RESULTS FROM LONG-TERM MONITORING OF ENERGY-EFFICIENT AND CURRENT PRACTICE HOUSING IN MONTANA

Mark A. Jackson
Montana Department of Natural Resources and Conservation

ABSTRACT

Monitoring the difference in electricity use between energy-efficient and current building practice housing in Montana provides an important piece of information for consumers, builders, and researchers. Whether or not the differences in energy use remain consistent over time is also an issue because of the variability of occupant behavior.

Sixty-seven energy-efficient all-electric homes were built in Montana for the Residential Standards Demonstration Program. These homes along with a control group of 65 homes representing current building practice were monitored for total, water heating, and space heating electricity use. Data was reported by the occupants on a weekly basis. Two years of monitored data were collected from a restricted sample.

This report presents a summary of electrical end use data collected from the two groups of homes. A comparison is made between the two types of homes for both years. Some occupants chose to burn wood during the second year of monitoring, and the impact of wood heating on space heating electricity use is presented. The results of this analysis help to better define the energy use differences between the two groups.

INTRODUCTION

The Montana Department of Natural Resources and Conservation (DNRC) has been actively involved in promoting energy-efficient residential construction for several years. Evaluating the energy savings of these homes and providing this information to homebuilders, policy makers, and the public is an important function of DNRC.

Previous analysis of data from the Residential Standards Demonstration Program (RSDP) (Jackson, 1986) suggests that builders participating in the program were successful in achieving pre-established space heating energy budgets, and that the RSDP homes use significantly less total and space heating electricity than do current practice homes. DNRC has used cost and thermal performance data to establish that the additional costs related to building Montana RSDP homes have a positive net present value to the consumer at current electricity costs and interest rates. (Jackson, 1986, Cartwright,1987)

This report uses two years of monitored data collected through RSDP to make a comparison between the electrical energy consumption of energy-efficient and control homes in Montana. Fifty RSDP homes and 49 control homes were in the monitoring program for the first year. During the second year, 23 RSDP and 23 control homes reported electrical end use data. Four RSDP and 13 control homes burned wood during the second year and are treated as a separate group for comparative purposes. To facilitate direct comparison, first year electrical end use statistics are recalculated for the remainder of the groups that stayed in the program for two years.

RSDP IN MONTANA

During 1984 and 1985, 67 energy-efficient homes were built as a part of RSDP in western Montana. These homes meet or exceed the Model Conservation Standards (MCS) for energy-efficiency developed by the Northwest Power Planning Council (Council, 1986). A control group of 65 homes was recruited from existing houses to represent current (1983-1984) building practice.

The occupants of both types of homes are self-selected and may not be representative of all occupants of energy-efficient or current building practice homes. RSDP homeowners chose to purchase an energy-efficient home and to participate in the monitoring program. The occupants of control homes volunteered to participate in monitoring. Both groups of occupants received incentives to abstain from wood burning during the first year of

monitoring. The bias introduced by the self selected nature of the occupants cannot be quantified, but the occupants of both types of homes inquired about the performance of their homes compared to other homes. This may indicate that the occupants in general are interested in energy conservation.

General Characteristics of RSDP and Control Homes

Montana RSDP Homes. All 67 RSDP homes built in Montana were designed to use less than 3.2 kWh/ft^2 of space heating electricity during a typical year. In addition they have full air-vapor barriers, low-E or triple pane windows, and air-to-air heat exchangers. However, there were few design constraints placed on the builders of RSDP homes, so a diverse range of styles and energy-efficient building techniques are represented by the homes.

House types range from small single story slab-on-grade homes to large two story homes with full daylight basements. The floor areas of the RSDP homes range from 1,144 ft^2 to 3,690 ft^2, with the average home having 2,356 ft^2.

In general, insulation levels in ceilings and walls exceed the minimums required by the MCS. Ceiling insulation levels in Montana RSDP homes range from R-38 to R-78 with a mean of R-49. MCS specify a minimum R-38 ceiling for homes built in Montana. The mean wall insulation in the RSDP homes is R-34, while the MCS specify at least an R-27 wall. Floors over unconditioned spaces are insulated in the RSDP homes, usually to R-19. Basement walls are usually concrete, with framed interiors insulated with R-19 fiberglass batt.

RSDP homes were designed to use electric resistance as the primary source of space and water heat. Most of the homes have baseboard heaters with individual temperature controls. This allows the occupants a degree of zone heating capability.

Montana Control Homes. Approximately 65 homes were originally included in the control group. Most of the control homes were built between 1980 and 1984. They represent the typical building practice and levels of insulation found in new residential construction during that period.

The control homes meet HUD Minimum Property Standards for insulation levels. In most cases these homes have R-38 ceilings and R-19 walls. Crawlspace floors are usually perimeter insulated with R-11 batt, and basement walls are generally

uninsulated and unfinished if the basement is not heated, or framed and insulated if the basement is heated or conditioned.

This group of homes also has a wide range of floor areas and house types. They are somewhat smaller than the RSDP homes, with floor areas ranging from 815 ft^2 to 3,000 ft^2, with an average of 1,785 ft^2. Like RSDP homes, the control homes have electric space and water heat. Most have baseboard heaters that allow zone heating.

DNRC staff was responsible for selecting the control homes and eliciting the participation of occupants for the monitoring project. RSDP homebuilders were asked to assist in the selection of control homes by recommending an appropriate control home for each of the RSDP homes that they built. An appropriate control home would be located near the RSDP home and would be similar in floor area and house type. Some homebuilders constructed several RSDP homes and had difficulty finding an appropriate control home for each RSDP home. Since an insufficient number of control homes were obtained through RSDP homebuilders, DNRC staff recruited additional control homes from the general public.

Data Collection

RSDP and Control homes were equipped with sub-meters to monitor space and water heating electricity use. "Other" electricity uses are obtained by subtracting the sum of the sub-metered uses from the total electricity use as measured by the main utility meter. In addition, indoor and outdoor temperatures, measured at a single point for each, were tracked by a device which displayed average temperatures, the number of accumulated degree hours, and the number of hours since reset. The RSDP and Control home occupants recorded these data on a weekly basis during the heating season, and on a monthly basis during the rest of the year.

EVALUATION OF MONITORED DATA

The original objective of RSDP was to demonstrate to homebuilders that energy-efficient housing could be built. Data collection was an afterthought. Nonetheless, it can be inferred from these data that the differences in total and space heating energy consumption between RSDP and control homes are significant, and that the builders were quite successful in meeting a maximum space heating energy budget.

Since the Montana sample of RSDP and control homes is not large and includes a diverse range of house types, floor areas,

and levels of energy efficiency, reasonable caution must be used when interpreting simple comparisons of the energy use differences between the RSDP and control homes.

Significance Tests for Differences in Consumption

Total and sub-metered energy uses are not always normally distributed for either RSDP or control homes. Due to the skewed nature of the distributions, inferences about the significance of differences in the means between the two groups are less than reliable if standard parametric significance tests, such as Student's t-test, are used to test hypotheses. To overcome this problem, non-parametric statistical methods were used to determine confidence levels for differences in median electrical consumption. For paired data, such as total electrical consumption of RSDP homes in 1985-86, and total consumption of RSDP homes in 1986-87, the matched sample sign test was used to determine if differences are significant. For other comparisons, such as total consumption for RSDP 1985-86 homes and total consumption for control 1985-86 homes, the Wilcoxon rank-sum test was used. Differences stated as significant in this paper have a 95 percent or better confidence level as determined by the appropriate test. Additionally, for small samples with non-normal distributions, median values are more representative of the central tendency of the samples than are the means. Where a single number must be used to represent the differences in consumption between two groups, the median difference is presented.

The First Monitored Year

The first year of energy use monitoring ran from April, 1985 to April, 1986. Fifty RSDP and 49 control homes remained in the monitoring program during this period. For the areas where most RSDP and control homes are located, there was an average of 8,220 base 65 ^{o}F degree days, which is 2.4 percent greater than the 30-year normal.

Total Electricity Use. The difference in total consumption between RSDP and control homes is significant. Montana RSDP homes used a median total of 17,500 kWh during the first monitored year. This was 6,300 kWh less than the median of 23,800 kWh used by control homes during the same period. Total electricity use normalized by the floor areas of the homes was 7.4 kWh/ft^2/year for the RSDP homes, and 13.0 kWh/ft^2/year for the control homes.

Space Heating Electricity Use. The difference in space heating electricity use between RSDP and control is also significant. RSDP homes used a median of 6,200 kWh for space heating during the first year, or 4,800 kWh less than the 11,000 kWh used by control homes. During this period the RSDP homes used 2.6 kWh/ft^2, which is 61 percent less than the 6.6 kWh/ft^2 used by control homes, and well below the 3.2 kWh/ft^2 required to meet MCS.

Water Heating and Other Uses. The differences between Montana RSDP and Control Homes for water heating and other electricity use are not significant. RSDP homes used an average of 4,896 kWh for water heating, and 6,830 kWh for other uses. Control homes used 5,306 kWh for water heating and 7,178 for other uses during the same period.

Table I. First year monitored energy use. (kWh/year)

	Median	Mean	Min	Max	Std. Dev.
Total					
-RSDP(50)	17,500	18,500	10,700	44,800	6,600
-Control(49)	23,700	23,600	11,200	51,000	7,200
Difference	6,200	5,100			
Total/ft^2					
-RSDP(50)	7.4	8.1	4.5	17.8	2.8
-Control(49)	13.0	13.7	6.8	23.8	3.7
Difference	5.9	5.6			
Space Heat					
-RSDP(50)	6,200	6,800	1,900	21,000	3,400
-Control(49)	11,000	11,100	5,000	28,000	4,300
Difference	4,800	4,300			
Space Heat/ft^2					
-RSDP(50)	2.6	3.0	0.9	6.2	1.2
-Control(49)	6.6	6.4	2.8	11.2	1.9
Difference	4.0	3.4			
Water Heat					
-RSDP(50)	4,900	4,900	1,400	8,900	2,000
-Control(49)	5,200	5,300	2,200	11,000	1,800
Other Uses					
-RSDP(50)	6,200	6,800	3,000	18,200	3,500
-Control(49)	6,800	7,200	3,000	20,000	3,300

The Second Monitored Year

Monitoring was continued for a second year to determine if the electrical consumption of the two groups would remain reasonably stable, considering differences in weather. Also, since the occupants were under no obligation to refrain from wood burning during the second year, there was an opportunity to observe the impact of wood burning on space heating electrical consumption. Four RSDP homes and 13 control homes burned wood during this period.

During the second year of monitoring, from April, 1986 to April, 1987, 19 RSDP and 10 control homes remained in the monitoring program and did not burn wood. The occupants were not paid an incentive to report data, so the homes monitored during the second year are self-selected. Smaller sample size and the self-selected nature of the groups suggest that these homes and their occupants may not be representative of the larger groups monitored during the first year. For purposes of this comparison between first year and second year medians, first year statistics are recalculated for the smaller, restricted group that remained in the program.

The following table lists the medians for the restricted two-year groups for both years. Space heating electricity consumption data normalized by floor area are in parenthesis. These data are graphically presented in Figure 1.

Table II. Median electrical end uses and annual differences within the restricted group, kWh/year ($kWh/ft^2/year$)

n=19	RSDP (85/86)	RSDP (86/87)	Difference (86/87)-(85/86)
Total	16,800	16,500	-300
Space Heat	6,200(3.2)	5,000(2.2)	-1,200(1.0)
Water Heat	4,200	4,500	+300
Other	6,300	6,700	+400

n=10	Control (85/86)	Control (86/87)	Difference (86/87)-(85/86)
Total	22,500	19,000	-3,500
Space Heat	9,600(5.0)	8,000(4.9)	-1,600(0.1)
Water Heat	6,000	5,100	-900
Other	6,900	6,800	+100

Table III presents the differences in the medians for the restricted sample of RSDP and control homes that was monitored for two years and did not report burning any wood.

Table III. Differences in the medians between the restricted group of RSDP and Control homes for both monitored years, kWh/year (kWh/ft^2/year)

	RSDP-Control 85/86	RSDP-Control 86/87
Total	-5,700	-2,500
Space Heat	-3,400(1.8)	-3,000(2.7)
Water Heat	-1,800	-600
Other	-600	-100

The differences in median space heating consumption between the restricted RSDP and the restricted control group are significant for both years, but the annual variations in space heating use for each type of home are not significant. The difference in area normalize space heating consumption between RSDP and control homes is significant for both years, but the annual variation for each type of home is, again, not significant.

Data from the second year can be used to generate some interesting observations about the variability of energy use from year to year. Given that the same occupants lived in the homes during both monitored years, it would be reasonable to assume that there would not be a large variation in the annual amount of electricity used for water heating and "other" uses. When the annual medians are compared, there are not significant (95% confidence level) differences; however, the annual variation for individual homes can be quite large. Two RSDP homes showed an increase in "other" use exceeding 6,000 kWh. The data from individual homes seems to indicate that a constant set of

occupants does not always result in constant occupant behavior, and annual fluctuations in energy consumption in individual homes should be expected.

Weather conditions and the rate of internal heat gains from appliances are two factors that probably had an impact on the space heating consumption of both groups of homes. The second monitored year was significantly warmer, by 10 percent (or 800 base 65 0F degree days) than the first year. This should result in reduced space heating requirements for both RSDP and control homes during the second year. Yet for the RSDP homes, the reduction in space heating use due to warmer weather may have been effectively canceled by increases in both water heating and "other" electricity uses.

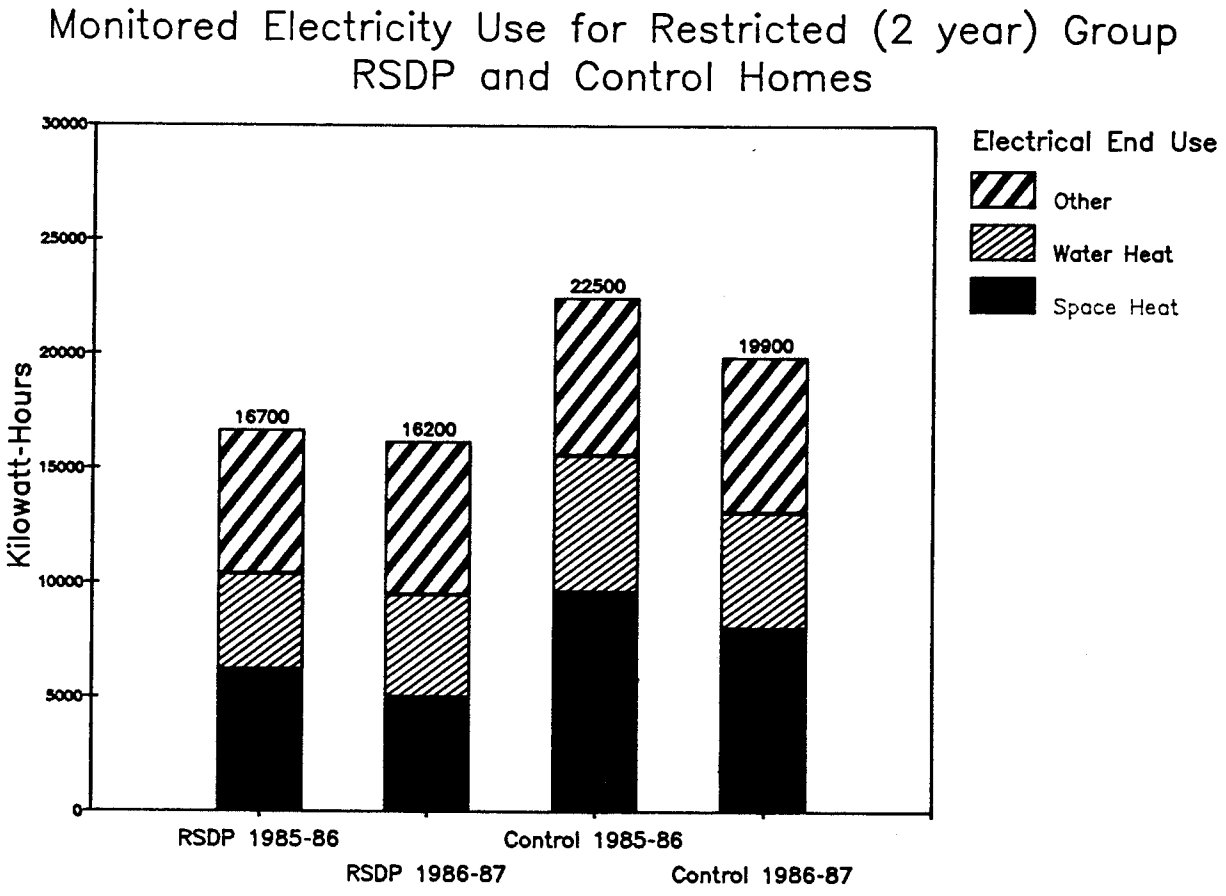

Figure 1. Median electricity end use for the sample of homes monitored for two years.

IMPACT OF WOOD BURNING

There were 4 RSDP and 13 control homes that burned wood during the second year of monitoring. Wood burning had a significant impact on total and space heating electricity use for both RSDP and control homes. For the wood-burning RSDP homes, the median space heating electricity use during the first year was 8,400 kWh (3.0 kWh/ft^2/year), and 4,300 kWh (1.0 kWh/ft^2/year) during the second year, which is a decrease of 4,100 kWh or 2.0 kWh/ft^2/year. For control homes, the median space heating electricity use was 9,200 kWh (5.1 kWh/ft^2/year) during the first year, and 2,300 kWh (2.0 kWh/ft^2/year) during the second year, which is a decrease of 6,900 kWh or 2.4 kWh/ft^2/year. In dollar amounts, at $0.053/kWh which is a typical rate in Montana, the median gross savings for the RSDP homes was about $217.00, and about $367.00 for the control homes.

Both RSDP and control homes that burned wood during the second year have significantly larger floor areas than the remainder of the RSDP and control homes. Larger areas to heat and the lack of a direct payment to abstain from wood-burning may have been some of the reasons the occupants chose to use wood heat during the second year.

The occupants estimated the volume of wood burned during the second year. For RSDP homes, the mean amount burned was 1.6 cords, the maximum was 4 cords, and the minimum amount was 0.5 cord of wood. Control home occupants reported a mean of 2.4 cords, a maximum of 4.5, and a minimum of 0.25. The median amount of wood burned in the RSDP homes was 1 cord, and the median amount burned in control homes was 2.5 cords.

No correlation was found between the reported amount of wood burned in the homes and the monitored decrease in space heating electricity. One possible reason for the lack of correlation is that the estimates of how much wood was burned are gross approximations. In addition to possible estimation errors there may be several other reasons for the lack of correlation, such as the type and efficiency of the wood burning device, or source of combustion air.

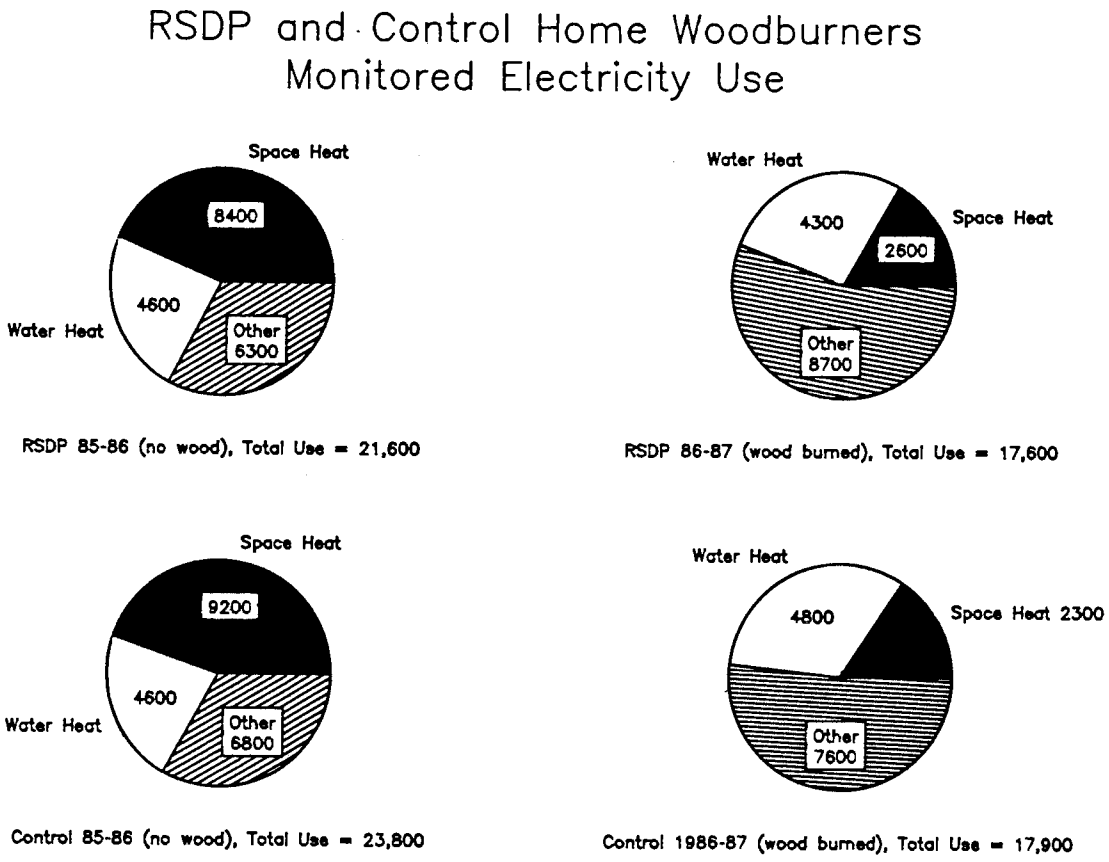

Figure 2. The impact of wood burning on electricity use in RSDP and control homes.

CONCLUSIONS

The energy savings realized by RSDP homes, relative to the control homes, are significant, and indicate that homebuilders were successful in applying energy-efficient construction techniques. Several builders that participated in RSDP have elected to participate in subsequent building programs administered by DNRC. The ability of the department to recruit new homebuilders has been enhanced by the field data that demonstrate the actual energy savings of these homes.

RSDP homes continued to use significantly less space heating electricity than control homes during the second monitored year. The influence of weather, and changes in appliance use by the

occupants of both groups of homes are variables that are reflected in space heating and total electrical consumption. The basic difference in performance between RSDP and control homes remained within reasonable limits.

The data presented in this report show that wood burning reduces the amount of space heating electricity used by both RSDP and control homes, but there is no correlation between the amount of wood burned in an individual house and the reduction in space heating electricity use for that house.

From a policy perspective, the data have been useful for presenting a convincing case for the benefits derived from energy-efficient housing. The department has used RSDP data to illustrate that the additional cost of these homes has a positive net present value to the consumer. DNRC's conclusions about the costs and energy saving of these homes have been used during hearings conducted by local governments considering adoption of the MCS as a building code for electrically heated homes.

Peripheral data acquired by DNRC during a survey of Montana homebuilders in 1987 (Cartwright, 1987) may be used to infer that these builders are now routinely exceeding the levels of energy-efficiency found in the 1980-1984 control homes. Programs such as RSDP have directly influenced the way in which homes are now being built and insulated in Montana.

REFERENCES

Cartwright, P. 1987, Economic Feasibility of RSDP Homes, DNRC, Helena, MT

Cartwright, P. 1987, Survey of 1986 Building Practices for Single Family Residences, DNRC, Helena, MT

Jackson, M. 1986, Montana RSDP Cost Data Analysis, DNRC, Helena, MT

Jackson, M. 1987, Thermal Performance of New Energy-Efficient Housing in Montana: Results From The Residential Standards Demonstration Program, DNRC, Helena, MT

Northwest Power Planning Council, 1986, Northwest Conservation and Electric Power Plan, Portland, OR