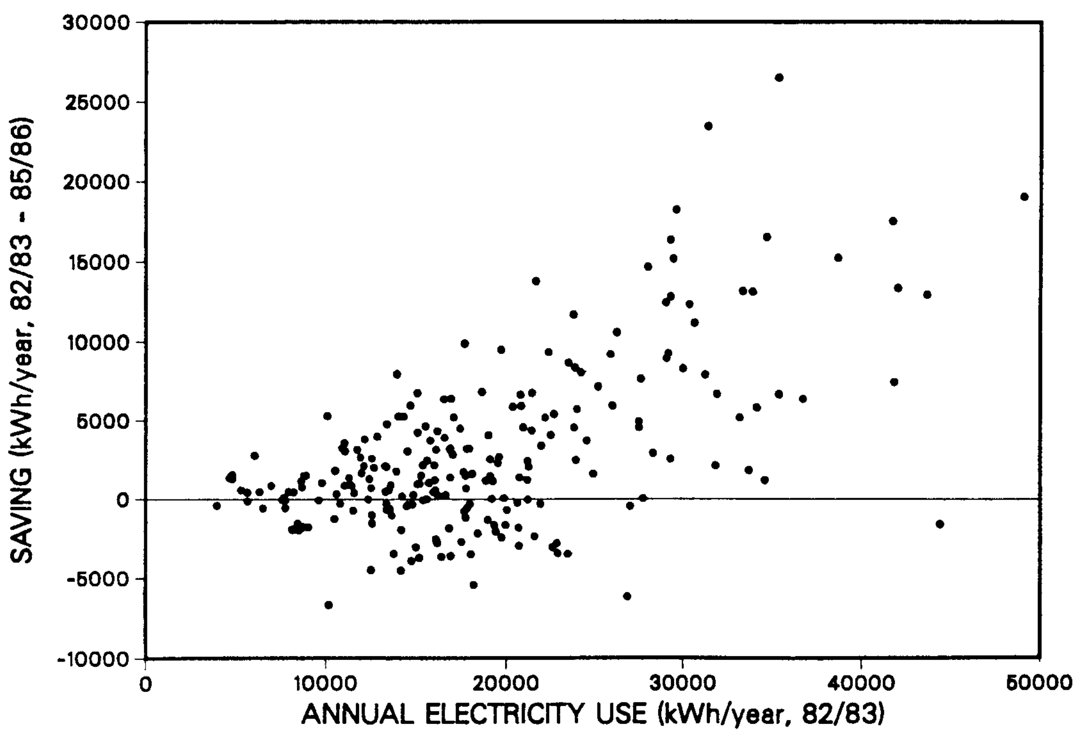

Fig. 5. Electricity savings (1982/83 - 1985/86) as a function of NAC_1 (1982/83) for a random sample of homes retrofit by HRCP.

attributable to the much lower electricity prices faced by HREC customers (Table 6) and the higher fraction of single-family homes in the HREC service area.

The savings averaged 3050 kWh for single-family homes that had not participated in prior retrofit programs, lower than that observed in prior residential retrofit programs in the Pacific Northwest. For example, the one-year saving (pre- vs post-retrofit) averaged 5400 kWh for participants in BPA's pilot program and 4900 kWh for participants (one to two years later) in the regionwide program (Hirst and Keating 1987). These BPA savings are similar to those reported for other residential programs in the region (Burnett 1982; Hannigan and King 1982; McCutcheon 1983; and Weiss and Newcomb 1982). Analysis of end-use monitored data obtained from 68 homes retrofit by PP&L, Portland General Electric, and Puget Sound Power & Light showed average savings (between 1981/82 and 1983/84) of 3700 kWh (Perry, Ritland, and McDonald 1985). Overall, the HRCP savings of 15% of total preretrofit electricity use were comparable to those observed in the BPA program.

Recent (1985) participants in BPA's program provide the most meaningful comparison with HRCP. These BPA participants experienced much lower savings than achieved by earlier participants, roughly 2000 kWh/year (Bronfman and Lerman 1987), substantially less than the 2900 kWh saving achieved by single-family homes retrofit by HRCP. (However, HRCP spent $5400 on retrofit materials and installation, compared with $1900 for the BPA program.) Presumably, these later BPA participants were faced with similar changes in their external environment. The 1985 participants in BPA's RWP saved only 8% of their preretrofit electricity use.

Just as there are several factors that explain the low levels of pre-HRCP electricity use, so there are many reasons for the modest electricity savings: wood use, room closures, indoor temperature settings, electricity price increases, etc. Perhaps the most important reason is the low level of preparticipation electricity use. Analyses of electricity savings after retrofit by BPA's RWP showed that preparticipation consumption (NAC_1) is the single most important determinant of savings; on average a 1 kWh/year increase in NAC_1 increases savings by about 0.25 kWh (Hirst et al. 1985b).[3] This correlation suggests that savings would have been about 1500 kWh higher had pre-HRCP consumption been the same as that for participants in BPA's RWP. Many of the factors that account for low levels of pre-HRCP consumption are reversible (e.g., room closures, temperature settings). Savings that now look modest could increase substantially if energy-use behaviors revert to earlier patterns.

Other factors that affected the HRCP savings include the mix of housing types, the income of participants, changes in the community's economy (especially unemployment), wood use for heating, and participation in prior programs (which reduced the potential for savings by HRCP). Single-family homes retrofit by HRCP saved 3050 kWh if they had not participated in a prior program, compared with only 1960 kWh if they had received earlier retrofit financing from either PP&L or HREC.[4] These factors help explain the large variation in actual savings (Fig.

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3. The correlation coefficient (r) between DNAC and NAC_1 for HRCP participants is 0.53. By comparison, the correlation between DNAC and predicted electricity savings for HRCP-financed measures is only 0.18.

4. The 1090 kWh difference (3050 - 1960) is not the saving due to prior programs because we did not analyze electricity use before 1982/83.

5) and the house-to-house differences between actual and predicted savings (Fig. 6).

HRCP was unlike most retrofit programs in that HRCP sought and obtained participation from all housing types. Most programs, including BPA's RWP, involve primarily single-family homes. Not surprisingly, savings are larger for single-family homes (Tables 7 and 8). On average, the savings in single-family homes (2900 kWh) were almost double those in multifamily units and 15% higher than those in mobile homes. However, the percentage reduction in electricity use, relative to 1982/83 levels, was roughly constant across housing types at almost 15%. Similarly, the savings per unit floor area were similar across housing types, roughly 2.2 kWh/ft^2 (Table 8).

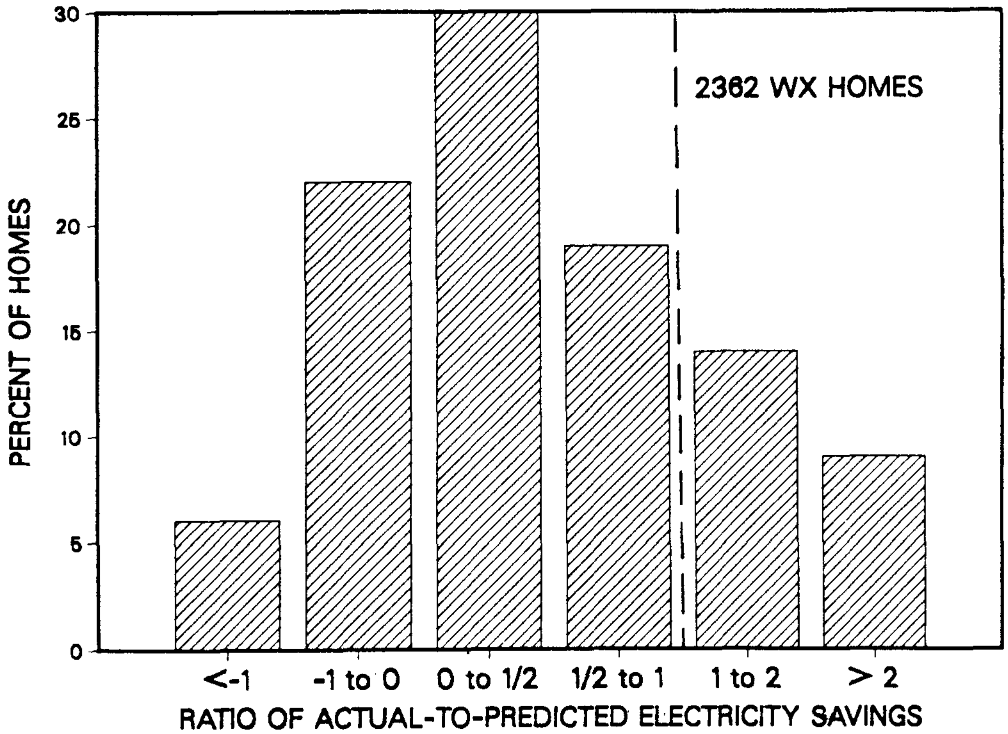

Fig. 6. Distribution of the ratio of actual-to-predicted savings for homes retrofit by HRCP. A ratio of 1.0 means that the actual saving equaled the predicted saving. More than 25% of the homes increased electricity use between 1982/83 and 1985/86.

Savings also are a function of house age (Table 9). Savings are larger for older homes than for newer homes. The savings are almost negligible for homes built during the 1980s, reflecting improvements in new-construction practices during the past several years.

Savings increase with retrofit cost (Table 10), but only up to a point; the correlation coefficient between DNAC and retrofit cost is 0.16. Retrofit costs are closely related to the size and age of the homes: as size and age increase, so do costs. The data suggest that diminishing marginal returns become quite important for retrofit investments beyond about $5000. The Project's focus on 100% participation led to inclusion of many homes with only modest cost-effective potentials for saving electricity. Although the average retrofit cost was $4300, costs exceeded $6000 in almost one-fourth of the homes. Eliminating these high-cost homes cuts the average savings by only 12% but reduces retrofit costs by 33%.

Savings also depend on changes in household behavior, pre- vs post-HRCP. Indoor temperatures were measured in the EUM homes for a full year before and a full year after retrofit. Dinan's (1987) analysis of indoor temperatures across both households and years suggests that households increased indoor temperatures by about 0.6^{o}F after retrofit. Increases were greater in low-income homes and lower in all-electric homes. The effect of this "takeback" was to cut annual electricity savings by 200 to 400 kWh per home.

Table 9. Electricity use and savings for homes retrofit by HRCP, by year house built: mean values of PRISM results

	Year house built					
	<1930	1931-60	1961-70	1971-76	1977-79	>1979
Electricity use (kWh/yr)						
Total NAC						
1982/83	19,600	18,600	18,800	19,700	17,400	14,400
1985/86	16,800	15,500	15,700	17,000	15,300	14,300
Space heating						
1982/83	8,400	7,100	7,600	8,400	6,800	5,000
1985/86	5,000	4,000	5,000	5,600	4,400	4,000
Total savings						
1982/83-85/86	2,800	3,100	3,100	2,700	2,100	200
Number of households	361	525	436	509	367	161

Table 10. Electricity use and savings for homes retrofit by HRCP, by retrofit cost:[a] mean values of PRISM results

	Retrofit cost ($)					
	<1500	1501-3000	3001-4500	4501-6000	6000-7500	>7500
Electricity use (kWh/yr)						
Total NAC						
1982/83	15,100	15,900	18,000	19,800	21,800	23,200
1985/86	14,100	13,700	15,800	16,000	18,400	19,700
Space heating						
1982/83	6,200	6,800	7,000	8,000	8,100	9,300
1985/86	5,100	4,500	4,600	4,200	5,200	5,300
Total savings						
1982/83-85/86	1,100	2,100	2,200	3,700	3,400	3,500
Floor area (ft^2)	1,100	1,060	1,250	1,350	1,640	1,930
Year built	1972	1967	1959	1954	1950	1945
Number of households	374	539	395	429	287	338

[a]Retrofit costs are a function of house size and age, as well as the measures installed.

Wood Use. Wood use is a crucial factor in explaining differences between HRCP and other programs. Wood use has two relevant aspects. First, homes that use wood for some or all of their heating will, all else equal, use less electricity and will experience smaller electricity savings after retrofit. Second, households may use less wood after retrofit than before, further reducing the electricity savings. In other words, some people will take the efficiency improvements associated with HRCP-financed retrofits partly in terms of reduced electricity bills and partly in terms of increased convenience and comfort.

We examine wood use in several ways because of its complexity and importance. First, comparison of the Goodfit4 homes with the other homes shows the effects of wood use on electricity use. The Goodfit4 households used 12% more electricity pre-HRCP than did participants overall (21,000 vs 18,600 kWh; compare Tables 5 and 11). These households also saved almost 25% more than did participants overall, 3200 vs 2600 kWh. For single-family Goodfit4 homes, pre-HRCP consumption averaged 24,400 kWh (close to the value for the 1985 participants in BPA's RWP) and their four-year savings were 4000 kWh (double the BPA savings). Single-family homes that had not participated in a prior program saved 4500 kWh, compared with only 2200 kWh for prior participants.

Because wood use is such an important determinant of electricity use, a survey of HRCP participants was conducted in mid-1986 to better understand the patterns and trends of wood use among these households (Kaplon 1987). The survey included questions on primary and supplemental heating fuels and on the amount of wood burned during the

Table 11. Electricity use and savings for homes retrofit by HRCP that probably used electricity as their primary heating fuel[a]

	Total	Housing type		
		Single-family	Multi-family	Mobile home
Electricity use (kWh/yr)				
Total NAC				
1982/83	21,000	24,400	10,600	20,800
1983/84	20,600	23,900	10,800	20,400
1984/85	19,100	21,600	10,200	20,000
1985/86	17,800	20,400	8,700	18,800
Space heating				
1982/83	9,200	10,300	5,000	9,700
1983/84	8,800	9,800	5,000	9,200
1984/85	7,500	8,000	4,200	9,000
1985/86	6,600	7,000	3,200	8,100
Total savings				
1982/83 - 83/84	400	500	-100	400
1982/83 - 84/85	1,900	2,800	500	800
1982/83 - 85/86	3,200	4,000	1,900	2,000
Model R^2	0.95	0.94	0.95	0.96
Floor area (ft^2)	1,360	1,670	810	1,010
Pre-HRCP use/ft^2	16.8	16.0	13.1	21.8
Savings/ft^2	2.5	2.8	2.4	2.0
Retrofit cost ($)	4,080	5,480	2,080	2,070
Number of households	615	362	115	138

[a]These results are based on PRISM models for households that met the Goodfit4 criteria: model $R^2 > 0.75$, the PRISM coefficients significant at the 10% level or better, Tref < maximum outdoor temperatures, and the standard error of Tref < 20°F for each of the four years.

1984/85 and 1985/86 heating seasons. Almost two-thirds (66%) of the survey respondents reported electricity as their primary heating fuel, while 31% reported wood as the primary fuel. An additional 28% used wood as a supplemental fuel. Thus, almost 60% of the HRCP participants used some wood for heating during 1985/86.[5]

The survey asked "what percentage of your space heating is provided by wood." Responses showed that electricity use declined as the percentage reported for wood increased: homes in which wood provided more than three-fourths of the space heating used 6000 kWh less in 1985/86 than did homes in which wood provided less than one-fourth of the total. The difference in 1982/83 was higher, 6800 kWh/year.

Comparison of NAC estimates for the Somefit4 and Goodfit4 households (Tables 5 and 11) shows differences in electricity use less than half that implied by the wood-use survey results: 3200 kWh in 1982/83 and 2400 kWh in 1985/86. These differences are reasonable because some of the Goodfit4 households probably used wood as a supplemental heating fuel. Also, the comparison of Goodfit4 and Somefit4 results implicitly reflects the fact that many homes that use wood do not rely on wood as their primary heating fuel.

Of those who used no fuels other than electricity and/or wood for heating, 68% reported no change in (including no use of) wood use between 1984/85 and 1985/86, 9% reported an increase in wood use (an average of 1.5 cords), and 23% reported a decrease in wood use (an average of 2.4 cords). Thus, overall wood use decreased between the two heating seasons by an average of 0.4 cords. This decrease in wood use was also observed in comparing the pre- and posttest mail surveys,

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5. The pre- and posttest surveys (discussed in the following section) showed similar results: almost 60% of the Hood River respondents used electricity as their primary heating fuel, about a third used wood as the primary fuel, and almost 60% used some wood for heating. Similarly, the on-site home interviews conducted among 314 end-use monitored homes in mid-1984 showed that 61% of these HRCP participants used electricity as their primary fuel, 39% used wood as their primary fuel, and 74% used some wood.

discussed in the following section (Table 16).

NAC results were merged with wood-survey responses to examine changes in electricity use as a function of changes in wood use (Fig. 7). A decrease in wood use of one cord/year increases electricity use by about 800 kWh/year, higher than the 500 kWh/cord observed among homes in BPA's RWP (Hirst et al. 1985b). This suggests that the 0.4 cord/year average reduction in wood use among HRCP participants (in general, not just those that used wood) between 1984/85 and 1985/86 led to an increase in electricity use of approximately 300 kWh/participant.

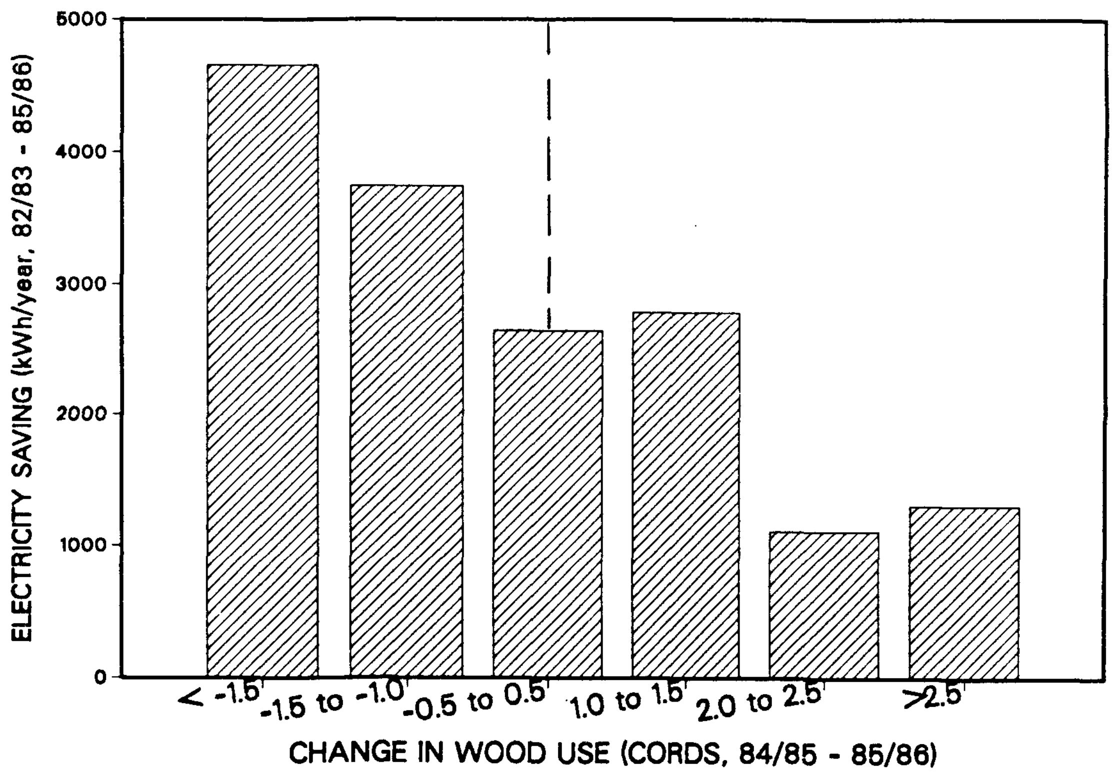

Fig. 7. Four-year electricity savings as a function of one-year changes in wood use (1984/85 vs 1985/86).

The EUM homes provide another view of changes in electricity and wood uses. Simple comparisons of annual summations of the electricity-use-channels from 1984/85 and 1985/86 are meaningful because these homes were all retrofit in mid-1985 and because the two years differed by only 4% in HDD. After deleting homes with missing data, 189 had two full years of data for both total and space heating electricity uses. Eliminating the homes that received HRCP measures beyond the cost-effectiveness limit reduces the number to 141. Of these homes, 32 were monitored for wood use and had two full years of reliable wood-use data. Outputs from the wood channel were calibrated to reflect the energy output of each stove in terms of kWh (Oliver et al. 1984).

Wood use in these 32 homes declined by the equivalent of 1800 kWh/year between 1984/85 and 1985/86. Nonspace-heating and space heating electricity uses dropped by 700 and 1000 kWh/year, respectively. Thus, total space-heating energy use (electricity plus wood) dropped by 2800 kWh, 22% of the pre-HRCP level. However, the 1800 kWh decline in wood use was 26% of pre-HRCP wood use. Thus, 300 kWh of the reduction in wood use (and consequent "loss" of electricity saving) occurred because of changes in household wood-use behavior, consistent with the estimate based on the wood-use survey, discussed above.

The one-year electricity saving among the EUM homes in general differed substantially by primary heating fuel, based on the 141 homes examined below. Homes with electricity as the primary fuel saved almost 2600 kWh, compared with only 1000 kWh for wood-heated homes.

In summary, some of the efficiency gains produced by the HRCP retrofits were taken in reduced wood use, amounting to roughly 300 kWh/year when averaged over all HRCP participants. In addition, prior levels of wood use cut electricity use by at least 3000 kWh/year. These results are consistent with other analyses of wood use in the Pacific Northwest (Tonn and White, 1986). In general, homes retrofit by BPA's RWP that used electricity as a supplemental fuel saved less electricity than those that used electricity as the primary heating fuel.

Post-HRCP electricity use. Average levels of electricity use after installation of retrofit measures (1985/86) were very low, because of the low levels of pre-HRCP electricity use and the savings produced by the HRCP retrofit measures (Tables 5, 7, 8 and 11). Single-family homes retrofit by HRCP used less than 18,000 kWh/year after retrofit, compared with 22,000 kWh for homes retrofit by the BPA program in 1985.

Space-heating electricity use in HRCP single-family homes heated primarily with electricity averaged 7000 kWh/year, equivalent to 4.2 kWh/ft^2. This is 25% less than that for new homes constructed during the early 1980s (Meier et al. 1986). It is only 25% higher than the level achieved by new homes that meet the Regional Council's Model Conservation Standards. Levels of electricity use were even lower among HRCP single-family homes that relied heavily on wood and among other housing types.

Watson (1987) reviewed post-retrofit levels of electricity use among homes retrofit by other programs throughout the U.S. His search suggests that post-HRCP levels of space-heating electricity use are less than half that achieved in other programs.

Comparison of PRISM with Other Results. As a check on the accuracy of the PRISM results, we compare load-research data from the EUM homes with PRISM results. Specifically, we compare the annual totals of the whole-house and space-heat uses with PRISM estimates of NAC and space-heating electricity use (adjusted as described earlier). The comparisons are done separately for homes with electricity as the primary vs supplemental heating fuel, as reported in the mid-1984 interviews (Table 12).

Differences in estimates of total annual electricity use are quite small, about 400 kWh (less than 3%). As a consequence, differences in estimates of the one-year savings are also small - 300 kWh for primary-heat homes and 100 kWh for supplemental-heat homes. The estimates of annual space heating use are also similar, differing by only about 300 kWh. These comparisons lend confidence to our use of PRISM as the primary analytical tool to examine electricity use and savings and to our adjustment of PRISM's space-heat estimates.

Table 12. Comparison of PRISM results with end-use monitored data (kWh/yr)[a]

	Total use		Space-heat use	
	PRISM	EUM	PRISM	EUM
Electricity is primary heating fuel (n = 106)				
Annual electricity use				
1984/85	21,800	22,000	8,800	9,100
1985/86	19,300	19,900	7,700	7,600
Savings	2,500	2,200	1,100	1,500
Electricity is supplemental heating fuel (n = 67)				
Annual electricity use				
1984/85	17,100	17,400	3,500	3,000
1985/86	16,200	16,600	2,400	2,500
Savings	900	800	1,100	500

[a]The second year (1985/86) was only 4% colder than the first year (see Table 6) so there is little need to weather-adjust these results. PRISM estimates are computed with long-run temperature data, with 8 to 12% fewer HDD than the two years examined here. Thus, PRISM results are slightly low.

Finally, we estimate community-level models. These models pool all the monthly bills for each group, WX, AO, and NP, and estimate PRISM models with these aggregate bills. These community models include higher fractions of multifamily units with changes in occupancy than do the individual household models. The community model for the WX households, with 2834 "bills," shows a pre-HRCP NAC of 18,400 kWh, only 200 kWh lower than that obtained with the individual household models (Table 5). However, post-HRCP NAC is slightly higher than that obtained with the individual models, yielding four-year savings of 1600 kWh with the community models, compared with 2600 kWh with the individual models.

CROSS-SECTIONAL MODELS (STAGE TWO)

The NAC values computed above were used as the dependent variable in pooled time-series/cross-section models for homes retrofit by HRCP. The purpose of these "stage two" models is to control for the effects of several factors in examining electricity savings and to explain how these factors affect NAC. These models used data on household demographics, structure characteristics, appliance holdings, and HRCP retrofit costs as explanatory variables, all from the Project data base.

Because single-family homes accounted for two-thirds of all retrofit dwelling units, we focused on this housing type. Two sets of models were estimated, one for all households with sufficient data and the second for the subset that responded to the wood use survey (Table 13). The second set of models provides additional insights into the effects of wood use on electricity use and savings.

Table 13. Time-series/cross-section model results for single-family homes in Hood River that were retrofit by HRCP

Explanatory variable	All homes[a]		Respondents to wood use survey[b]	
	Model coefficient	t statistic[c]	Model coeff	t stat[c]
Constant	5470	4.6	7860	6.6
Participation dates[d]				
Audit	-375	2.0	-102	0.4
Retrofit begun	-1840	7.0	-1060	3.0
Completion	-1000	3.9	-2020	5.4
HRCP retrofit cost ($)	-0.135	3.8	-0.206	4.5
HRCP retrofit costxHREC	-0.271	8.6	-0.109	1.9
Audit prediction of savings (kWh/year)	0.236	4.7	0.190	3.2
Area of glass (ft^2)	10.2	2.8	7.5	1.8
Floor area (ft^2)				
AreaxHeat pump	2.76	4.4	3.34	4.9
AreaxCentral furnace	2.28	4.1	2.72	4.0
AreaxBaseboard	3.45	5.6	4.01	4.5
AreaxPortable heaters				
used extensively	-0.431	1.6	--	--
used modestly	-0.955	2.5	--	--
Appliances[d]				
Freezer	351	1.0	785	1.6
Refrigerator	1720	3.7	412	0.8
Air conditioner	1210	3.3	--	--
Dishwasher	85	0.2	965	1.7
Pump	400	1.1	--	--
Pool	7730	3.7	--	--
No. of household members (HH)	614	1.2	1490	6.5
HHxHH	78.3	1.1	-65.0	5.4
Household income ($)	0.037	2.2	0.042	2.0
Electricity price (1982-¢/kWh)	-376	2.4	-294	1.5
Served by HREC[d]	4310	9.3	2720	3.6
Wood-burning equipment[d]				
Furnace	--	--	-2630	1.1
Stove	--	--	-2690	3.8
Fireplace insert	--	--	-2180	2.5
Fireplace	--	--	1170	1.8
Wood use (cords/yr)	--	--	-511	2.3
Wood usexCompletion date	--	--	466	6.0

[a]Based on 5032 observations (1258 households times 4 years). This sample is restricted to single-family homes that were retrofit by HRCP, with four years of usable billing data.

Table 13. continued

[b]Based on 1840 observations (460 households times 4 years). These households are the subset of the prior sample that responded to the wood use survey.

[c]Corrected for heteroscedasticity using the White (1980) method.

[d]These are binary (0,1) variables. The participation variables are equal to one between the date identified and the date of the next phase. Thus, the binary variable for Retrofit begun is one only during the time between start of retrofit installation and completion of work.

Results of the random-effects model (left half of Table 13) show small savings (375 kWh/year) after the energy audit, probably because of the four low-cost measures installed during the audit (water-heater wrap, low-flow showerheads, hot and cold water pipe wrap, and outlet gaskets). The savings caused by HRCP-financed retrofits depend on retrofit cost and on whether the home is served by HREC or PP&L. The model suggests average savings after retrofit of 2300 kWh,[6] less than the 2900 identified by the NAC results alone (Table 8). The incremental saving per retrofit dollar for HREC customers was more than double that for PP&L customers (0.406 vs 0.135 kWh/$), probably because HREC customers had much higher levels of pre-HRCP electricity use (4310 kWh higher according to model results).

Results show that electricity use increases with the number of household members, with an elasticity of 0.2. (Elasticities reported here should be considered long-run usage estimates because they are conditional on the appliance stock holdings reported at one time.) An increase in household members from three to four, for example, increases

6. The average retrofit cost was $5420 for single-family homes, 37% of which were served by HREC. Thus, the overall electricity saving estimated by the model is $1000 + (0.135 + 0.271 \times 0.37) \times 5420 = 2275$ kWh.

electricity use by 1200 kWh.

Both household income and electricity price have statistically significant effects on electricity use, with elasticities of 0.06 and -0.08, respectively. The coefficient of electricity price should be viewed cautiously because there were only two prices for each of the four years.

The presence of different kinds of electric appliances and equipment affects usage. The swimming-pool coefficient is much too high; it probably includes an income effect. The coefficients for pumps, dishwashers, and freezers are statistically insignificant.

Electricity use increases with house floor area at a rate that depends on the type of heating equipment. Consumption increases by about 3 kWh/ft^2. Electricity use is lower in homes that use portable heaters than in those that do not, by 0.431 kWh/ft^2 for homes that make extensive use of portables and by 0.955 kWh/ft^2 for homes that make modest use of portables. Presumably, portable heaters are used primarily to heat only certain zones of the house and thus permit room closures in winter, which reduces electricity use.

A similar model was estimated for households that responded to the wood use survey (right half of Table 13). The additional data for these households permit estimation of the effects of wood use, of different types of wood-burning equipment, and of changes in the number of household members on electricity use and on postretrofit savings. Wood use was treated endogenously, through inclusion of an instrumental variable in the model; this corrects for the effects of simultaneity bias. This model shows HRCP-induced savings of 3360 kWh for homes that did not use wood, compared with 2050 kWh for homes that used wood.[7] This difference is almost the same as that observed between the Somefit4 and Goodfit4 homes (Tables 8 and 11). The overall and post-HRCP wood-use coefficients show reductions of about 500 kWh/cord, lower than the estimates developed above (800 and 900 kWh/cord).

Almost all the mobile homes were retrofit just before or during the last heating season of this analysis (1985/86). Therefore, it is very difficult to identify the HRCP-induced electricity savings for this housing type. The fixed-effects model for the 180 mobile homes completed before the 1985/86 heating season showed a saving from HRCP retrofits of 1230 kWh for homes in the PP&L area and 1860 kWh for homes in the HREC area, much lower than savings obtained with PRISM results alone (Tables 7 and 8).

Almost all the multifamily units in the Project were in the PP&L area (97%), had central heat (99%), and did not use wood (99%). This lack of variation made it difficult to estimate useful random-effects models. Results of the fixed-effects model for the 217 multifamily units in the data base showed average savings of 1590 kWh, close to the estimate obtained with PRISM results alone (Table 8).

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7. The savings are computed from $2020 + (0.206 + 0.109 \times 0.37) \times 5420 - 466 \times 2.8 \approx 2050$ for wood users (3355 for nonwood users, excluding the last term). The wood-use term is based on 2.8 cords/year.

5. ELECTRICITY USE AND SAVINGS: THREE COMMUNITIES

The preceding section examined changes in electricity use for households in the HRCP data base, especially those that received HRCP-financed retrofits (WX). Here we analyze electricity use and its changes for respondents to the early 1986 posttest survey.

This survey was mailed to random samples of households in Hood River, Grants Pass, and Pendleton. The survey included questions on fuel use and equipment for space heating to identify households that met the HRCP eligibility requirements. As noted earlier (Table 4), discrepancies were often found between the household self-reports and the HRCP data base: 21% of the Hood River respondents who reported meeting the eligibility requirements were not in the HRCP data base; however, only 7% of the eligible households were not in the data base (Hirst and Goeltz 1986b). These discrepancies complicate interpretation of PRISM results for the posttest respondents. We present results for those who reported electricity as the primary or supplemental heating fuel; however, we think that those using electricity as their primary fuel are more nearly representative of those eligible for HRCP.

SCOREKEEPING RESULTS (STAGE ONE)

Pre-HRCP electricity use levels are generally below 20,000 kWh in all three communities (Table 14), confirming the low levels discussed above. As expected, electricity use is substantially higher for homes that use electricity as the primary, rather than supplemental, heating fuel: 3400 kWh higher in Hood River, 5000 kWh in Grants Pass, and 2400 kWh in Pendleton. Electricity use in Hood River was higher than in the other two communities by about 10%, regardless of whether electricity

Table 14. Electricity use and savings for homes with electric heating equipment in the three communities, by use of electricity as primary or supplemental heating fuel: mean values of PRISM results[a]

	Hood River		Grants Pass		Pendleton	
	Primary	Supplemental	Primary	Supplemental	Primary	Supplemental
Electricity use (kWh/yr)						
Total NAC						
1982/83	20,100	16,700	18,300	13,300	18,000	15,600
1983/84	19,100	16,300	18,000	12,800	18,400	14,200
1984/85	17,700	15,700	18,100	12,400	18,500	13,800
1985/86	16,800	15,100	18,500	12,200	18,500	13,000
Space heating						
1982/83	9,200	4,300	5,300	700	5,800	2,000
1983/84	8,400	3,400	5,400	200	6,600	900
1984/85	7,000	2,700	5,200	300	4,800	1,300
1985/86	6,000	2,100	5,000	0	5,900	300
Total savings						
1982/83 - 83/84	900	400	400	500	-500	1,500
1982/83 - 84/85	2,300	1,100	200	800	-500	1,800
1982/83 - 85/86	3,300	1,600	-100	1,100	-500	900
Model R^2	0.82	0.61	0.80	0.46	0.82	0.54
Number of households[b]	170	111	96	92	87	75

[a]See footnotes for Table 5.

[b]The percentages of homes in each community that use electricity as the primary heating fuel are 60% in Hood River, 53% in Grants Pass, and 54% in Pendleton (Table 3).

was the primary or supplemental heating fuel. This occurs because HREC customers used 30 to 40% more electricity than did PP&L customers in Hood River, probably because of lower electricity prices (Table 6).

The weighted mean value of NAC_1 for the Hood River respondents (18,700 kWh) is almost identical with the mean value obtained by taking the weighted average of the households in the HRCP project data base (Table 5). Similarly, the three-year savings for Hood River respondents

(2600 kWh from Table 14)[8] are only slightly larger than that obtained with the HRCP data base (2300 kWh). This encouraging agreement is surprising, given the discrepancies between household self-reports and the Project data base.

The three-year reduction in electricity use was much higher in Hood River than in the other two communities: 2600 kWh vs 500 kWh in Grants Pass and 100 kWh in Pendleton. If the Grants Pass and Pendleton data are averaged, these results suggest that the net effect of the Project was savings of 2300 kWh per household.

As expected, total savings for primary-electric heat homes were much higher than for supplemental-electric heat homes in Hood River: 3300 vs 1600 kWh. The net savings attributed to HRCP averaged 3600 kWh for homes with primary electric heat and only 600 kWh for homes with supplemental electric heat. The small net savings for supplemental-heat homes results from the unexpectedly large savings for such homes in the two comparison communities.

We also estimate PRISM models using community-level data, in which all the billing data for each community are aggregated into one monthly "bill." These results (Table 15) include more multifamily units than the individual-household models. As a result, pre-HRCP NAC values are generally lower for the community models than for the individual models (compare Tables 14 and 15); Grants Pass is an exception because a much larger fraction of their billing data failed the Somefit4 tests than failed in the two other communities. Similarly, reductions in electricity use are smaller with the community models with Grants Pass

8. 2600 kWh = 3300x0.58 + 1600x0.42, with 58% of the Hood River homes reporting electricity as their primary heating fuel (Table 16).

being an exception again.

The pre- and posttest surveys provide interesting snapshots of the three communities in early 1983 (before HRCP began) and in early 1986 (after HRCP retrofits were all installed). Both surveys included questions on primary and supplemental heating fuels. Responses to these questions show that electricity was the primary heating fuel in more than half the homes, both pre- and post-HRCP (Table 16). The percentages of households that reported electricity as the primary fuel remained essentially constant in Hood River, increased slightly in Grants Pass, and dropped dramatically (by 12 percentage points) in Pendleton.

More than half the households in Hood River and Grants Pass used wood as either the primary or supplemental heating fuel (compared with less than half in Pendleton), both before and after HRCP. Overall, wood use decreased in Hood River (pre- vs post-HRCP), especially as the primary fuel; wood use increased in the two comparison communities. This suggests that the HRCP retrofits made it easier for participants to reduce wood use, consistent with the earlier discussion of wood use (Section 4).

CROSS-SECTIONAL MODELS (STAGE TWO)

We used NAC values for each household for four years as the dependent variable in pooled time-series/cross-sectional models. Data for the explanatory variables were obtained from the 1986 posttest survey. The models estimated here are restricted to homes that met the HRCP eligibility requirements and whose billing data met the Somefit4 criteria. Separate models were developed for single-family, multifamily, and mobile-home units.

Table 15. Electricity use and savings for homes with electric heating equipment in the three communities: community-level models

	Hood River		Grants Pass		Pendleton	
	Primary	Supplemental	Primary	Supplemental	Primary	Supplemental
Electricity use (kWh/yr)						
Total NAC						
1982/83	19,300	15,600	18,500	13,700	17,100	14,200
1985/86	17,100	15,300	18,300	12,500	18,300	12,600
Total savings						
1982/83 - 85/86	2,200	300	300	1,200	-1,100	1,600
Model R^2	0.98	0.97	0.97	0.85	0.95	0.91
Number of households	192	129	141	126	108	93

Table 16. Household reports of primary and supplemental heating fuels in the pre- and posttest surveys[a]

	Percentage of households reporting		
	Electricity is primary heating fuel[b]	Use of wood	
		Primary heating fuel	Total[c]
Hood River			
Pretest	59	34	58
Posttest	58	31	57
Grants Pass			
Pretest	50	40	63
Posttest	53	39	64
Pendleton			
Pretest	61	21	39
Posttest	49	28	47

[a]These results are based on responses from 1070 households to the early 1983 pretest survey and from 1096 households to the early 1986 posttest survey.

[b]All these households met the eligibility requirements for participation in HRCP; therefore they all used electricity as either their primary or supplemental heating fuel.

[c]Total is the sum of the percentages who reported wood as their primary or supplemental heating fuel.

Single-family homes accounted for two-thirds of the participant homes (and three-fourths of the homes analyzed here; Table 14). The random-effects model (Table 17) shows HRCP-induced (net) savings of 2690 kWh/year for homes that used electricity as the primary heating fuel and 1570 kWh/year for homes that used electricity as a supplemental heating fuel. Overall, the net electricity saving caused by HRCP is 2300 kWh, close to the estimate obtained with the NAC results alone (Table 14).

Electricity use increases at almost 100 kWh/year for each $1000 increase in household income. Electricity use decreases by about 700 kWh per 1¢ increase in electricity price. The elasticities estimated with this model, which assume fixed capital stocks of appliances, are 0.14 for income and -0.20 for price. Because cross-sectional variation in electricity prices was limited (with only two utilities serving all households), the price elasticity computed here should be viewed cautiously. Dubin and McFadden (1984) in their study of households throughout the U.S., obtained short-run income and price elasticities of 0.06 and -0.16.

Electricity use increases with the number of household members at a slightly diminishing rate. For example, an increase in occupancy from two to three increases electricity use by 1300 kWh, while an increase from three to four increases use by 1200 kWh. The elasticity with respect to household members is 0.19.

Floor area is positively related to electricity use, especially for homes that use electricity as the primary heating fuel. Annual electricity use increases almost 7 kWh/ft^2 in homes with primary electric heat and 3 kWh/ft^2 in homes with supplemental electric heat. The elasticities are 0.50 and 0.22, respectively.

Table 17. Time-series/cross-section model results for electric-heat, single-family homes in Hood River, Grants Pass, and Pendleton[a]

Explanatory variable	Model coefficient	t statistic[b]
Constant	1530	4.1
Income (1986-$)	0.0950	3.9
Number of household members (HH)	1563	2.4
HHxHH	-55.2	0.7
House floor area (ft^2)		
Floor areaxPrimary[c]	6.51	9.0
Floor areaxSupplemental[c]	2.82	3.3
Electricity price (1982-¢/kWh)	-740	3.9
Served by HREC		
HREC[d]	10100	3.6
HRECxPrimaryxFloor area	-3.44	2.0
HRECxSupplementalxFloor area	-3.69	2.0
Participation dates[d,e]		
CompletionxPrimary[c]	-2690	7.3
CompletionxSupplemental[c]	-1570	3.5

[a]Based on 1624 observations (406 households times 4 years). This sample is restricted to single-family homes with electric space heating equipment, eligible for HRCP, and with four years of usable electricity billing data.

[b]Corrected for heteroscedasticity using the White (1980) method.

[c]Primary means that electricity was reported (in the posttest survey) as the primary heating fuel. Supplemental means that electricity was a supplemental heating fuel.

[d]These are binary (0,1) variables.

[e]These coefficients are all zero for households that did not receive HRCP-financed retrofits.

The three HREC variables show that, all else equal, homes served by HREC use about 5400 kWh/year more than do the homes served by PP&L. This difference is probably caused by HREC's lower electricity prices (Table 6) and the larger homes in its predominantly rural service territory.

We also estimated models for multifamily homes and for mobile homes. Unfortunately, the small sample sizes (74 mobile homes and 54 multifamily units) and the existence of a few outliers in these data sets led to unstable results. The mobile-home results, for example, showed no savings for homes that used electricity as the primary heating fuel and savings of about 1900 kWh for homes that used electricity as a supplemental fuel. Dropping the outliers (about 10% of the observations) led to a statistically significant savings for primary-heat homes (1800 kWh). The model for primary-heat multifamily units showed net savings of almost 1500 kWh/year. We did not obtain results for supplemental-heat because only two of the multifamily units used electricity as a supplemental heating fuel.

6. DISCUSSION

LIMITATIONS OF DATA AND ANALYSIS

The primary purpose of this report is to develop and apply methods for estimating the electricity use and savings attributable to HRCP. Because estimation of actual savings caused by a conservation program is difficult, we tested a variety of methods and data sets. Our hope was that these different approaches would yield similar results, lending confidence to estimates of HRCP-induced electricity savings.

Although the question "How much energy did HRCP save?" sounds simple, there are many ways to view it. Answers to the question are influenced by inclusion or exclusion of:

participants who had no major measures installed,
occupants of multifamily units or mobile homes,
renters,
households that use wood for some or all of their heating,
households that participated in prior retrofit programs,
households that moved during the analysis time period,
early participants, and/or
eligible households that chose not to participate in HRCP.

Differences in the periods selected for analysis can also affect results. Because of the multimonth lag between initial energy audits (and associated installation of several low-cost measures) and installation of retrofit measures, selection of the appropriate pre- and post-retrofit periods is not obvious. If the periods chosen are too close to each other (e.g., 1984/85 and 1985/86), then some of the HRCP measures will have been installed during one or both of these heating seasons. This choice will yield energy-saving estimates that are too low. On the other hand, if the periods are too far apart (e.g., 1980/81 vs 1985/86), so much time will have elapsed that other factors affecting household electricity use (e.g., changes in income, electricity price, and wood use) may complicate identification of HRCP's effects.

Finally, selection of an appropriate control group is crucial to identification of net (program-induced) electricity savings. Inclusion of homes that do not use electricity for space heating will yield misleading results. Use of comparison communities as controls may be confounded by differences between Hood River and the other communities in income growth, year-to-year variations in winter severity, availability and cost of firewood, and other factors that affect electricity use. Use of non-participating but eligible Hood River residents offers other problems (self-selection) in estimating net savings.

To deal with these issues, we developed a two-stage approach. The first stage analyzes monthly electricity bills to estimate weather adjusted (for variations in winter severity) annual electricity use (NAC). The second stage uses the NAC estimates in pooled time-series/cross-sectional models of electricity use to analyze variation across households and years as functions of structure, demographic, economic, and community factors as well as participation in HRCP. These models yield estimates of the effects on electricity use of changes in electricity prices, house size, appliance holdings, number of household members, and of HRCP itself.

Because the first-stage results are so important, both in their own right and as inputs to stage two, we used different ways to estimate weather-adjusted annual electricity use. We estimated PRISM models of individual households both for HRCP participants and for households in the three communities who reported use of electricity as the main or supplemental heating fuel. We presented results for all households with four years of electricity billing data (1982/83 through 1985/86) and for the subset of these households that use electricity as their primary heating fuel. We also estimated PRISM models for aggregates of households - the average of all HRCP participants and the averages of the electric-heat households in the three communities.

INTERPRETATION OF RESULTS

Estimates of three-year electricity savings (1982/83 minus 1985/86) for HRCP participants range from 1600 kWh/year for those households (6% of the total) that had no major retrofit measures installed by HRCP, to 2600 kWh for all HRCP-retrofit homes, to 4500 kWh for those single-family homes that used electricity as their primary heating fuel and had not participated in an earlier utility retrofit program. Savings were larger for HREC participants than for PP&L participants, probably because preparticipation electricity use was higher for HREC households (22,500 vs 16,300 kWh/year). Overall, savings averaged 14% of pre-HRCP electricity use.

The community-level models show electricity savings similar to those obtained with the HRCP data alone. Time-series/cross-section models show the net effect of HRCP, savings of 2700 kWh/year for homes using electricity as their primary heating fuel and 1600 kWh for homes using electricity as a supplemental fuel.

The actual saving caused by the HRCP-financed retrofits was only 43% of the audit prediction (Fig. 8). Analysis of other residential retrofit programs showed higher ratios of actual-to-predicted savings, on the order of 70% (Hewett et al. 1986, Hirst et al. 1985b, Sebold and Fox 1985). These differences were attributed (Hirst et al. 1985b) to:

errors in audit methodology,
errors in auditor data collection and interpretation,
installation of inappropriate measures,
use of poor quality retrofit materials,
sloppy installation of measures,
changes in occupant energy-related behavior after retrofit,
errors in electricity billing data, and
limitations in methods used to analyze electricity-use data.

The HRCP audit methodology used "C-factors" to compute potential savings (McKinstry and Busse 1983). These C-factors were derived from analysis of homes that used much more electricity than did HRCP homes. Thus, the engineering calculations used to estimate potential savings did not reflect actual electricity use in the particular house (i.e., pre-HRCP effects of wood use, room closures, indoor temperatures). On the other hand, HRCP's strict quality-control standards and inspections probably reduced discrepancies caused by inadequate installation of poor-quality materials.

The substantially lower than anticipated pre-HRCP electricity use levels affected actual savings. As discussed earlier, NAC_1 was low because of the 40% increase in electricity prices in Hood River during the two years before HRCP began, the high and increasing levels of unemployment (reaching 14% the year before HRCP began), and the consequent changes in household energy practices and use of wood. In addition, NAC_1 was lower than expected because HRCP attracted many multifamily and mobile homes to the project, in contrast to typical retrofit programs that attract single-family homes almost exclusively.

Changes in household behaviors also reduced electricity savings. We estimated a 300 kWh "loss" caused by reductions in wood use and another 300 kWh loss caused by increases in indoor temperatures after retrofit.

These results suggest that the modest savings attributed to HRCP were caused partly by pre-HRCP changes and partly by household increases in comfort and convenience (more comfortable indoor temperatures and less time devoted to chopping and burning wood). Roughly one-fourth of the technical improvements due to HRCP measures was taken in comfort and convenience, and the remaining three-fourths was taken in reduced electricity bills. It is likely that much of the pre-HRCP electricity savings and the post-HRCP behavioral changes are reversible. The savings stimulated by the retrofits, on the other hand, are more dependable and permanent. Thus, if electricity prices remain stable and households relax their energy conservation behaviors, the savings due to HRCP retrofits will increase.

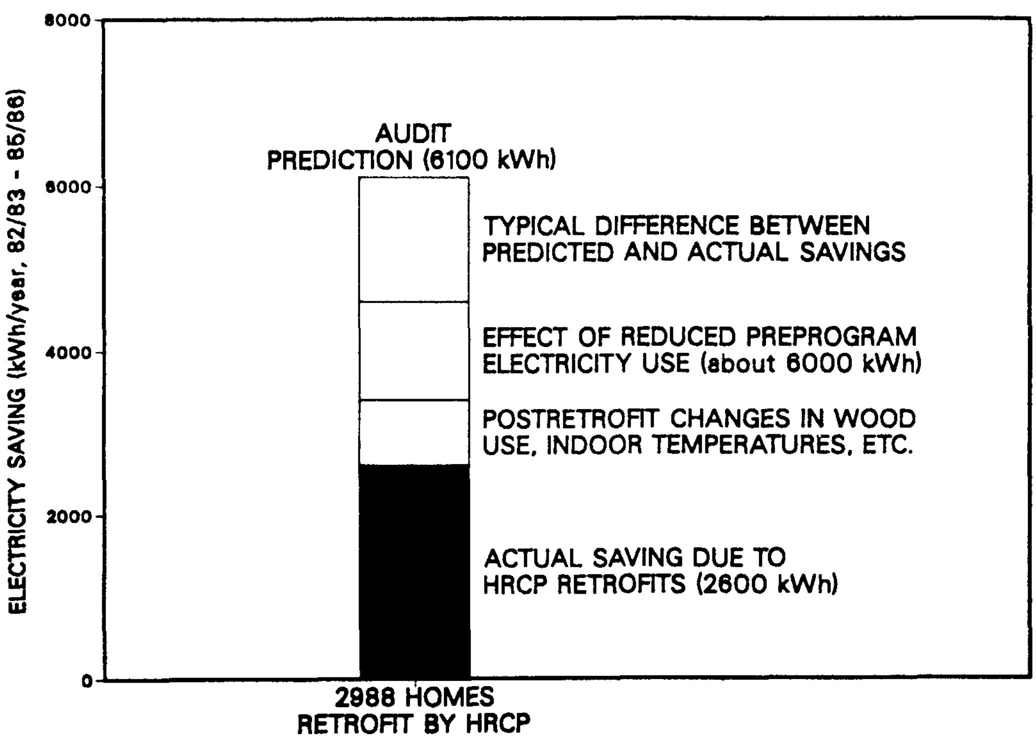

Fig. 8. Rough accounting of differences between actual and predicted electricity savings caused by HRCP retrofit measures.

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