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Abstract: RSEP stands for The Regional Supply Expansion Program. The study has the objective to determine electric energy savings resulting from different energy-efficiency measures. This project is to discuss the statistical significance of the resulting estimates of energy savings. This is important because of the small size of the sample population of houses ,and the large amount of data on each house.

# RSEP Manufactured Home Study

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EMGT 510

Research Methodology

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# RSEP Manufactured Home Study

## 1. Program Description

The "Regional Supply Expansion Program (RSEP) Manufactured Home Study" has the objective to determine electric energy savings resulting from different energy-efficiency measures. Thirty-five manufactured (formerly called "mobile") homes were weatherized or had heat pumps installed. Electric usage and temperatures were monitored and recorded. The energy savings have been estimated. For additional background information and discussion of customer screening and selection, see Appendix A.

The goal of this paper is to discuss the statistical significance of the resulting estimates of energy savings. This is important because of the small size of the sample population of houses, and the large amount of data on each house. Each house has four channels of electricity usage and two channels of temperature data recorded at five-minute intervals. With approximately one year of recording, there are in excess of 20 million data points to analyze.

## 2. Evaluation Methods: Preliminary Energy Analysis

The first step in the energy analysis consisted of an evaluation of energy usage patterns before and after installation of the measures in order to estimate annual electrical heating loads in each case. The data was recorded and initially manipulated by a LAN-based software product called MV-90 (Reference 1).

For each house, the data was summed over 60-minute intervals and reviewed to identify time periods when data was missing due to power failures.

The data files for each house were then transferred to a PC-based spreadsheet, Quattro Pro (Reference 2), which was used for data cleaning and analysis. If temperature data was missing for six hours or less, the missing data was interpolated. If the gap was more than six hours, the entire day was excluded. Also excluded were days when the occupants were on vacation, when steady-state heating tests ("coheat" tests) were being run, when installation of monitoring instrumentation or measures was going on, or when the electric furnace did not run. Only full days of data were used, beginning at one minute past midnight and running through the following midnight.

The basic assumption used in the evaluation of residential energy usage is that heating energy used is proportional to the indoor-to-outdoor temperature difference. Using standard techniques of linear regression, the correlation between electric heating loads and Heating-Degree Days (HDDs) was checked and found to be significant (R-squared more than 0.5). HDDs were based on the difference between a standard reference temperature of 65°F and the outdoor temperatures at each house. Due to thermal storage and other dynamic effects, the use of twenty-four-hour sums (of kWh) and averages (of temperatures) were found to better correlate than the use of shorter time intervals. In addition, it was shown that the house outdoor temperatures correlated well (R-squared more than 0.9) with National Weather Service (NWS) data for the applicable weather station. This allowed use of long-term NWS data for yearly HDDs.

In the preliminary stage of the analysis, the only normalization for weather conditions was to try to match similar days before and after the measures were installed. Per recommendations by Hill and Blasnik (Reference 3), in general days with at least 15 HDDs were selected. The goal was to use the maximum number of full days of data that met the above criterion. The simplified model assumed that electrical usage is directly proportional to HDDs. Other factors, such as solar insolation and woodstoves, were neglected. Ratios of kWh to HDDs were determined for each house, calculated both for the time period before and the time period after measures were installed. The ratios of kWh to HDD for the monitoring periods were assumed to be representative of full years of operation and were extrapolated to full year estimates based upon long-term NWS data for HDDs. The difference in the estimates for the before and after conditions then equalled the energy savings.

## 3. Evaluation Methods: Final Energy Analysis

In order to correct for the effects of temperatures in 1993 that fluctuated above or below long-term average conditions, the final stage of the analysis calculated the Normalized Annual Consumption ("NAC") of each house. The final analysis used data recorded during the intervals from the installation of monitoring equipment through the end of April 1993, plus November and December 1993. For houses with heat pumps, the months of August and September 1993 were separately analyzed. Models were developed for heat pump coefficients of performance (COPs) and for woodstove usage.

The contributions of wind and solar radiation were examined and found to be second-order effects, so were not generally included.

The final analysis method was based on the procedure used by "PRISM" (PRInceton Scorekeeping Method, Reference 4), but used daily monitored data instead of monthly billing data. (The PRISM procedure includes an optimization routine to calculate the best reference temperature for each house. This gives better predictions than always assuming a reference temperature of 65 degrees F.) Using the daily data, linear regressions were performed to correlate daily kWh usage with NWS-recorded mean daily temperatures. The basic relationship is:

$$y = a + bx$$

where y = daily total heating kWh
a = daily constant heating kWh
b = building heating (or cooling) coefficient
x = Delta-T = $T_{ref}$ - (NWS mean daily temperature)
$T_{ref}$ = Reference temperature for each house

Because in Oregon daily constant heating is generally not needed during the summer, the 'a' term, above, was forced to approach zero by selecting the appropriate value of reference temperature. This was done by trial and error for each house for both the before- and after-condition. See the example regression output, Figure 1. The 'b' term, above, is listed in the regression output as "X coefficient(s)."

Separately, an "average" year was developed based on NWS 30-year records. For weatherization measures, the average year developed had 365 days with the 30-year mean temperature. Because heat pumps have a non-linear behavior at lower temperatures, the heat pump houses used the "bin" method, which consisted of the actual recorded frequency distribution of mean temperatures over the same 30-year period. The NAC is then the summation of all the daily-calculated electric loads. The daily loads are the products of the calculated "X-coefficient(s)" and the indoor-to-outdoor delta-Ts. Delta-Ts were based on the difference between the reference temperature for each house and the actual NWS-recorded daily mean temperatures for that day.

This procedure was performed for each house both before and after the measures were installed. NAC was then estimated by applying first the pre-mod coefficient and then the post-mod coefficient to the "average" year. The estimated energy savings is equal to the difference between these calculated values.

Because the final analysis has not yet been completed for all homes, the reported estimated annual usage is a combination of results from the preliminary and final analyses. The attached tables 1 through 3 show the results for the fifteen houses that were weatherized and the ten houses with new heat pumps installed. Note that two houses that were weatherized had existing heat pumps and four houses had woodstoves.

## 4. Program Energy Reductions

Tables 1 and 2 show mean energy savings of 27% for weatherized PGE houses and 50% for the EWEB houses. These results are higher than those reported in other studies. For example, Reference 5 reports NAC savings of 1 to 24%. However, these reported studies involved much less expensive weatherization measures. For more discussion of results, see page 2 of Appendix A.

Table 3 shows mean energy savings of 51% for newly-installed heat pump homes. For more discussion of results, see page 3 of Appendix A.

## 5. Statistical Analysis

The null hypothesis that will be checked is that there is actually no difference between the calculated energy savings for the different treatments. SPSS software was used for the analysis (Reference 6.) The SPSS data is shown in Table 4. Because the resulting percentage reduction is of more interest than the absolute values of kWh per year, the results were first normalized by calculating the ratios of final kWh to initial kWh.

The treatments were defined as the initial condition (0), added heat pump (1), one weatherization measure (2), and two weatherization measures (3). First, the individual treatments were examined by calculating their statistics and making plots. See examples in Figures 2 through 8. Because of the small sample sizes, the distribution of cases for each treatment departs from the ideal normal distribution. The normal and detrended normal plots (Figures 9 and 10) show that the assumption of normality is not too bad. Next, a boxplot of the all treatments was made (Figure 11). This suggests that the means of the treatments are different, except possibly for treatments 2 and 3.

Because treatments 2 and 3 were not independent and because of the small size of treatment 2 ($n = 6$), it was decided not to include treatment 2 in further analysis. For reference, t-tests were performed on the various combinations of treatments (see Figures 12-14). The results for Levene's test indicate that the group variances are not equal. The results also shows that in all cases, the significance was very small (<0.004) at both the 95% and 99% confidence levels, leading to a rejection of the null hypothesis.

However, because multiple comparisons were made using the same means, the t-tests may underestimate the confidence intervals and the null hypothesis may be incorrectly rejected. An analysis of variance (ANOVA) is needed. ANOVA is based on the assumptions that "each of the groups is an independent random sample from a normal population" and that "in the population, the variances of the groups are equal." (Reference 7, page 270.)

Even though these assumption may not hold true, a one-way analysis of variance was performed. The results show that most of the variance is attributed to differences between groups. The F-ratio is large and the significance very small (see Figure 15). In addition, Figure 16 shows that there are significant differences between Treatments 0, 1, and 3. If applicable, the ANOVA would indicate that the null hypothesis should be rejected at the 95% confidence level.

From the t-tests, the 95% confidence intervals (unequal) are: heat pumps, 0.452 to 0.548; weatherization measures, 0.582 to 0.751. Note that the intervals do not overlap.

## 6. Summary and Recommendations

The energy analysis (thus far) has successfully predicted average heating energy savings for the manufactured houses. The remaining TPU houses should be analyzed and all preliminary results should be redone using the final analysis methods.

The statistical analysis suggests the differences in means are real. However, the small sample sizes need to be increased by adding TPU houses. The possible violations of the ANOVA assumptions are a problem and need to be investigated further.

In the future, it is recommended that the statistical analysis include other variables such as costs of measures, sizes of houses, or ages of houses.

## References


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