1 of 1

Non-Space Heating Electrical Consumption in Manufactured Homes

**Residential Construction Demonstration Project
Cycle II**

Final Report

**Stephen Onisko
Carolyn Roos
David Baylon**

June 1993

Prepared for Bonneville Power Administration
under Contract Number DE-AM79-91BP13330

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED
97M

Table of Contents

Executive Summary	iv
1 INTRODUCTION	1
2 METHODOLOGY	1
3 SAMPLE CHARACTERIZATION	5
3.1 Occupancy	5
3.2 Location of Homes	6
3.3 Size of Homes	6
3.4 Space Conditioning	6
3.5 Water Heaters	6
3.6 Appliances	6
3.7 Lighting	7
3.8 Miscellaneous Equipment	7
4 ELECTRICAL CONSUMPTION OF RCDP2 MANUFACTURED HOMES	10
4.1 Interaction between space heat and internal gains	11
5 DOMESTIC HOT WATER ELECTRICAL CONSUMPTION	13
5.1 Background	13
5.2 DHW Electrical Consumption in RCDP2 Manufactured Homes	13
5.3 Correlation With Occupancy	15
5.4 Prediction of Standby Loss	18
5.5 Climate and Season	19
5.5.1 Factors Contributing to Seasonality	20
5.5.2 Variation in Inlet Temperature vs. Occupancy Use Patterns	21
5.6 Other Factors	24
5.7 Potential for DHW Energy Conservation	24
5.7.1 Heat Transfer Measures	24
5.7.2 Volumetric Measures	24
5.7.3 Improved Heating Modes	25
5.8 SUMMARY OF DHW ELECTRICAL CONSUMPTION	25
6 NONHEATING ELECTRICAL CONSUMPTION	26
6.1 Background	26
6.2 Nonheating Electrical Consumption in RCDP2 Manufactured Homes	27
6.3 Climate and Season	28
6.3.1 Factors Contributing to Seasonality	30
6.4 Correlation with Occupancy	31
6.5 Presence of Selected Appliances and Miscellaneous Equipment	32
6.6 Composition of Nonheating Electrical Use	36
6.7 Potential for Nonheating Energy Conservation	40
6.7.1 Refrigerators and Freezers	40
6.7.2 Lighting	40
6.8 SUMMARY OF NONHEATING ELECTRICAL CONSUMPTION	41
7 REFERENCES	42

Table of Figures

A. Monthly Variation in Electrical Consumption	v
1. Monthly Variation in Electrical Consumption	11
2. Daily average electrical consumption by month	12
3. Daily Electrical Consumption vs. Outside Temperature	12
4. Annual DHW Electrical Use by Total Occupants	15
5. DHW electrical use vs. occupants, Predicted fit of Eq 2	17
6. Average Daily DHW Electrical Use By Season	19
7. Annual DHW Electrical Use By Rated Tank Volume	23
8. Annual DHW Electrical Use By Energy Factor	23
9. Seasonal Variation in Nonheating Electrical Consumption	29
10. Nonheating Electrical Use vs. Outside Temperature	30
11. Nonheating Electrical Use by Number of Occupants	32
12. Nonheating Electrical Use vs. Number of Freezers	34
13. Nonheating Electrical Use vs. Presence of Well Pump	34
14. Nonheating Electrical Use vs. Number of Water Beds	36

Table of Tables

A. Estimated Composition of Nonheating Electrical Use	vi
1. RCDP2 Sample Sizes of DHW Submeter Data	3
2. RCDP2 Sample Sizes of Nonheating Submeter Data	3
3. RCDP2 Sample Sizes for Selected Cases	3
4. Days of Unusual Conditions Reported by Participants	5
5. Location of Homes	5
6. Summary of Water Heater Characteristics	7
7. Summary of Water Heaters, By Home Manufacturer	8
8. Percent of Households Having Appliances	8
9. Volumes of Installed Refrigerators	9
10. Households Having Additional Lighting	9
11. Percent of Households With Selected Electrical Equipment	9
12. Average Electrical Use, Maximum and Minimum Months	10
13. DHW Characteristics & Electrical Consumption	14
14. Comparison with DHW Results of Quaid et al	14
15. Annual DHW Electrical Consumption per Occupant	17
16. Annual DHW Electrical Consumption, Actual and Predicted	18
17. Daily Average DHW Electrical Consumption by Season	20
18. Average Outside Air Temperatures (NWS)	21
19. Supply Water Temperatures, Selected Sites	22
20. Characteristics of Nonheating Electrical Consumption	27
21. Comparison with Nonheating Results of Quaid et al	28
22. Daily Average Nonheating Electrical Use by Season	29
23. Results of Multiple Regression on Annual Nonheating Use	33
24. Estimated Composition of Nonheating Electrical Use	38

Executive Summary

This report summarizes submeter data of the non-space heating electrical energy use in a sample of manufactured homes. These homes were built to Super Good Cents insulation standards in 1988 and 1989 under the auspices of RCDP Cycle 2 of the Bonneville Power Administration. They were designed to incorporate innovations in insulation and manufacturing techniques developed to encourage energy conservation in this important housing type. Domestic water heating (DWH) and other non-space heat energy consumption, however, were not generally affected by RCDP specifications. The results of the evaluation of space heating impacts are summarized in Baylon et al (1991).

The purpose of this study is to establish a baseline for energy conservation in these areas and to present a method for estimating total energy saving benefits associated with these end uses. The information used in this summary was drawn from occupant-read submeters and manufacturer-supplied specifications of building shell components, appliances and water heaters. Information was also drawn from a field review of ventilation systems and building characteristics conducted by the Battelle Pacific Northwest Laboratories and an occupant survey conducted by the Washington State Energy Office. The occupant survey included a census of appliances and occupant behavior in these manufactured homes.

A total of 150 manufactured homes were built under this program by eight manufacturers. An additional 35 homes were recruited as a control group. Of the original 185 houses, approximately 150 had some usable submeter data for domestic hot water and 126 had usable submeter data for all other nonheating consumption. These samples were used as the basis for all consumption analysis. The energy use characteristics of these manufactured homes were compared with that of a similar sample of RCDP site-built homes analyzed by the Washington State Energy Office in 1991 (Quaid et al 1991). In general, the manufactured homes were somewhat smaller and had fewer occupants than the site-built homes. This group of manufactured homes had a mean occupancy of 3 individuals and were approximately 1,500 ft², 20% smaller than the sample of site-built homes.

The degree to which seasonal variations were present in non-space heat uses was reviewed. Figure A illustrates the seasonality of water heat, space heat and other uses. DHW consumption during the peak winter month was 42% greater than that during the summer month of minimum consumption. Similarly, other non-space heating usage varied by 43% from minimum to maximum consumption. This variation is explained by changing use patterns between summer and winter months, the increasing requirement for lighting and the variation in temperature of water coming into the home. These calculations were made only after elimination of homes where portable space heaters were probably used as a heating supplement.

The analysis of the DHW consumption used regression analysis and other evaluation techniques. The findings include:

1. Median DHW electrical consumption for this sample was found to be 3,880 kWh per year or 11 kWh per day. The mean consumption of 4,160 kWh/year is less than was observed in Quaid's comparable study of RCDP2 site-built homes.
2. DHW electrical use was found to vary significantly with season. On the average, DHW consumption during the winter season (January, February and March) was 30% higher than during the summer. DHW consumption during the peak month of March was 42% greater than in July, the month of minimum DHW consumption. Annual DHW energy use per occupant in climate zones 2 and 3 was approximately 3% greater than in zone 1.
3. The total number of occupants was shown to be the most significant factor determining total DHW electrical consumption.

4. DHW electrical use was strongly correlated with the number of occupants up to a total occupancy of five. Use per occupant when adjusted for standby loss was found to be less for homes with five or more occupants than for homes with two, three or four occupants. Average DHW use per occupant is predicted to be about 1,000 kWh per year, exclusive of standby losses.
5. Standby losses are predicted to be approximately 600 kWh per year for each home or 15% of total DHW electrical consumption.

Since standby losses are now a relatively small proportion of total DHW energy use, the greatest potential for DHW energy savings can be obtained by improving heating modes and implementing volumetric conservation measures. Volumetric measures include low flow faucets and water efficient appliances, among others. These appear to offer relatively modest savings and would probably occur as appliances proceed to meet existing federal appliance efficiency standards. Improved heating modes, such as heat pump or solar water heating, probably offer the most effective method for saving DHW energy. Average net savings from these sources are estimated to be as much as 2,000 kWh per year per home.

All other non-space heating consumption excluding domestic hot water usage is referred to here as "nonheating" consumption. Many components make up this usage, including appliances, lighting, cooking and miscellaneous uses. Table A shows the distribution of estimated annual energy use of various appliances. Conditional demand analysis was used to estimate the energy consumption of selected appliances identified in the sample. Where such analysis was not

Figure A. Monthly variation in median electrical consumption for space heating, domestic water heating and other non-space heating ("nonheating") uses.

<p align="center">Table A</p> <p align="center">Estimated Composition of Nonheating Electrical Use</p>					
End Use	Estimated Energy Use (kWh/yr/unit)	Estimated Variation (kWh/yr/unit)	Percent Saturation of Sample	Saturation X Annual Energy Use (kWh/yr)	Percent of Total
Lighting ^a	1,000	±500 ⁴	100	1000	15
Refrigerator ^b	900	250 ¹	106	950	13
Cooking ^c	1,000	500 ⁴	100	1,000	18
Clothes Washer ^d	100	70 ²	98	98	1
Clothes Dryer ^e	1,000	800 ²	94	940	14
Dishwasher ^d	120	80 ²	88	110	3
Freezer ^f	1,300	380 ³	70	910	12
Water Bed ^f	900	450 ³	33	300	4
Well Pump ^f	1,200	550 ³	19	230	3
Air Conditioning, ^f (not including heat pump A/C)	1,500	680 ³	9	140	2
Miscellaneous ^g	1,000	1000 ⁴	-	1,000	15
Total	10,700	±5,300		6,700	100
<p>a - g, Please see the discussion in Section 6.6, pages 36 and 37, and notes and qualifications on page 39.</p> <p>1 - 4</p>					

appropriate, due to near 100% saturation of the sample, estimates were made based on the results of other studies. Because these loads were not separately metered and due to insufficient audit data, these estimates are quite uncertain. An estimate of the aggregate impact of these appliances per household for this sample is obtained by multiplying the saturation of the appliance by its estimated annual energy consumption, as shown in the fifth column. The overall total matches the median nonheating usage in the entire sample.

The conservation potential in this sector is expected to be captured for the most part by advances in federal appliance efficiency standards. Accelerating these standards may provide modest savings, particularly in refrigerators and freezers. Lighting efficiency improvements, such as the use of compact fluorescent lights and other high efficiency options, is the other principal source for energy conservation.

The findings of this analysis concerning appliance, lighting and other non-space heating, non-water heating consumption include:

1. Median nonheating energy use for this sample of RCDP2 manufactured homes was 6,670 kWh per year. Energy use per occupant was somewhat greater in than in RCDP2 site-built homes.

2. Nonheating electrical use varied significantly with season. On the average, nonheating use was 27% higher in the winter than in the summer. Nonheating electrical consumption was 43% higher in December than in May, the months of maximum and minimum usage.
3. Nonheating electrical consumption was found to be well correlated with the number of occupants per home. It is indicated that adults use more energy for nonheating purposes than children. Average nonheating energy use per occupant is predicted to be 1,720 kWh/year for adults and 624 kWh/year for children, exclusive of a level of nonheating consumption typically present in all homes.
4. Annual nonheating energy use per occupant in climate zones 2 and 3 was approximately 4% greater than that in zone 1. This may be due to increased indoor activities in colder climates, the larger cooling requirements in zones 2 and 3, or to the greater use of well pumps or other equipment in more arid, rural regions of the Northwest.
5. Both nonheating and domestic water heating electrical consumption are correlated with average outside temperature.
6. Most cost effective, technically feasible conservation strategies for appliances will be captured by the 1993/94 federal standards. However, savings are still possible through incentives that encourage the purchase of appliances that exceed these standards, that do not exceed prescribed size limits or do not have certain energy consuming features.
7. Potential savings for energy efficient lighting could be a significant fraction of the estimated 1,000 kWh used per year per home. More research would be required to better estimate the lighting conservation potential in these homes.

1 INTRODUCTION

This report summarizes the non-space heating electrical consumption of 150 all-electric manufactured homes located in the Northwest. The energy used for water heating, lighting, appliances and miscellaneous uses has become an increasing proportion of total residential energy use as building envelopes become tighter and better insulated. In this sample of well-insulated homes, non-space heating consumption accounted for 60% of total energy use. Our purpose is to characterize this energy use so that the potential for conservation in this residential sector may be evaluated.

About a third of single family homes built in the Northwest are manufactured homes. Yet federal law, including Housing and Urban Development (HUD) codes, preempts local building codes for these homes. HUD energy efficiency requirements for manufactured homes have been far below regional model conservation standards for site-built homes (Riewer 1988). Because all of the manufactured homes produced in the Northwest are constructed at eighteen manufacturing plants, these homes provide a unique opportunity for understanding and influencing energy conservation in a large part of the housing market.

The majority of the manufactured homes in this sample were participants in Cycle II of the Bonneville Power Administration's Residential Construction Demonstration Project (RCDP). The objective of RCDP was to increase the capacity of the new home building industry to produce cost-effective, energy-efficient housing by demonstrating new construction techniques and product innovations. Under Cycle II of this project (RCDP2), 181 site-built homes and 150 manufactured homes were constructed in the BPA's service area from 1987 to 1989. In addition to incorporating RCDP innovations, the homes also had to meet the April 1987 Super Good Cents (SGC) specifications. These specifications include building homes to certain insulation levels, implementing construction techniques and materials that reduce infiltration and equipping homes with mechanical ventilation systems.

Quaid et al (1991) examined appliance and DHW energy consumption of the 181 site-built homes participating in RCDP2. This sample of site-built homes is very similar to the present study in regard to the number of participants, the period of time in which data was collected and locations of the homes. Therefore, Quaid et al provides a useful comparison study. One significant difference between the two studies, however, is that 48% of the site-built homes have "efficient" DHW systems installed through the BPA's Blue Clue appliance efficiency program and 40% installed "efficient" appliances through the BPA's Blue Clue appliance efficiency program. There were no specifications for any of the RCDP2 manufactured homes regarding installation of energy efficient appliances or water heaters.

Typical DHW electrical consumption, including seasonal variation of consumption and correlation of consumption with the number of occupants, is summarized in Section 5. Section 6 summarizes the consumption characteristics of non-space heating uses other than water heating, or "nonheating" consumption, of 126 of these manufactured homes. Typical composition, dependence on occupancy and seasonal variation of nonheating electrical consumption were examined. Domestic hot water usage has been analyzed separately from other nonheating uses to provide an independent review of consumption patterns.

2 METHODOLOGY

Originally, 150 home buyers were recruited through manufacturers to participate in the RCDP study. Another 35 owners of manufactured homes were recruited as a control group through manufacturers and random telephone dialing. Information concerning 139 RCDP homes and 8 control homes was obtained through site visits. Data was also obtained through specifications, floor plans and appliance data submitted by the homes' manufacturers, by an occupant survey and from weekly survey/meter reading cards submitted by the occupants.

Electrical use of each home was submetered for up to two years between 1987 and 1989. Residents took readings of the whole house meter, furnace submeter and water heater submeter. These readings were reported generally on a weekly basis, although irregularities and missing periods of data were not uncommon. Other information, such as thermostat setpoints and periods of unusual use, was also reported with the meter readings.

Nonheating electrical consumption was determined by subtracting furnace and water heater submeter readings from whole-house meter readings. Since appliances and equipment were not separately metered, some heating end uses such as space heaters or furnaces located in outbuildings may be included in the nonheating consumption. However, we have attempted to identify homes with heavy auxiliary heating through occupant surveys, site audits of the homes, billing data patterns and photographs of the homes and adjacent buildings. Nineteen homes were eliminated from the nonheating analysis due to suspected auxiliary space heating consumption or the presence of heated outbuildings. Several homes show a greater than average winter peak in nonheating consumption, yet have not been eliminated for lack of evidence of auxiliary space heating.

Seasonal variation has been examined by comparing energy use during four three-month seasons. For the analysis of nonheating consumption, Spring season was defined as March, April and May of 1989, with similar three-month periods for Summer, Fall and Winter. For domestic water heating, Spring was defined as April, May and June of 1989. Seasons have been offset by one month for the DHW analysis because the variation in ground temperature typically lags behind that of air temperatures by one to three months (Hanford et al 1985). For the purposes of this study, we have assumed a lag of one month between ground water temperature and air temperature.

As in previous studies (Palmiter 1982), the sample has been divided into three separate climate zones to represent the severity of the heating climate. These are: Zone #1, including areas with less than 6000 heating degree days, generally western Washington and Oregon; Zone #2, 6000 to 8000 heating degree days, generally eastern Washington and Oregon and most of Western Idaho; and Zone #3, more than 8000 heating degree days, mostly western Montana and part of Idaho, as well as mountainous regions of northeastern Washington.

Of the 185 homes originally recruited, 150 have usable submeter data for domestic hot water electrical consumption and 126 have usable data for nonheating consumption. Reasons for eliminating data included meter malfunction or improper connection, insufficient data or unoccupied home for a substantial portion of measuring period. A majority of homes have sufficient submeter data to analyze energy use for all four seasons. Tables 1 and 2 show the number of homes with submeter data for each three-month season. Table 3 summarizes number of homes with DHW submeter data, occupancy data and water heater data for several cases.

Due to incomplete meter data, estimations were required in some cases. Where less than a full period of data are available, monthly, seasonal and annual totals were normalized; i.e., the daily average for the period with data was multiplied by the number of days in that period. Such normalized annual totals were used in all regressions. Because less data is available for Spring and Summer months, normalized annual totals found in this manner appeared to be artificially high in some cases. In order to avoid this bias, energy consumption data has been characterized using daily averages wherever possible. Also, the median and mean annual consumption for the sample were estimated by multiplying the median and mean normalized monthly consumption of the sample by 12. Thus, each month was given equal weight, irrespective of the number of data points for that month. Similarly, the sample's median consumption for each season was estimated by adding the median normalized consumption for each month in the season.

Table 1 RCDP2 Sample Sizes of DHW Submeter Data				
	Zone 1	Zone 2	Zone 3	Total
Spring 1989 (4/89 to 6/89)	64	39	3	106
Summer 1989 (7/89 to 9/89)	77	49	4	130
Fall 1989 (10/89 to 12/89)	83	55	4	142
Winter 1990 (1/90 to 3/90)	82	55	4	141

Table 2 RCDP2 Sample Sizes of Nonheating Submeter Data				
	Zone 1	Zone 2	Zone 3	Total
Spring 1989 (3/89 to 5/89)	51	34	3	88
Summer 1989 (6/89 to 8/89)	60	37	3	104
Fall 1989 (9/89 to 11/89)	66	47	3	123
Winter 1990 (12/90 to 2/90)	65	45	3	120

Table 3 RCDP2 Sample Sizes for Selected Cases DHW Submeter Data			
	No. of Homes with DHW Submeter Data	No. of Homes with Occupancy Data	No. of Homes with Water Heater Data
All	150	141	125
Occupancy less than 6	134	134	125
Occupancy less than 5	122	122	103

In general, medians have been used to characterize energy consumption, rather than means. Medians are less sensitive to outliers¹ and therefore give more typical estimates of energy consumption. Mean energy use is always higher than median use, because the very broad distribution of consumption is necessarily truncated on the low end by an absolute minimum of zero. There is no such truncation on the high end. We have included mean energy consumption data for the sake of comparison with other studies.

Data collected during site visits, conducted under the direction of Pacific Northwest Laboratories, primarily concerned space heating, ventilation and occupancy characteristics of the homes. In occupant surveys and manufacturer submittals, information gathered included manufacturers and model numbers of installed appliances. Insufficient information was gathered on numerous points to adequately analyze nonheating energy consumption. For example, retrofit air conditioning systems were not determined and complete lighting and equipment surveys were not performed. Regarding domestic water heating, data was not collected concerning DHW delivery temperature, inlet water temperature at each site or the existence of thermal traps and bottom insulation. Data was also not collected regarding water fixture types, although it may be assumed that conventional fixtures were installed in most homes. Less information is available from the control homes since occupant surveys were not taken and manufacturers were not requested to submit data for these homes.

Of the homes with usable submeter data and occupancy information, there is also data for 125 homes concerning the electric water heater manufacturer, model number and tank size. The energy factor was determined for these using the Gas Appliances Manufacturers' Association (GAMA) directory for October 1988. Data on rated standby losses and actual tank volumes was obtained for 76 homes using the California Energy Commission (CEC) Directory of Certified Water Heaters. Standby losses were estimated for the remaining sample based on these 76.

Eight manufacturers participated in the study and approximately 80% of the homes were constructed by only four manufacturers. A small number of water heaters installed by several manufacturers were undetermined. For these cases, water heater manufacturers were assumed to be the same as other tanks installed by the same home manufacturer. An energy factor of 0.89 was assumed for water heaters installed by Manufacturer 6, consistent with other units installed by that manufacturer. Since only one water heater installed by Manufacturer 7 was determined, no assumptions were made concerning other units installed by this manufacturer. Volumes for all undetermined units were not assumed.

For 94 homes, information was available concerning refrigerator manufacturer and model numbers. A large number of participants furnished their own refrigerator and no information is available regarding these. Information is also available concerning dishwashers and ranges installed in approximately 100 homes but this data has not been summarized. Clothes washers and dryers were not supplied by home manufacturers and no data is available.

Relationships between DHW submetered data and variables including number of occupants, tank volume energy factor and climate zone were examined using robust regressions and multiple regressions. Regression results were used to estimate the average standby loss of the sample. Relationships between nonheating consumption data and variables including number of occupants, presence of appliances, outside temperature and size of home were also examined using robust regressions. Regression results and literature data were used to estimate the composition of nonheating electrical use of RCDP2 manufactured homes. Monthly and seasonal variation in use and effects of occupancy characteristics were examined using nonparametric comparisons.

¹ Outliers are observations that are extremely inconsistent with the rest of the sample.

3 SAMPLE CHARACTERIZATION

3.1 Occupancy

The number of occupants per home ranged from one to eleven with the average being three. The number of adults ranged from one to six, and the number of children under the age of 11 ranged from zero to nine. Half the families had no children under the age of 18 at home and two-thirds had no children under the age of 11. Most of these, or more than one-third of the sample, were occupied by two adults with no children, the mode of the sample. Two-thirds of the families surveyed reported that someone was typically at home during weekdays at least 50% of the time.

Periods of unusual conditions, such as occupants leaving for vacation, having company or requiring heavy usage of appliances, lighting or hot water are noted in Table 4. Almost half the participants reported no periods when the home was unoccupied during the year. Of those who did report being gone at times, the median number of days away was eight. Almost two-thirds of the participants had company during the year, with the median length of stay being eight days.

Table 4		
Days of Unusual Conditions Reported by Participants		
	Percent of Sample Report- ing None	Median No. of Days for Those Reporting Positively
Home Unoccupied	46.8	8
Had Company	38.3	8
Used More Hot Water	35.1	8
Used More Lights	48.1	11
Did More Cooking	35.7	6

Table 5		
Location of Homes		
Climate Zone	No. of Observations DHW Analysis	No. of Observations Nonheating Analysis
1	88	73
2	58	50
3	4	3
Total	150	126

3.2 Location of Homes

The majority of homes are located in climate zone 1 (Table 5). The remaining homes are in climate zones 2 and 3 which include eastern Washington and Oregon, Montana and Idaho. Locations defined as climate zone 3 in Washington, such as the Republic area, are often mountainous and have dramatically varying subclimates within a few miles. Since only four homes were located in zone 3 and since classification is uncertain, zone 3 has been combined with zone 2 in summaries characterizing climate differences.

3.3 Size of Homes

The floor area of homes ranged from 1,020 to 2,600 square feet. The average floor area was 1,497 square feet with a standard deviation of 250. The comparison set of site-built RCDP2 homes were generally larger in size and showed more variation, with a mean floor area of 1,919 square feet and standard deviation of 522 (Quaid et al 1991).

3.4 Space Conditioning

Most homes (88%) were heated by electric forced air furnaces. The remaining had central heat pumps. Residents of 20% of the homes indicated in the occupant survey that they used air conditioning. Of these, 45% had heat pumps. It is uncertain if the remaining homes have through-the-wall or window units, or central air conditioning systems. For homes having heat pumps, air conditioning use is metered on the "space heating" meter. Residents of several homes with heat pumps indicated that they did not use air conditioning.

3.5 Water Heaters

Two-thirds of the water heaters installed are rated at 50 or 52 gallons, with the average of all water heaters being 46 gallons. Energy factors² range between 0.86 and 0.91 with the majority having energy factors of 0.87 or 0.89. Rated standby losses ranged from 543 to 630 kWh per year (Table 6). Characteristics of water heaters installed by each manufacturer are summarized in Table 7.

3.6 Appliances

Table 8 shows the percent of households surveyed in the nonheating sample (N=111) that have appliances. All homes have at least one refrigerator located indoors and 6% have a second refrigerator, generally located in garages or other outbuildings. Almost two-thirds of the homes also have one or two freezers and two-thirds of these were located indoors. The number of second refrigerators and freezers actually connected is uncertain. Almost all homes had both a washing machine and dryer and 88% have a dishwasher. Except for refrigerators, the rate of appliance ownership of these homes is greater than the national average for existing homes (Turiel et al). Regionally, refrigerator saturation in all single family Northwest residences has been estimated at 116% (ELCAP 1989).

Refrigerators installed by home manufacturers were made by Whirlpool, General Electric and Magic Chef. Refrigerator volume ranged between 14 and 20 ft³ with a mean of 16.4. The distribution of sizes is shown in Table 9. This is significantly smaller than refrigerators installed in RCDP2 site-built homes. Quaid observed a mean refrigerator volume of 19.2 ft³ for RCDP2 site-built homes that did not have "efficient" refrigerators.

² The energy factor is a measure of the overall efficiency of a water heater based on the model's recovery efficiency, standby loss and energy input.

3.7 Lighting

Standard lighting in these manufactured homes is incandescent. Additional interior and exterior lighting in several homes was noted in occupant surveys, as shown in Table 10. Other information regarding installed lighting was not obtained.

3.8 Miscellaneous Equipment

Percent ownership of selected electrical equipment is shown in Table 11, as determined by occupant surveys. Well pumps were reported in 19% of the homes. One-third of the sample have at least one water bed and a third of these had two. Power tools and shop equipment such as power saws, grinders and drills, arc welders and air compressors are found in 10% of the homes. One homeowner also reported having an auto engine block heater. No data was obtained regarding the use of dehumidifiers. These appliances may be common east of the Cascades and may significantly affect summer energy consumption.

Table 6					
Summary of Water Heater Characteristics					
Manufacturer	Model	Rated Volume	Energy Factor	Rated Standby Loss* (kWh/yr)	Quantity Installed
Rheem	71-30S	30	0.90	-	6
	71-40D	40	0.89	-	14
	71-52D	50	0.87	-	25
American	EFR-32-S	32	0.91	543	8
	EFR-42-S	42	0.89	630	4
	EFR-52-D	52	0.89	613	29
Nordine	HE-40F	40	0.89	525	9
	HE-50F	52	0.87	571	26
State	CV-40-2H	40	0.87	-	3
	CV-50-2H	50	0.86	-	1
Undetermined	-	-	-	-	25
Means, Total		46	0.88	580	150
* Rated standby loss determined from hourly rates listed in the CEC directory.					

Table 7 Summary of Water Heater Characteristics, By Home Manufacturer				
Home Manufacturer	Water Heater Manufacturer	Mean Rated Volume	Mean Energy Factor	Quantity Installed
1	Undetermined	-	-	1
2	Nordine, State	47	0.87	39
3	Rheem	45	0.88	15
4	Rheem	45	0.88	4
5	Rheem	45	0.88	27
6	American	50	0.89	8
7	American	-	-	9
8	American	46	0.89	40
Control	-	-	-	7

Table 8 Percent of Households Having Appliances			
Appliance	Percent of Sample Surveyed		
	With One	With Two	Total Saturation
Refrigerator	93.7	6.3	106.3
Freezer	57.7	6.3	70.3
Clothes Washer	98.2	0	98.2
Clothes Dryer	93.7	0	93.7
Dishwasher	88.3	0	88.3

Table 9 Volumes of Installed Refrigerators	
Rated Refrigerator Volume (Cubic Feet)	Percent of Installed Refrigerators
14	26
15	23
18	41
19	3
20	6

Table 10 Households Having Additional Lighting		
	Percent of Sample	Examples of Fixture Type, Location
Interior	3.8	Ceiling fans with lights, Fluorescent fixtures, Neon
Exterior	12.0	Area lights, Sidewalk bollards, Garage light

Table 11 Percent of Households Having Selected Electrical Equipment			
Equipment	Percent of Sample Surveyed		
	With One	More than One	Total
Well Pumps	19.0	0	19.0
Water Beds	23.4	9.9	33.3
Electric Blankets	21.6	4.5	26.1
Power Tools, Shop Equipment	-	9.9	9.9

4 ELECTRICAL CONSUMPTION OF RCDP2 MANUFACTURED HOMES

Annual electrical consumption from March 1989 to February 1990 ranged from 6,370 to 41,500 with a median of 17,600 kWh per year. Nonheating electrical consumption accounted for 38% of total usage and domestic water heating accounted for 22%. In the RCDP2 site-built homes that did not install "efficient" appliances, Quaid observed a very similar electrical energy use profile: 36% space heating, 40% nonheating and 24% domestic water heating. This profile is also very similar to the distribution observed in the ELCAP study of more than 300 all-electric single family homes located in the Northwest primarily constructed before 1983 (ELCAP 1989).

Nonheating, domestic water heating and space heating electrical consumption all exhibited seasonality. Monthly variation in electrical consumption for space heating, domestic water heating and nonheating uses is shown in Figures 1 and 2. Space heat, domestic water heat and nonheating electrical consumption peaked in February, March and December, respectively. Average daily consumption during months of maximum and minimum consumption is shown in Table 12.

In robust regressions³ on electrical consumption with outside temperature as the independent variable, domestic water heating and nonheating energy use both were found to be well correlated with average outside temperature. Regression coefficients were significant at the 0.0005 level⁴. Nonheating use is likely only indirectly related to outside temperature; reduced daylight hours during the winter leads to increased lighting and indoor activities. The coefficients for water heating and nonheating energy use were strongly correlated (0.977) with the constant in both cases. This is consistent with the observation that variation of use with temperature is much smaller than the consumption that is present throughout the year.

Table 12						
Median Daily Average Electrical Consumption for Months of Maximum and Minimum Use						
	Month of Maximum Use			Month of Minimum Use		
	Month	Average Consumption (kWh/day)	Ratio to Annual Median	Month	Average Consumption (kWh/day)	Ratio to Annual Median
Whole House	Feb.	80.9	1.53	June	28.5	0.54
Space Heating	Feb.	47.8	2.24	July	0.58	0.03
Water Heating	March	12.4	1.20	July	8.7	0.84
Nonheating	Dec.	22.3	1.13	May	15.5	0.79

³ If a bivariate plot of data seems to have a linear structure, we can summarize the basic relationship between the two variables by choosing a particular straight line that passes through the data. This process is called linear regression analysis. In a robust regression, an initial screening to eliminate gross outliers (Cook's distance > 1) is performed prior to calculating starting values. Then, Huber iterations are performed, followed by biweight iterations. The statistics and data management program, STATA (release 3) was used in this analysis.

⁴ The level of a test is the probability of wrongly declaring a difference to be significant. For the purposes of this study, a level of 0.05 or less is considered significant.

Figure 1. Monthly variation in median electrical consumption for space heating, domestic water heating and nonheating uses.

The dependence of electrical consumption on outside temperature is illustrated in Figure 3, which plots medians of average daily electrical use over the period of a month against average monthly temperatures in 5°F bins. As expected, space heating use shows a strong and fairly linear relationship with temperature below about 60°F. The declining slope for nonheating and DHW electrical consumption is more gentle in comparison.

4.1 Interaction between space heat and internal gains

The potential energy savings of efficient lighting, appliances and water heaters are reduced by the interaction of internal gains with space heat consumption. The waste heat of an appliance in a conditioned space reduces the heating load of the home. An efficient appliance consumes less energy, but produces less waste heat, causing the heating system to use more energy. This interaction is customarily quantified by dividing the amount of additional space heat required by the gross savings of the efficient appliance.

Space heat interaction of lighting, appliances and miscellaneous conveniences has previously been estimated at approximately 0.5 (Palmiter and Kennedy 1983). Interaction may be less in homes, such as these, that have central temperature control (Quaid et al 1991). With central control, the thermostat for the heating system is typically not located in the same zone where most appliance waste heat occurs. Interaction is also less in homes that are well-insulated, have low infiltration rates and have low thermal mass. However, interaction would be greater for winter peaking non-space heating consumption, as is typical in this sample.

The heat of domestic hot water use is largely lost down drains and does not affect space heating consumption. Only DHW standby losses, approximately 15% of total DHW energy consumption, interacts with space heat use.

In this sample, because all water heaters were located inside the conditioned space and no efficient appliances were installed, it is impossible to assess space heat interaction from the meter data. An interaction of 0.5 has been assumed for nonheating consumption and 0.15 for DHW consumption.

Figure 2. Daily average electrical consumption for space heating, domestic water heating and nonheating uses for each month⁵.

Figure 3. Median whole-house electrical use, space heating, domestic water heating and nonheating uses versus average outside temperature.

⁵ Box plots: The line through the middle of each box is the median (the value below which half of the sample falls). The upper and lower bounds of each box are the quartiles. The isolated circles are points that are extremely inconsistent with the rest of the data. The width of each box is proportional to the number of data points.

5 DOMESTIC HOT WATER ELECTRICAL CONSUMPTION

5.1 Background

Factors affecting domestic hot water energy consumption include the number of occupants, water heater energy efficiency rating or energy factor, inlet water temperature, delivery water temperature and location of the water heater. Other influencing factors include ownership and use of appliances and numerous lifestyle and occupancy variations.

There are two components of DHW energy consumption: standby loss and usage-related consumption. The most common conservation measures implemented in the past, such as tank wraps and pipe insulation, reduce water heater standby loss. Typical standby losses have dropped dramatically in the last ten years and generally are a relatively small component of total DHW energy use. The greatest potential for DHW conservation is now in reducing hot water usage-related consumption.

For all single family detached residences in the Northwest, including those heated by fossil fuels, the electricity consumed in water heating is approximately equal to electric space heating use (ELCAP 1989). Each comprise about one-quarter of the regional load for single-family dwellings.

5.2 DHW Electrical Consumption in RCDP2 Manufactured Homes

Annual DHW electrical consumption per home varied from 808 to 16,900 kWh. Median annual DHW consumption per household for this sample was 3,880 kWh (Table 13). Mean usage was 4,160 kWh per year with a standard deviation of 2,280 kWh. Average DHW usage per occupant was 1,470 kWh. Average DHW consumption of this sample is less than was observed by Quaid et al in 1991, as shown in Table 14. Note that results of RCDP2 site-built homes shown in Table 14 are only for participants who did not receive incentive payments for installation of efficient water heaters.

Daily average DHW electrical use for this sample is 11 kWh per day or 3.7 kWh per day per person (Table 13). This corresponds to an estimated water usage of 20 gallons per day per person, assuming tank temperatures of 125°F, inlet water temperature of 52°F and standby losses as estimated using the CEC directory.⁶

Since no DHW energy conservation measures were implemented in the RCDP2 homes, there is no significant difference in consumption characteristics between the RCDP2 homes and control homes.

⁶ Tank temperature was assumed based on Quaid et al's results. In that study, very consistent measured delivery water temperatures were observed in zones 1 and 2, ranging between 122°F and 127°F. Average inlet water temperature was estimated based on mean air temperatures at weather stations near each site, as discussed in Section 5.5, "Climate and Season".

Table 13 DHW Characteristics & Electrical Consumption			
	Zone 1	Zone 2 and 3	Total
Number of Homes	88	62	150
Mean Energy Factor Rating	0.88	0.88	0.88
Mean Rated Volume (gallons)	44	48	46
Mean Average Daily DHW Consumption (kWh/day)	10.8	12.2	11.4
Mean Annual DHW Consumption ¹ , (kWh/year)	3,950	4,450	4,160
Median Annual DHW Consumption ¹ , (kWh/year)	3,520	4,340	3,880
Average Total Occupants	2.9	3.2	3.0
Consumption per occupant ² , (kWh/yr-person)	1,450	1,500	1,470
Daily DHW Consumption per Occupant ² (kWh/day-person)	3.7	3.8	3.7
¹ These values have been normalized as described in Section 2. ² Use per occupant is based on the mean of ratios, rather than the ratio of mean consumption to mean number of occupants.			

Table 14 Comparison with DHW Results of Quaid et al			
	RCDP2 Manufactured Homes	RCDP2 Site Built Homes *	% Difference
Median Energy Factor	0.89	0.88	-1
Mean Rated Volume (gallons)	46	54	17
Mean 1st Hour Rating (gallons)	54	59	9
Mean Annual DHW Consumption, (kWh/year)	4,160	4,675	12
Average Total Occupants	3.0	3.4	13
Consumption per occupant, average of ratios (kWh/yr-person)	1,470	1,610	9
* Results for homes that did not install "efficient" DHW system (Quaid et al 1991)			

5.3 Correlation With Occupancy

DHW electrical use was shown to be strongly correlated with the number of occupants up to a total occupancy of five. Cases with occupancies greater than five were too few to characterize energy use with certainty in this data set (Figure 4). No significant difference was noted in DHW consumption per occupant between families with children and those without. There was also no difference between those who reported that someone was typically home at least 50% of weekdays and those who did not.

Figure 4. Annual domestic hot water electrical consumption by total number of occupants per home.

Table 15 shows median DHW consumption per occupant, adjusted for CEC rated standby losses. For each case, annual rated standby loss was subtracted from total annual DHW consumption and the result divided by total occupants in order to obtain an estimate of usage-related consumption per occupant. This adjusted DHW energy use per occupant peaked at an occupancy of three and was notably less for homes with one, five and more than five residents compared to homes with two, three and four residents.

Perlman and Mills (1985) monitored DHW use of 58 homes between 1981 and 1985. They reported that average hot water usage per person reached a peak at a family size of three and declined for larger families. However, results were presented only for homes with occupancies ranging from two to five. It is also unclear if DHW energy consumption was adjusted for standby losses. To include standby losses obscures the relationship between usage-related energy consumption and occupancy.

Several robust regressions were performed with annual DHW electrical consumption as the dependent variable and total occupants as the independent variable. In the first, no restrictions were placed on the number of occupants, resulting in a slope coefficient of 809 kWh per year per person and a constant of 1,482 kWh/year (significant at levels of 0.0005). A robust regression was then performed screening out points with occupancy greater than five. This resulted in the relationship shown in Equation 1. A third robust regression for occupancies of four or less resulted in Equation 2.

Equations 1 and 2. Results of robust regressions with DHW electrical consumption as the dependent variable and total occupants at the independent variable. In equation 1, the regression coefficient and constant were significant at the 0.0005 and 0.001 level, respectively. In equation 2, the coefficient and constant were significant at levels of 0.0005 and 0.0064.

(Equation 1)	$Q = 957 + 1016 N$	(for $N < 6$)
(Equation 2)	$Q = 624 + 1169 N$	(for $N < 5$)
<p>where Q = Annual DHW electrical consumption (kWh/year) and N = Total number of occupants</p>		

As discussed in the following subsection, equation 2 appears to give the better estimation of standby losses. We suggest that the relationship between DHW electrical consumption and occupancy is a step function, composed of equation 2 for occupancy of four or less and an undetermined function for occupancy greater than four. Again, it must be noted that there are too few homes with high occupancies in this sample to characterize DHW use of these cases. Neither Quaid et al, Palmiter (1982) nor Perlman and Mills presented results for occupancies greater than five.

Actual DHW energy use and that predicted by Equation 2 are compared in Table 16. Figure 5 shows the predicted fit of Equation 2. When adjusted for the smaller average DHW energy use of this sample, this variation with number of occupants is similar to the trend observed in ELCAP (1992), except for homes having only one occupant. The ratio of the DHW energy use of the 12 RCDP manufactured homes with one occupant to the mean of the entire sample was approximately half that observed in the ELCAP study. This may be due to the small cell size of this group. ELCAP found that cell sizes of 15 to 20 were required to produce meaningful information regarding a categorization of data.

Quaid et al performed a multiple regression with total occupants, delivery temperature, energy factor and water heater location as independent variables. Occupancy was not restricted for their regression and resulted in a regression coefficient of 930 kWh per person, similar to that found for RCDP2 manufactured homes. Quaid found occupancy to be the only significant factor in determining DHW energy use. This result was corroborated by this sample of manufactured homes by a multiple regression with total occupancy, energy factor, tank volume and climate zone as independent variables.

A reduction in use per occupant over the past decade is indicated by comparison of this sample, the results of Quaid et al and results reported by Palmiter in 1982. Palmiter summarized submeter data of eight studies performed in the early 1980's. A regression for 91 homes resulted in a slope coefficient of 1,310 kWh/person, more than 300 kWh per person greater than the coefficients derived from the both RCDP2 samples. A reduction in use per occupant may be the result of lower average delivery water temperatures, more efficient fixtures and appliances or more conscientious use by occupants. For example, in 1981 Reese and Wall observed average DHW temperature of 144°F, while in 1991 Quaid et al typically measured DHW temperatures between 122°F and 127°F. Lowering tank temperature reduces both standby and volumetric losses.

Figure 5. Annual DHW electrical consumption versus number of occupants per home. The line indicates the predicted fit of Equation 2. Equation 2 was obtained from a robust regression of annual DHW consumption with occupancy restricted to four or less.

Table 15

**Median Annual DHW Electrical Consumption per Occupant
Adjusted for Standby Loss***

Number of Occupants	Number of Observations	DHW Consumption per Occupant, (kWh/yr/person)
1	12	940
2	51	1,150
3	32	1,280
4	27	1,140
5	12	990
over 5	7	640

* Mean standby loss was estimated from CEC rated values and subtracted from total annual DHW consumption. This result was then divided by total occupants.

<p align="center">Table 16</p> <p align="center">Annual DHW Electrical Consumption, Actual and Predicted</p>				
Number of Occupants	Number of Observations	Annual DHW Consumption (kWh/year)		Percent Difference
		Actual (Median)	Predicted by Equation 2*	
1	12	1,500	1,790	+19
2	51	2,890	2,960	+2
3	32	4,440	4,130	-7
4	27	5,150	5,280	+3
5	12	5,530	6,470	+17
Total	134	3,880	3,918	-1
<p>* Equation 2 was obtained from a robust regression of annual DHW consumption with occupancy restricted to four or less.</p>				

5.4 Prediction of Standby Loss

The constants resulting from these regressions are expected to approximate mean standby loss of the sample, including pipe losses and losses due to leaky faucets. The constant of 620 kWh per year in Equation 2 is 7% greater than the mean rated standby loss of the 76 tanks with CEC data available.

Equation 1 appears to give a poor estimate of standby loss. The regression constant of 960 kWh per year is 70% higher than the CEC mean rated standby loss. The lower consumption per person for homes with five occupants compared to homes with two, three and four occupants (Table 15) shifts the intercept upward in the regression.

It is likely that standby losses listed in the CEC directory are greater than actual losses. Water heaters typically have no bottom insulation and losses through an uninsulated bottom account for approximately 60% of the calculated standby loss under steady state conditions. Yet, in practice these tanks sit on floors with at least R-19 insulation. Even for hot water tanks not situated on insulated floors, actual losses may differ from rated standby losses. In Seattle City Light's study of 30 water heaters located in unheated basements, for example, measured standby losses were 16% lower than standby losses predicted by laboratory measurements of similar tanks (Reese and Wall 1981, Ek 1982).

In the past decade, standby losses of standard tanks have been reduced by approximately two-thirds. Water heaters in this sample were installed in the late 80's and have approximately R-12 insulation on the top and sides and mean rated standby loss of 580 kWh per year. Water heaters installed during the 70's and early 80's typically had only R-5 insulation on the sides with uninsulated top and bottom. Palmiter's 1982 regression of data for 91 homes produced a constant of 1,955 kWh per year. This is consistent with measurements of water heater standby loss at the time. Average measured standby loss of 26 water heaters in the 1981 Seattle City Light study was 1,610 kWh/year and BPA laboratory measurements in the same time period were 1,925 kWh/year (Reese and Wall 1981, Ek 1982).

5.5 Climate and Season

As expected, DHW electrical consumption exhibited seasonality. For all three climate zones DHW electrical use was highest in the winter and lowest in the summer (Figure 6, Table 17). For the entire sample, median DHW electrical consumption during the winter season (January, February, March) was about 30% higher than that in the summer. This seasonality is more pronounced in climate zones 2 and 3 where median winter DHW consumption was 40% greater than summer's (Table 17). In climate zones 2 and 3, average outside air temperature was 27°F greater in the winter than in the summer, compared to a 21°F difference in climate zone 1 (Table 18).

DHW energy consumption peaked in March, while average outside temperature was minimum in February. This supports our assumption of a one month lag between air and ground temperature. DHW consumption in March was 42% greater than in July, the month of minimum DHW consumption.

While total DHW energy consumption was 13% greater in climate zones 2 and 3 than in zone 1, the number of occupants per home was also greater in zones 2 and 3. DHW energy consumption per occupant was only 3% greater in zones 2 and 3 (Table 13).

Figure 6. Average daily domestic hot water electrical consumption by season. Spring season is defined as April, May and June for the DHW analysis.

<p align="center">Table 17</p> <p align="center">Median Daily Average DHW Electrical Consumption</p> <p align="center">By Season</p>						
Season	Zone 1		Zone 2 and 3		All Zones	
	Consumption (kWh/day)	Ratio to Average	Consumption (kWh/day)	Ratio to Average	Consumption (kWh/day)	Ratio to Average
Spring 1989	9.7	0.99	10.3	0.95	10.2	0.99
Summer 1989	8.7	0.89	9.6	0.88	8.8	0.85
Fall 1989	9.8	1.01	11.6	1.06	10.6	1.02
Winter 1989	10.7	1.10	13.4	1.22	11.5	1.12
Year	9.7		11.0		10.3	

The average seasonal variation noted in this sample is less than that reported by Fels et al (1984) but somewhat greater than reported in ELCAP (1992). Fels summarized measurements made by utilities in New Jersey and Denver, finding 42% variation in DHW electrical consumption from summer to winter. Average energy use and seasonal variation observed by Fels et al are very similar to that observed in climate zones 2 and 3 in this sample. Since the ELCAP study was performed in the same geographical area with a nearly identical distribution of homes throughout the climate zones, seasonality of these two sample is expected to be fairly similar. However, DHW consumption observed in ELCAP during the winter season was only 24% greater than in summer. Water heating use in January was 31% higher than that in August, the months of maximum and minimum consumption in that study respectively. This may be due to differences in average outside temperatures during the measurement periods of the two studies.

5.5.1 Factors Contributing to Seasonality

Seasonality in DHW electrical consumption may be the result of three factors: occupant use patterns, seasonal variation in standby losses and variation of inlet water temperatures.

Occupant water use patterns have been shown to vary substantially with season. Different families often have quite different responses to weather changes. On the average, however, the volume of hot water used is greater during the winter than in the summer, as reported in three independent studies presenting data of actual monitored use of a total of 147 homes for up to four years (Merrigan and Parker 1990, Gladhart and Weihl 1986, Perlman and Mills 1985). In some cases, hot water volume used during the winter season was as much as 45% greater than during the summer (Perlman and Mills 1985).

Variation in standby losses in this sample is expected to be minimal since all water heaters were installed inside the manufactured homes. Even where water heaters are located in unheated spaces, however, standby losses generally affect seasonality to much less extent than inlet water temperatures (Merrigan and Parker 1990).

Variation in inlet temperature is generally the greatest factor contributing to seasonality of DHW consumption. In addition to increasing the energy required to bring incoming water up to the setpoint, lower cold water temperatures lead to a greater volume of hot water used for bathing, hand washing and other uses where mixed water temperatures are adjusted by feel.

Average ground temperature at any depth is typically about 2°F above the mean annual air temperature at the location and generally varies about 5°F to 15°F from the average, depending on climate and the depth of the pipes. In colder climates pipes are usually buried deeper, tending to minimize differences in variation between locations (Palmiter 1982). The variation in ground temperature typically lags behind that of air temperatures by one to three months. For this study, we have assumed a lag of one month between ground water temperature and air temperature. An average inlet water temperature for this sample was estimated to be 52°F, based on mean annual air temperatures measured at weather stations near each site.

Table 18 Average Outside Air Temperatures (NWS) (°F)			
Season	Zone 1	Zone 2 and 3	All Zones
Spring 1989 (4/89 to 6/89)	56.8	55.1	56.2
Summer 1989 (7/89 to 9/89)	63.0	63.4	63.2
Fall 1989 (10/89 to 12/89)	48.0	41.7	45.4
Winter 1989 (1/90 to 3/90)	42.3	36.2	39.8
Year	51.7	47.7	50.0

5.5.2 Variation in Inlet Temperature vs. Occupancy Use Patterns

For the purpose of estimating the proportion of seasonality due to inlet temperature versus occupancy patterns, a hypothetical average variation from average inlet temperatures was calculated by artificially assuming this to be the only factor affecting seasonality. Inlet temperature variation for the sample was calculated to be between $\pm 13^{\circ}\text{F}$ and $\pm 15^{\circ}\text{F}$, assuming tank temperatures between 125°F and 135°F . This is larger than has typically been measured in the Northwest (Table 19) and is also greater than the average seasonal variation in outside air temperature at the sites (Table 10). That this hypothetical temperature swing is greater than physically possible indicates that occupant behavior patterns significantly affected seasonal use. Assuming an actual average variation in inlet water temperature of 10°F , it is estimated that seasonal variation in occupancy water use patterns accounts for 20% to 30% of the seasonality in DHW electrical consumption.

Table 19**Supply Water Temperatures
at Selected Sites**

Location	Annual Average (°F)	Average Seasonal Variation from Mean (°F)	Water Source	Reference
Portland, OR	53	±9	Surface	1
Salem, OR	50	±12 (Jan, Aug))	Surface	2
Seattle, WA	47	±15 (Jan, Aug)	Surface	3
Medford, OR	55	±6	Ground	4
Yakima, WA	58	±7	Ground	4
Kalispell, MT	50	±8	Ground	4
Olympia, WA	54	±7 (Sept, Feb)	Ground	5a
Olympia, WA	55	±11 (Sept, Dec)	Ground	5b

1. Portland Water Bureau records for April 1, 1989 to March 31, 1990. Annual variation was estimated to be the standard deviation of data taken at 57 sites in Portland's municipal water distribution system.
2. Personal communication with Bill Light, City of Salem Water Production Supervisor. Estimation based on measurements of water temperature average and variation in municipal distribution system.
3. Reese and Wall, 1981
Originally from Seattle Water Department records for the period October 1978 to April 1980.
4. Hanford et al, 1985
Measurements of water inlet temperatures at 48 homes over the period of 18 months. Water source for these homes were private wells.
5. Personal communication with Doug Floyd, City of Olympia Water Department.
 - a. City records of measurements taken on water distribution loop from August 1991 to May 1992.
 - b. City records of measurements taken on two dead end lines of water distribution system from August 1991 to May 1992.

Figure 7. Annual domestic hot water electrical consumption by water heater rated volume.

Figure 8. Annual domestic hot water electrical consumption by water heater energy factor.

5.6 Other Factors

As shown in Figures 7 and 8, median DHW energy use did increase slightly with increasing volume and decreased with increasing energy factor. However, multiple regression of the data showed effects of volume, energy factor and climate zone to be insignificant in determining DHW energy use when compared to the effects of occupancy.

Quaid et al also found the number of occupants to be the only significant factor in determining DHW usage. In RCDP2 site-built homes, energy consumption was fairly flat in the energy factor range 0.85 to 0.95 when corrected for occupancy.

5.7 Potential for DHW Energy Conservation

DHW energy conservation measures are of three types: heat transfer measures, volumetric measures and improved or altered heating modes. A brief overview of these measures follows, including estimations of energy savings observed in studies of site-built homes. Since the average annual DHW consumption of these manufactured homes was found to be less than has typically been observed in site-built homes, potential savings due to volumetric measures and improved heating modes can be expected to be less in this housing sector than has generally been reported.

5.7.1 Heat Transfer Measures

Heat transfer measures reduce standby loss of the system and include efficient water heaters, tank wraps, thermal traps and in-line point-of-use water heaters. Indications are that we have reached the point of diminishing returns regarding heat transfer measures. Standby losses of standard tanks now account for a relatively small proportion of total DHW energy use. In this sample, predicted standby losses were at most 15% of the total DHW electrical consumption.

The BPA's Blue Clue program provides incentives for installation of efficient water heaters having an energy factor of 0.94 or better, a heat transfer measure. As previously stated, Quaid et al reported energy use to be fairly flat with respect to energy factor between 0.85 and 0.95. Savings attributed to increasing energy factor from 0.88 to 0.94 are expected to be a maximum of 200 kWh per year.

5.7.2 Volumetric Measures

Volumetric measures relate to the volume of hot water used and include measures such as low-flow faucets, use of water efficient appliances and change of occupancy use patterns. Potential savings may be significant. However, it is obvious that the studies performed in site-built homes described below greatly overestimate the conservation potential in manufactured homes. For example, estimated gross savings reported by Robison (1990) for low flow showerheads and by Turiel et al for water efficient appliances would account for more than half of the average annual hot water usage in this sample. Clearly, more research will be required to assess the true distribution of these savings and a more realistic estimate of the potential savings in manufactured homes.

Low Flow Showerheads:

In a Pacific Power study of 66 homes, water savings with low flow showerheads averaged 1.4 gallons per minute (Robison 1990). At this rate, assuming two 10 minute showers per day per household at a water temperature of 105°F and space heat interaction of 0.15, savings can be estimated at 1,200 kWh per year. However, Robison measured instantaneous flows rather than actual use over a period of time. In a study of the actual energy use of nine families, the overall savings of low flow showerheads was significantly less than predicted by "bucket-tests" because of compensating behaviors by some participants. Two of the nine families actually consumed more hot water because dislike of the

showerheads resulted in substitution of baths for showers and longer showers to "get the soap out". Average savings in hot water used for bathing was only 14%, much less than the predicted savings of 50% (Turner and Gruber 1988).

Potential savings for manufactured homes is expected to be less than for site built homes considering smaller typical family size and possibly different occupant water use patterns. Given the total energy used for DHW in this sample it would be surprising if the level of savings suggested by Robison were available among manufactured homes. Automatic dishwashing, clothes washing and bathing are not affected by low flow shower heads.

Water Efficient Appliances:

Most of the energy consumed by clothes washers and dishwashers is for water heating. According to DOE annual estimates of energy consumption, these two appliances may account for approximately 40% of total DHW energy consumption (Turiel et al 1990).

DHW electrical use for clothes washing can be reduced by 76% with design changes including elimination of warm rinse and warm/warm options and the use of horizontal axis machines. Estimated annual water heating savings are 500 kWh per year with a space heating interaction of 0.15 and assuming 380 cycles per year and a reduction of 7.8 gallons per cycle and an 85% efficient heater (Turiel et al 1990).

Hot water consumption of dishwashers can be reduced by as much as 22% by the use of more efficient food filters, improved spray arms and improved fill control among other methods. In addition, water may be heated more efficiently by water heater dishwashers that are equipped with a booster heater. Estimated annual water heating savings were at most 100 kWh per year, with a space heat interaction of 0.15 and assuming 150 to 230 cycles per year, a reduction of 2.6 gallons per cycle and an 85% efficient heater (Turiel et al 1990).

5.7.3 Improved Heating Modes

Improved heating modes include use of heat pump water heaters, solar assisted water heaters, wood stove heat exchangers and heat recovery from appliances. These measures offer the greatest potential for DHW energy conservation. For example, a number of studies and field tests of heat pump water heaters have shown gross annual savings of about 50 percent compared to electric resistance heating (Hanford et al 1985, Merrigan and Parker 1990, Bamberger et al 1988). Potential savings of solar assisted water heaters are estimated to range between 40% and 70% of a home's annual hot water requirements, depending on climate and the family's water use patterns (Mathur 1990). Gross savings of 32% to 62% have been observed for solar systems in the Pacific Northwest (Bamberger et al 1988). Heat recovery from waste water can be accomplished by use of a water-to-water heat pump, resulting in estimated savings of 60% compared to electric resistance heaters (Perlman 1986).

While these savings estimates are promising and point to net energy savings of 1,000 to 2,000 kWh per year per home, the applicability of these technologies to this sector remains a topic of further investigation.

5.8 SUMMARY OF DHW ELECTRICAL CONSUMPTION

1. Median DHW electrical consumption for this sample was found to be 3,880 kWh per year or 11 kWh per day. The mean consumption of 4,160 kWh/year is less than was observed in Quaid et al's comparable study of RCDP2 site-built homes.

2. DHW electrical use was found to vary significantly with season. On the average, DHW consumption in the winter was 30% higher than in the summer. DHW consumption during the peak month of March was 42% greater than in July, the month of minimum DHW consumption. Annual DHW energy use per occupant in climate zones 2 and 3 was approximately 3% greater than in zone 1.
3. The total number of occupants was shown to be the most significant factor determining total DHW electrical consumption.
4. DHW electrical use was shown to correlate strongly with the number of occupants up to a total occupancy of five. Use per occupant when adjusted for standby loss was found to be less for homes with five or more occupants than for homes with two, three or four occupants. Average DHW use per occupant is predicted to be about 1,000 kWh per year, exclusive of standby losses.
5. Standby losses are predicted to be approximately 600 kWh per year for each home or 15% of total DHW electrical consumption. Since standby losses are now a relatively small proportion of total DHW energy use, the greatest potential for energy savings can be obtained by improving heating modes and implementing volumetric conservation measures. These measures include low flow faucets, water efficient appliances and heat pump water heaters, among others.
6. The potential for DHW energy conservation in manufactured homes must be reviewed further before definitive estimates can be made.

6 NONHEATING ELECTRICAL CONSUMPTION

6.1 Background

Nonheating electrical consumption includes the energy use of appliances and lighting, as well as miscellaneous items such as water bed heaters, electric blankets, power tools, toaster ovens, televisions, stereos and well pumps. These loads comprise a significant proportion of residential electrical consumption, both nationally and in the Northwest. Regionally, nonheating loads are estimated to account for approximately 50% of the electricity consumed in all single family residences, including homes heated by electricity, fossil fuels and wood (ELCAP 1989). Lighting accounts for approximately 11% of electricity consumed by all U.S. residences (Nadel 1990). Miscellaneous conveniences, other than lighting and major appliances, may account for as much as 20% of total residential electricity consumption (Ranier et al 1990). For all-electric homes, usage as a percent of total consumption is, of course, less.

In the all-electric RCDP2 site-built homes analyzed by Quaid, these nonheating or "other" uses comprised approximately 40% of total energy use. Of this, 5% was refrigeration use while 35% was uncategorized. Domestic water heating accounted for another 23% of total energy use.

The energy use and conservation potential of appliances has been the focus of many studies in recent years. Under the National Appliance Efficiency Conservation Act, federal efficiency standards applying to refrigerators, freezers, room air conditioners and water heaters were developed by the U.S Department of Energy and took effect in 1990. More stringent federal standards will take effect in 1993 (Turriel et al 1990). Standards applying to dishwashers, clothes washers and dryers will take effect in 1994 (Code of Federal Register 1992). Residential lighting has received less attention, although efficiency standards have been enacted or are planned in some locations including Massachusetts, New York and San Francisco (Nadel 1990).

The energy use of some miscellaneous items, such as clocks, is truly insignificant. However, it would be a mistake to ignore others. A water bed heater, for example, may consume more energy than any other appliance in the house. The electrical consumption patterns of dehumidifiers and well pumps are often very similar to air conditioning patterns. To neglect their presence may lead to errors such as overestimation of savings predicted for cooling conservation measures (Ranier et al 1990).

6.2 Nonheating Electrical Consumption in RCDP2 Manufactured Homes

Normalized annual nonheating electrical consumption per home varied from 1,625 to 21,895 kWh. The median annual usage per household for this sample was 6,670 kWh (Table 20). Because of skew toward high values, mean annual consumption was greater than the median at 7,340 kWh with a standard deviation of 3,912. Median nonheating usage per occupant was 2,500 kWh. Daily average nonheating electrical use was 18.3 kWh per day.

Homes in zones 2 and 3 used more energy on average than those in climate zone 1. However, on average zone 2 and 3 homes also had more occupants.

Average nonheating consumption of this sample is less than was observed by Quaid, as shown in Table 21. However, average occupancy was also less. Nonheating energy use per occupant appears to be greater in RCDP2 manufactured homes than in RCDP2 site-built homes that did not install efficient appliances.

Table 20 Characteristics of Nonheating Electrical Consumption ¹			
	Zone 1	Zone 2 and 3 ²	Total
Number of Homes	73	53	126
Average Total Occupants	2.7	3.3	3.0
Mean Floor Area (Square feet)	1,410	1,590	1,530
Median Daily Consumption (kWh/day)	16.5	20.8	18.3
Annual Consumption ³ , (kWh/year)			
Mean	6,890	7,990	7,340
Median	6,050	7,600	6,670
Median Consumption per Occupant ⁴ , (kWh/yr-person)	2,500	2,590	2,500
Consumption per Square Foot of Floor Area (kWh/sq.ft.)	4.65	4.80	4.69
¹ Cases with an outbuilding or where auxiliary space heating was noted were not included. ² Zone 2 and 3 were combined due to very small number of zone 3 homes and uncertainty in determining actual climate characteristics of zone 3 homes. ³ These values have been normalized as described in Section 2. ⁴ Use per occupant is based on the mean of ratios, rather than the ratio of mean consumption to mean number of occupants.			

<p>Table 21</p> <p>Comparison with Results for RCDP2 Site-Built Homes</p>			
	RCDP2 Manufactured Homes	RCDP2 Site Built Homes	% Difference
Mean Annual Nonheating Consumption, normalized (kWh/year)	7,340	7,878	7
Average Total Occupants	3.0	3.4	13

6.3 Climate and Season

Annual nonheating energy use per occupant in climate zones 2 and 3 was approximately 4% greater than that in zone 1 (Table 20). This small difference may be due to increased indoor activities in colder climates, the larger cooling requirements in zones 2 and 3, or to the greater use of well pumps or other equipment in more arid, rural regions of the Northwest.

Nonheating energy use varied significantly with season. Median average nonheating electrical consumption in December was 44% higher than in May, the months of maximum and minimum usage (Table 12). By season, average nonheating electrical consumption in the winter was 27% higher than in the spring and summer (Table 22). Seasonality was slightly more pronounced for climate zone 1 than for zones 2 and 3, perhaps due to the greater cooling requirements of zones 2 and 3.

The seasonal variation observed in this sample is very similar to that reported by Fels. However, less seasonality was observed in the ELCAP study of homes located in the Northwest (1992). In that study, nonheating consumption during the winter season of December, January and February was only 13% greater than that during the spring and 12% more than summer consumption. Monthly nonheating use in December was 26% greater than that in June. The difference between these studies may indicate the inadvertent inclusion of some portable space heater use in the nonheating category of the RCDP manufactured homes. We have attempted to minimize this as described in Section 2, although some contamination of this "catch-all" category may be unavoidable. Another possible explanation is greater summer peaking of older, less efficient refrigerators and freezers in the relatively poorly insulated, older homes of the ELCAP study. ELCAP refrigerators used on average about 50% more energy than refrigerators in the RCDP2 site-built homes, and thus would have a proportionally greater impact on nonheating seasonality. It has also been argued that refrigerator and freezer consumption is less seasonal in tight, well-insulated houses such as these manufactured homes, although this point is somewhat controversial.

Nonheating electrical consumption was shown to be correlated with outside temperature. The decrease of nonheating electrical use with increasing temperature up to 60°F is shown in Figure 10. In bins above 65°F some increase in consumption was noted in both "space heating" and nonheating categories. This is largely due to the 20% of the sample that use air conditioning, either with a central heat pump ("space heating") or retrofit air conditioning system (nonheating). Below about 50°F the variability of nonheating loads, indicated by the whiskers of the box plots, increases with decreasing temperature. This trend of increased variability during winter months was also apparent in the ELCAP study. It may be explained by differences in seasonal occupant use patterns of lighting and other nonheating loads, as well as possible contamination by some portable space heater use.

Figure 9. Seasonal variation in nonheating electrical consumption.

Table 22

**Median Daily Average Nonheating Electrical Consumption,
Averages Based on Seasonal Totals**

Season	Zone 1		Zone 2 and 3		All Zones	
	Consumption (kWh/day)	Ratio to Average	Consumption (kWh/day)	Ratio to Average	Consumption (kWh/day)	Ratio to Average
Spring 1989 (Mar-May)	16.0	0.97	19.2	0.92	17.4	0.95
Summer 1989 (Jun-Aug)	14.8	0.90	19.1	0.92	16.4	0.90
Fall 1989 (Sep-Nov)	17.3	1.05	21.1	1.01	19.1	1.04
Winter 1990 (Dec-Feb)	19.0	1.15	22.6	1.09	20.8	1.14
Year	16.5		20.8		18.3	

Figure 10. Nonheating electrical consumption versus average outside temperature.

6.3.1 Factors Contributing to Seasonality

Factors contributing to seasonality of nonheating electrical consumption include lighting and variation in daylight hours, variation of refrigerator and freezer consumption with outside temperature, air conditioning use during warm months, seasonal use of devices such as water beds and electric blankets, seasonal requirements of well pumps and variation of occupancy use patterns with season.

Lighting is expected to be the most seasonal component of nonheating consumption. This is supported by the finding that nonheating electrical use peaked in December, the month of least daylight hours. Fels reported seasonal fluctuations in lighting use of -23% and +30% from average. ELCAP reported less pronounced seasonality of its "lights and conveniences" category. However, the inclusion of miscellaneous plug loads with lighting obscures the seasonal fluctuation of lighting by itself.

Refrigerator consumption has been shown to vary with outside temperature in Pacific Northwest homes (Nelson and Short 1990). In the ELCAP study, refrigerator consumption varied from -6% to +11% of the average seasonal consumption in winter and summer seasons, while freezer usage varied by -13% and +19%. Some have argued, however, that this correlation is degraded when the appliance is located inside tight, well insulated homes such as these (Quaid et al 1991). In this sample, almost all refrigerators and the majority of freezers are located inside the homes, while the locations of refrigerators and freezers in the ELCAP study were not specified. For these reasons, refrigerator energy use in RCDP2 manufactured homes may not be as strongly seasonal as was observed in ELCAP. Summer peaking of cooling loads decreases the overall winter to summer ratio of nonheating usage.

Even the energy use of dishwashers, clothes dryers, clothes washers and cooking ranges has been observed to be greater during the winter season than in the summer. In ELCAP (1992), variation from the mean of summer consumption ranged from -3% for clothes washers to -14% for ranges. Variation of winter consumption ranged from +4% for clothes washers to +10% for ranges. Fels also reported a very similar seasonal variation for these appliances.

The energy use of water beds and electric blankets has been shown to be quite seasonal. Over the year, water bed heating may vary by as much as a factor of five. Again, the correlation between the energy use and outside temperature may be expected to be degraded by the well insulated, tight envelopes of RCDP2 homes. The energy use of well pumps generally shows a significant peak in summer months (Ranier et al 1990).

6.4 Correlation with Occupancy

Nonheating energy use was shown to be strongly correlated with the number of occupants per home. Results of a robust regression on nonheating energy use with number of occupants as the independent variable are shown in Equation 3.

Equation 3. Results of a robust regression on nonheating energy consumption with number of occupants as the independent variable. The regression coefficient and constant were significant at the 0.0005 level.

$$Q = 2,703 + 1,470 N$$

where Q = Annual nonheating electrical consumption (kWh/year)
and N = Total number of occupants per home

Families having children less than 11 years old living at homes generally consumed less energy per person for nonheating uses than those without children. Results of a robust multiple regression with annual nonheating energy use as the dependent variable and number of adults and number of children as independent variables indicated that adults use more electricity for nonheating purposes than children (Equation 4).

Equation 4. Results of a robust multiple regression on nonheating energy consumption with number of adults and number of children under 11 years old per home. The regression coefficient and constant were significant at the 0.0005 level.

$$Q = 2,598 + 1,720 A + 624 C$$

where Q = Annual nonheating electrical consumption (kWh/year)
and A = Number of adults per home (≥ 12 yr.)
 C = Number of children per home (< 11 yr.)

No difference in nonheating energy use was found for those reporting that the home was occupied more than 50% of week days. There was also no difference between those who reported periods when the house was empty, periods when company was present or periods of additional appliance usage. Such subjective estimates of energy use and behavior by occupants has previously been found to be a poor determinant of actual energy use characteristics (Perlman and Mills 1985).

Figure 11. Dependence of nonheating electrical consumption on number of occupants.

6.5 Presence of Selected Appliances and Miscellaneous Equipment

Results of a multiple robust regression with independent variables of total occupants, number of freezers, number of well pumps, presence of water beds and usage of air conditioning are shown in Table 23. Each regression coefficient approximates the typical annual consumption per unit. This method is referred to as conditional demand analysis.

Variables such as the presence of refrigerators, clothes washers and dryers were not included in the regression. Their inclusion would have led to meaningless results because they were present in almost all of the homes. Although only 9% of the sample use air conditioning but do not have heat pumps, this variable was included because it substantially improved the quality of the regression. Presence of dishwashers was not included because its low expected energy use and the high saturation in the sample resulted in poor regression results.

Both the regression constant and slope coefficient comprise the energy use of electrical equipment not represented as independent variables in the regression. For example, refrigerator consumption is expected to be fairly independent of the number of occupants and so would be contained in the constant. Lighting and usage of clothes washers, dryers and dishwashers are expected to be dependent to a certain extent on occupancy with some base level of consumption. This energy consumption would therefore affect both the occupancy term and the constant.

Note that the standard errors associated with these estimates of energy use per unit are quite large, ranging from 30% to 48% of the total estimate. Standard deviations of similar magnitude have been noted for appliance energy usage in other studies of submetered data (EL-CAP, Quaid). Large standard deviations and standard errors may indicate the wide range of consumption per unit, depending on a variety of factors, including variation in size or application of the unit and differences in occupant use.

Large standard errors may also result from certain statistical characteristics of the sample that may not have a physical interpretation. For example, strong correlation between the independent variables used in the regression may lead to large errors. In this regression, correlation between variables was low and the correlation coefficients did not exceed 0.20. Evenso, results from this sort of regression model should be used with caution. The information presented here is used to indicate consumption patterns in RCDP manufactured homes and may not be easily generalizable to other samples or populations.xx

<p align="center">Table 23</p> <p align="center">Results of Multiple Robust Regression on Annual Nonheating Electrical Consumption</p>			
Dependent Variables	Coefficient (kWh/yr/unit)	Standard Error	Level of Test [†]
Total Occupants	1,322	136	< 0.0005
Freezers	1,284	381	0.001
Well Pumps	1,224	547	0.027
Presence of Water Bed (Y=1, N=0)	947	451	0.038
Use of Air Conditioning* (Y=1, N=0)	1,499	684	0.031
Constant	1,530	520	0.004
* Does not include central heat pump air conditioning.			
† The level of the test is the probability of wrongly declaring a difference to be significant. For the purposes of this study, a level of 0.05 or less is considered significant.			

Freezers

The energy use slope coefficient of freezers found in the preceding regression is considerably greater than the estimate of 700 kWh per year made according to DOE test procedures for new freezers manufactured during the same time period as these homes were manufactured. However, since no freezers were installed by the home manufacturers, the age and efficiency of the freezers may vary. This result is very similar to the ELCAP (1992) finding of 1,400 kWh/yr (median) for 26 freezers.

Annual nonheating electrical consumption of homes with and without freezers is compared in Figure 12. The incremental value between the medians of those without a freezer and those having one is 2,270 kWh per year. This difference is larger than regression results due to occupancy differences of the two groups. Average number of occupants for homes not having freezers was 2.8, while average occupancy was 3.1 for homes with one or two freezers. Between homes with one freezer and those with two the incremental value is 1,490 kWh/year, comparable to the coefficient found in the regression.

Figure 12. Annual nonheating energy consumption versus number of freezers

Figure 13. Annual nonheating electrical consumption versus presence of well pump.

Well Pumps

The energy used by a well pump depends on the amount of water pumped, the height lifted and the efficiency of the pump. A typical residential well pump has a rated capacity of between 0.5 and 2 kW and generally operates not more than a few hours per day. Use for irrigation purposes can significantly increase energy consumption. The coefficient found in the regression is more than twice the average energy consumption of 31 well pumps that were monitored in Michigan (Ranier et al 1990), but is within a plausible range for pumps in the Northwest. Many of the homes having well pumps were located in rural areas and some may be used for irrigation purposes. Half were located in climate zones 2 and 3 which are generally more arid than Michigan.

Annual nonheating electrical consumption for homes with and without well pumps is compared in Figure 13. The incremental value between the medians of these two groups of homes is 1,200 kWh/year, very similar to the coefficient found in the regression.

Water Beds

The energy use of water beds depends on size, bed temperature, ambient temperature, bed coverings and insulation around the water bag. Bed temperatures are typically around 90°F. Measured energy use has been observed to range from 500 to 3,000 kWh/year (Ranier et al 1990). The water bed coefficient found in the regression is within this range of measured energy use.

Annual nonheating energy use for homes with and without water beds is shown in Figure 14. Note that the energy use of homes with more than one water bed was not significantly greater than those having only one. This might indicate that the second water bed is generally not connected. However, because the sample size of homes having two is relatively small, this result is not significant. Because of the lack of distinction between these two groups, the regression was performed using presence or absence of water beds as an independent variable, rather than the *number* of water beds. The incremental value between the medians of homes with and without water beds is 1,730 kWh/year, greater than the coefficient found in the regression due to occupancy differences between the groups. Homes having water beds averaged 3.3 occupants while average occupancy for those without water beds was 2.8.

Air Conditioning

The energy use of air conditioning varies considerably, depending on climate zone, system type and occupant use patterns. In a study of more than 600 cases simulated using SUN-CODE, Heller and Kennedy (1991) found that very small changes in setpoint, venting and shading strategies resulted in very large changes in cooling energy requirements. Predicted cooling requirements in all three Northwest climate zones ranged from 0.166 kWh/ft² to 2.075 kWh/ft², or 250 to 3,100 kWh for a 1,500 ft² house. Through-the-wall or window units may use considerably less. At two manufactured homes examined in that study, located in Spokane WA and Yakima WA, the predicted cooling energy use was approximately 800 kWh per year, based on WATTSUN's default conditions. Actual energy use was about 1,600 kWh per year (Heller 1992). The regression coefficient is within the range of predicted values and is very similar to metered results of these two manufactured homes.

Figure 14. Annual nonheating electrical consumption versus number of water beds.

For homes with heat pumps, air conditioning use was metered as "space heat". Heat pump air conditioning has not been included in the nonheating category since it is impossible to separate heating and cooling energy for these homes. Heat pump consumption in July and August ranged from zero for most houses to more than 500 kWh per month. For twelve homes that did not have zero heat pump consumption during the summer, average heat pump energy use was 280 kWh per month for July and August. There is likely to be some air conditioning use, as well as heating, during the months of April, May, June and September.

6.6 Composition of Nonheating Electrical Use

The estimated composition of nonheating electrical use for this sample is shown in Table 24. Major end uses were predicted to be refrigerators and freezers, cooking, clothes drying and lighting.

Typical energy use of selected electrical equipment was estimated from literature information and the regression results shown in Table 23. The uncertainty of these estimates cannot be emphasized too strongly. First, interpreting multiple regression results in which there are many opportunities for correlation among independent variables is very difficult. For these results we have tried to restrict the conditional demand model to that subset where such correlations were minimized. Second, none of the components of nonheating energy use were separately metered in this study and relevant audit data is limited. Site audits of each home emphasized HVAC and ventilation characteristics, rather than appliance, lighting and miscellaneous electrical loads. There is very little information regarding the number, type and use of electrical appliances in each home. In any study of submeter data, the separation of lights and miscellaneous electrical conveniences will always be a problem unless lighting is given a dedicated, submetered circuit, an unlikely arrangement. Third, there is a wide range of energy consumption per unit of all these items, as indicated by the large standard errors of the regression shown in Table 23 and in the large standard deviations found in other analyses of submeter data. For example, in the ELCAP study, even the energy use of refrigerators, a relatively consistent load compared to others, had a standard deviation that was 42% of the mean energy consumption.

An estimate of the aggregate impact of these appliances per household for this sample is obtained by multiplying the fraction of the home owners having that item (the saturation) by its estimated annual energy consumption. This result is shown in the fifth column of Table 24. Since this sample of manufactured homes is not statistically representative of the general population of manufactured homes in the Northwest, the aggregate impact of this sample may not represent the regional nonheating end-use of manufactured homes in general.

The energy use of miscellaneous items was estimated by subtracting the sum of all categorized loads from the median annual nonheating electrical consumption of the sample. Thus, the sum of the aggregate end use (column 5) of each component is equal to the median consumption of this sample. The median, rather than the mean, is assumed to represent energy consumption typical of the sample.

Lighting energy use includes both interior and exterior lighting. Since typical hours of usage, number and type of fixtures and wattages of lamps were not determined, further research would be required to arrive at a more certain estimate of use. The energy use attributed to cooking includes use of the electric range as well as toaster ovens and microwave ovens. This estimate is also highly uncertain, given wide variation in occupant use patterns.

Miscellaneous uses comprised an estimated 15% of the total nonheating energy use. Items in this category include televisions, stereos, the home's ventilation system, power tools and electric blankets among others. A major component of this category may be television usage. Color televisions, present in 96 to 99% of homes in the U.S., consume from 75 to 1,000 kWh per year, depending on size and hours of use (Ranier et al 1990).

<p>Table 24</p> <p>Estimated Composition of Nonheating Electrical Use</p>					
End Use	Estimated Energy Use (kWh/yr/unit)	Estimated Variation (kWh/yr/unit)	Percent Saturation of Sample	Saturation X Annual Energy Use (kWh/yr)	Percent of Total
Lighting ^a	1,000	±500 ⁴	100	1000	15
Refrigerator ^b	900	250 ¹	106	950	13
Cooking ^c	1,000	500 ⁴	100	1,000	18
Clothes Washer ^d	100	70 ²	98	98	1
Clothes Dryer ^c	1,000	800 ²	94	940	14
Dishwasher ^d	120	80 ²	88	110	3
Freezer ^f	1,300	380 ³	70	910	12
Water Bed ^f	900	450 ³	33	300	4
Well Pump ^f	1,200	550 ³	19	230	3
Air Conditioning, ^f (not including heat pump A/C)	1,500	680 ³	9	140	2
Miscellaneous ^g	1,000	1000 ⁴	-	1,000	15
Total	10,700	±5,300		6,700	100
<p>a - g, Please, see notes and qualifications on the following page. 1 - 3</p>					

**Notes to Table 24,
Estimated Composition of Nonheating Electrical Use**

I. *Estimations of Annual Energy Consumption:*

- a. Fels estimated average daily energy use of lighting to be 3.29 kWh/day, based on measurements made by a utilities in New Jersey and Denver. For our estimate, we have reduced this figure by 20% to reflect the lower typical energy consumption of this sample.
- b. The DOE estimate of the energy used by a refrigerator manufactured in 1989 is 950 kWh/year (Turiel et al 1990). Quaid found average refrigerator energy consumption to be 925 and 854 kWh/year for "efficient" and "inefficient" units, respectively. These site-built homes were constructed during the same period as the manufactured homes. Since a large portion of refrigerators were provided by the home owners, age and efficiency may vary.
- c. Fels reported typical energy use of cooking to be 1,700 kWh/year using a 1979 information source. For this case, we have reduced this value substantially, considering increased use of microwave ovens and other changes in occupant behavior in the past decade and the lower typical energy consumption of manufactured homes. ELCAP (1992) reported an energy consumption of approximately 500 kWh per year for ranges. However, this does not include the use of microwaves, toaster ovens and other minor appliances often used in cooking.
- d. The estimated energy use of dishwashers and clothes washers does not include water heating, except for that of a dishwasher booster heater. Clothes washer energy use was estimated assuming 350 cycles per year with motor energy use of 0.3 kWh per cycle. Dishwasher energy use was estimated assuming 150 cycles per year with booster heater use of 0.2 kWh/cycle, motor energy use of 0.3 kWh/cycle and dryer energy of 0.3 kWh/cycle. Energy use per cycle is based on Turiel et al (1990). ELCAP reported median average energy consumption within 10% of these estimates for clothes washers and dryers. The energy consumption calculated for dishwashers is 20% higher than the median reported in ELCAP, but our estimate is well within one standard deviation of that result.
- e. (Turiel et al 1990)
- f. From regression results shown in Table 23. See Section 6.5 for discussion.
- g. The energy use of miscellaneous items was estimated by subtracting the sum of energy use attributed to all categorized items from the median annual nonheating electrical use of the sample.

II. *Estimations of the Variation in Annual Energy Use:*

- 1 Based on the standard deviation of refrigerator consumption ("inefficient" units) reported by Quaid.
- 2 Based on the standard deviation of appliance consumption reported in ELCAP (1992).
- 3 Based on the standard errors from results of the conditional demand analysis described in Section 2. These results are shown in Table 23.
- 4 The energy use of lighting, cooking and miscellaneous loads is highly variable and depends strongly on occupant behavior. In addition, these loads are difficult to quantify due to the inability to separately meter them in most real situations. We found a paucity of information available in the literature. The range of variability has been assumed to be $\pm 50\%$ of the estimated annual energy consumption for lighting and cooking and $\pm 100\%$ for miscellaneous loads.

6.7 Potential for Nonheating Energy Conservation

The potential for energy savings in nonheating residential end uses is modest. Available energy savings are dominated by lifestyle changes that probably cannot be affected by utility incentives. Further, the energy savings potential is reduced by the interaction between appliance usage and space heating consumption. Most appliance conservation strategies that are cost effective and technically feasible at this time will be implemented by manufacturers to meet the 1993/94 federal standards. Federal standards will continue to be tightened at intervals of approximately five years (Turiel et al 1990). Even so, some savings may be obtained by incentive programs that encourage the purchase of energy efficient lighting and refrigerator/freezers that exceed federal standards and that do not include energy inefficient options. The savings potential of other appliances is minimal at this time.

6.7.1 Refrigerators and Freezers

The 1993 standards for refrigerators and freezers are significantly more stringent than those implemented in 1990. For example, for all classes of refrigerators, refrigerator-freezers and freezers on the market in 1990, only 7 of 2,114 meet the 1993 standards (Turiel et al 1990). Once manufacturers introduce new lines, there is still expected to be a variety of models available with a range of efficiencies, even if narrow.

An 18 ft³ refrigerator/freezer with automatic defrost⁷ that exceeds the 1993 federal standards by 10% is estimated to save an additional 70 kWh per year, compared to a unit just meeting the standards. This estimate is based on DOE testing requirements that have been shown to overpredict average energy consumption by 5 to 16% (Quaid et al 1991, Nelson and Short 1990). In this sample of manufactured homes, 70% of the participants purchased new refrigerators with the home. Thus, with an assumed space heat interaction of 0.5, average savings across the sample would be negligible at 25 kWh per year per home.

Savings may be possible, however, with utility incentive programs that address the impact of refrigerator size and features. Under the federal standards, allowable energy use is a linear function of the adjusted volume of the unit. Therefore, energy savings may be obtained by limiting the size of refrigerator which is eligible for an incentive payment. Greater energy use is also allowed for refrigerators having features such as through-the-door icemakers, automatic defrost or side-mounted freezers. For example, an 18 ft³ refrigerator with side-mounted freezer and a through-the-door icemaker is allowed to use 178 kWh per year more than a similar unit without these options.

6.7.2 Lighting

Compact fluorescent lights consume about three-quarters less energy than incandescent sources. Assuming 50% penetration in each home, average lighting energy use of 1,000 kWh/year and space heat interaction of 0.5, savings per home would be approximately 200 kWh per year. More research would be required to better estimate the lighting conservation potential in these homes.

⁷ For this example, an adjusted volume of 20.8 ft³ has been used. Adjusted volume is defined as the volume of the refrigerator plus 1.5 times the volume of the freezer. For this class of refrigerator/freezer, allowable energy use under the 1993 standards is $Q = 16.0 AV + 355$ (Code of Federal Register 1992).

6.8 SUMMARY OF NONHEATING ELECTRICAL CONSUMPTION

1. Median nonheating energy use for this sample of RCDP2 manufactured homes was 6,670 kWh per year. Energy use per occupant was somewhat greater in than in RCDP2 site-built homes.
2. Nonheating electrical use varied significantly with season. On the average, nonheating use was 27% higher in the winter than in the summer. Nonheating electrical consumption was 43% higher in December than in May, the months of maximum and minimum usage.
3. Nonheating electrical consumption was found to be well correlated with the number of occupants per home. It is indicated that adults use more energy for nonheating purposes than children. Average nonheating energy use per occupant is predicted to be 1,720 kWh/year for adults and 624 kWh/year for children, exclusive of a level of nonheating consumption typically present in all homes.
4. Annual nonheating energy use per occupant in climate zones 2 and 3 was approximately 4% greater than that in zone 1. This may be due to increased indoor activities in colder climates, the larger cooling requirements in zones 2 and 3, or to the greater use of well pumps or other equipment in more arid, rural regions of the Northwest.
5. Both nonheating and domestic water heating electrical consumption are correlated with average outside temperature.
6. Most cost effective, technically feasible conservation strategies for appliances will be captured by the 1993/94 federal standards. However, savings may still be possible through incentives that encourage the purchase of appliances that exceed these standards, that do not exceed prescribed size limits or do not have certain energy consuming features.
7. Potential savings for energy efficient lighting is estimated to be 200 kWh per year. More research would be required to better estimate the lighting conservation potential in these homes.

7 REFERENCES

- Bamberger, J. A., R.C. Hanlen, B. A. Le Baron, W. L. Nicholson and P.W. Zimmerman, B. Cody 1988. *Comparison of the Performance and Energy Savings Potential of Heat Pump, Solar and Conventional Water Heaters in the Pacific Northwest*, Proceedings of the ACEEE 1988 Summer Study on Energy Efficiency in Buildings, American Council for an Energy Efficient Economy, 1988
- Baylon, David, Bob Davis, Mike Kennedy, Mike Lubliner, 1991. *Manufactured Homes Thermal Analysis and Cost Effectiveness Report*. Prepared for the Bonneville Power Administration under Contract Number DE-AM79-87BP35738
- Bonneville Power Administration, 1987. *Super Good Cents Technical Specifications for Manufactured Homes*. Division of Residential Programs, Portland, Oregon
- California Energy Commission, 1989. *Directory of Certified Water Heaters*, 1989
- Code of Federal Register. 1992. Energy, Title 10, Section 430.31. January 1, 1992
- Ek, Calvin. 1982. *The Effects of External Insulation On Electric Water Heaters*, Bonneville Power Administration, Division of Laboratories
- ELCAP 1989. Pratt, R.G., C.C. Conner, E.E. Richman, K.G. Rigland, W.F. Sandusky, M.E. Taylor, *Description of Electric Energy Use in Single-Family Residences in the Pacific Northwest, End-Use Load and Consumer Assessment Program*, prepared for the U.S. Department of Energy under contract DE-AC06-76RL0 1830, July 1989
- ELCAP 1992. Cahill, James M., Keith G. Ritland, Wendy Lin-Kelly, *Description of Electric Energy Use in Single-Family Residences in the Pacific Northwest: 1986 - 1992, End-Use Load and Consumer Assessment Program*, Bonneville Power Administration, December 1992
- Fels, M., J. Rachlin and R. Socolow. 1984. *Seasonality of Non-Heating Consumption: A Study Based on Submeter Data*, Center for Energy and Environmental Studies, Princeton University, Proceedings of the ACEEE 1984 Summer Study on Energy Efficiency in Buildings, American Council for an Energy Efficient Economy, 1984
- Gas Appliance Manufacturers Association, 1988. *The Consumers' Directory of Certified Efficiency Ratings for Residential Heating and Water Heating Equipment*, October 1988
- Gladhart, Peter and Jeffrey Weihl, 1986. *Institute for Family and Child Study, Monitored Hot Water Use: A Seasonal Analysis*, Proceedings of the ACEEE 1986 Summer Study on Energy Efficiency in Buildings, American Council for an Energy Efficient Economy, 1986
- Gunn, Lawrence, 1982. *Residential Single Family Electric Water Heat*, Seattle City Light, April, 1982
- Hanford, J., M. Kennedy, M.J. DeLaHunt, L. Palmiter. 1985. *Heat Pump Water Heater Field Test*. Prepared for the Bonneville Power Administration under Contract Number DE-AC79-84BP17060
- Heller, Jonathan. 1992. Ecotope, Inc., personal communication.
- Heller, Jonathan, and Michael Kennedy, 1991. *Proposed Cooling Energy Prediction Technique: For Use in the WATTSUN Program*, Ecotope, October 1991

Mathur, G.D. 1990. "Solar Water Heating", *Heating Piping and Air Conditioning*, May 1990

Merrigan, Tim and Danny Parker, 1990. Florida Solar Energy Center, *Electrical Use, Efficiency and Peak Demand of Electric Resistance, Heat Pump, Desuperheater and Solar Hot Water Systems*, Proceedings of the ACEEE 1990 Summer Study on Energy Efficiency in Buildings, American Council for an Energy Efficient Economy, 1990

Nadel, Steve. 1990. *Efficiency Standards for Lamps, Motors and Lighting Fixtures*, Proceedings of the ACEEE 1990 Summer Study on Energy Efficiency in Buildings, American Council for an Energy Efficient Economy, 1990

Nelson, Peter E. and John A. Short. 1990. *Analysis of 12 Japanese Refrigerators in the Northwest*, Proceedings of the ACEEE 1990 Summer Study on Energy Efficiency in Buildings, American Council for an Energy Efficient Economy, 1990

Palmiter, Larry, June, 1982. *Potential for Conservation of Electrical Energy in Northwest Residences*. Prepared for Pacific Northwest Laboratory.

Palmiter, Larry and Ian Brown, 1989. *Northwest Residential Infiltration Survey: Sample Selection and Bias Assessment*, Prepared for the Washington State Energy Office under Contract No. 88-24-01

Palmiter, Larry, Tami Bond, Ian Brown, David Baylon, 1992. *Measured Infiltration and Ventilation in Manufactured Homes, Residential Construction Demonstration Project, Cycle II*. Prepared for the Bonneville Power Administration under Contract Number DE-AM79-91BP13330.

Palmiter, Larry and Mike Kennedy, 1983. *Annual Thermal Utility of Internal Gains*, Proceedings of the 8th National Passive Solar Conference, American Solar Energy Society, September 1983

Perlman, M. and B.E. Mills, 1985. *Development of Residential Hot Water Use Patterns*, ASHRAE Transactions, volume 2a, 1985

Perlman, Maier. 1986. *Residential Water Heating Energy Conservation Alternatives*, Proceedings of the ACEEE 1986 Summer Study on Energy Efficiency in Buildings, American Council for an Energy Efficient Economy, 1986

Quaid, Maureen, Rick Kunkle and Brian Lagerberg, 1991. *RCDP Cycle 2 Appliance Analysis*, Washington State Energy Office, August 1991,

Rainer, Leo, Steve Greenberg, and Alan Meier. 1990. Lawrence Berkeley Laboratory, Applied Science Division, "The Miscellaneous Electrical Energy Use in Homes", Proceedings of the ACEEE 1990 Summer Study on Energy Efficiency in Buildings, American Council for an Energy Efficient Economy

Reese, Scott and Harry Wall, 1981. *Residential Electric Water Heater Conservation Potential*, Seattle City Light, May 1981

Riewer, Sheila. 1988. *Demonstrating Model Conservation Standards in Manufactured Housing*, The Bonneville Power Administration, Proceedings of the ACEEE 1988 Summer Study on Energy Efficiency in Buildings, American Council for an Energy Efficient Economy, 1988

Robison, David, 1990. *Field Measurements of Low Flow Showerheads*, Proceedings of the ACEEE 1990 Summer Study on Energy Efficiency in Buildings, American Council for an Energy Efficient Economy, 1990

Turiel, Isaac, Douglas Berman, Peter Chan, Jon Koomey, Benoit Lebot, Mark Levine, James McMahon, Greg Rosenquist and Steve Stoft, 1990. U.S. Residential *Appliance Energy Efficiency: Present Status and Future Directions*, Lawrence Berkeley Laboratory, Proceedings of the ACEEE 1990 Summer Study on Energy Efficiency in Buildings, American Council for an Energy Efficient Economy, 1990

Turner, Carolyn and Kenneth Gruber, 1988. *Occupant Use Factors Influencing Optimal Results from Energy Conservation Strategies*, Proceedings of the ACEEE 1988 Summer Study on Energy Efficiency in Buildings, American Council for an Energy Efficient Economy, 1988

Wall, Harry, 1982. *Single-Family Residential Electric Water Heat Conservation Measures Analysis - Report No. 1*, Seattle City Light, February 1981

**DATE
FILMED**

10/27/93

END