MANUFACTURED CONSERVATION: TRANSFORMING NEW MANUFACTURED HOMES IN THE PACIFIC NORTHWEST

Bob Davis, Ecotope, Inc., Seattle, Washington

Introduction

Manufactured homes, long ignored by most organized conservation programs, have received increasing attention in recent years. The sector is particularly intriguing because it offers a unique opportunity to capture lost opportunity resources. Because construction practices are standardized, and quality control oversight often more uniform than in the site-built industry, evaluators have a head start in predicting effects of organized conservation programs.

Manufactured homes are factory-built according to construction and safety standards promulgated by the US Department of Housing and Urban Development (HUD 1994). These standards include provisions for thermal comfort and indoor air quality. Until recently, there was little effort on the part of the industry to produce homes that exceeded the minimum requirements. In general, the industry accepted its role of providing economical, no-frills housing and left innovation to the site-built market.

In the Pacific Northwest, stricter energy codes began their rapid evolution after the passage of the Northwest Power Planning Act. Various incentive and marketing plans addressing site-built construction were begun in the early 1980s. In the mid-1980s, Bonneville Power Administration (BPA) began to investigate including manufactured housing in its growing portfolio of electrical energy conservation activities in the residential sector. Electrically heated manufactured homes at that time accounted for about 10% of the new housing stock. Over the next several years, some manufacturers participated in various marketing (Super Good Cents [SGC]) and research (Residential Conservation Demonstration Program [RCDP]) projects offered by the BPA through the State Energy Offices (SEOs) in the region. There was a growing awareness amongst manufacturers that an improved product, incorporating energy efficiency features, would enable the industry to compete with the site-built industry while offering very attractive pricing to the consumer.

The Manufactured Housing Acquisition Program (MAP) was the culmination of efforts on behalf of the industry, BPA, and regional utilities to deliver energy-efficient electrically heated manufactured homes to Northwest homebuyers. Manufacturers were paid cash incentives for every home built to the MAP specifications, which mandated increased levels of insulation, better performing windows, and improved air sealing practices. Over the four-year life of the program, over 55,000 homes were built to the MAP standards, and over $100 million in incentives were transferred to the region's manufacturers.

Thermal standards specified by MAP were about 60% more efficient than the 1976 HUD standards, based on the overall heat loss rate of the home and subsequent annual heating energy requirements. Homes built under the program were to have a maximum overall heat loss rate (U_o) of 0.053 Btu/hr-°F- ft^2 (not including heat loss rate due to air infiltration). Homes were equipped with a mechanical ventilation system, which for most manufacturers consisted of two 50 CFM fans with 24-hour timers.

A random sample of 178 homes built during the program's first year were evaluated to determine the overall cost-effectiveness of the program. The evaluation included a field review -- where the on-site installation and air-sealing performance of the homes were evaluated -- and a billing analysis. The billing analysis, conducted on a total of 115 homes that had usable bills, combined a two-step base load (non space-heating) estimation procedure with a variable-base degree-day regression analysis to determine the heating electricity requirements for the homes. The field data and billing analysis results were used to recalibrate earlier engineering simulations of energy use for a prototype MAP home sited in different weather conditions and thereby facilitate an overall calculation of program cost-effectiveness.

Sampling Methodology

During the initial phases of planning the evaluation, the main point of interest was the quality of the home's on-site installation, primarily the structural support and proper installation of the heating ducts connecting one section of the home to the other ("crossover duct"). A manufactured home is mostly complete when it leaves the factory; however, a great deal of set-up work remains when the home arrives at the home site. Quality installation is crucial, since improper structural support or faulty duct installation can affect many aspects of the home's performance and longevity; however, direct quantification of energy savings from set-up compliance levels is not at all straightforward.

As the goals of the field evaluation evolved, much more interest was expressed in measuring the homes' heating energy use. It became apparent that a billing analysis would be necessary. Thus, MAP homes' kWh usage per year became an important consideration in the sample selection process.

Thermal specifications for MAP homes are similar to those met by a group of manufactured homes built and studied under BPA's Residential Conservation Demonstration Program (RCDP) two years prior to MAP (Baylon et al. 1991). The group of 150 RCDP homes had an average U_o of 0.060 Btu/hr-°F- ft^2 and underwent submetering during the RCDP to measure space heating and non-space heating electricity usage.

The coefficient of variation of normalized space heating (kWh/ft^2-yr) in the RCDP sample was used to determine the size of the MAP field sample. The coefficient of variation is defined as the standard deviation of the sample variable in question, divided by the mean value of this variable. The sample size is proportional to the square root of the coefficient of variation. As the coefficient of variation of a sampling distribution increases, a larger sample size is required to ensure a distribution of results within a desired confidence interval.

In the RCDP sample, the coefficient of variation for kWh/ft^2 - yr was 0.27. Standard formulas were used to find a MAP sample size given the desired 95% confidence interval. A minimum sample size of 112 homes for the four-state region was judged adequate to measure annual heating energy per square foot with a significance of 5%. The actual number of homes audited and included in the billing analysis (178) was considerably greater than the minimum sample required to describe normalized space heating energy. Since the actual performance of the MAP homes was expected to be different from the RCDP homes, and since the measurement technique used to estimate heating energy was billing analysis rather than submetering (implying more attrition due to unusable bills), it was desirable to over-sample when possible.

It was important, however, that each state be represented, especially in evaluating compliance with on-site installation ("set-up"). Therefore, new targets were determined using a more relaxed confidence interval. The sampling targets for each state were set at approximately 35 homes (assuming a coefficient of variation of about 0.3) if confidence intervals were reduced to 0.90. Montana and Idaho were asked to obtain at least 40 homes in order to produce reasonable statewide results. Washington and Oregon (which between them received about 80% of the homes sited during the program's first year) were asked to obtain 50 homes in order to ensure that they would be adequately represented in any regional sample. With these sampling targets, individual states could learn more about their MAP housing stock, and a more robust comparison of summary statistics by state could be drawn.

Field Audit Goals and Results

The field audit consisted of four main parts. An occupant survey was conducted first. The survey documented and catalogued basic demographic information, homeowner perceptions, and homeowner behavior (primarily thermostat setpoint and setback temperature and duration). Following the survey, a walk-through audit was conducted. The field technician surveyed heating, ventilation, and combustion appliances, checked the hot water system, and measured the relative humidity inside the home. The third phase of the field audit assessed the condition of the crossover duct and the structural support of the home (footings, piers, and point loads). The final portion of the field audit measured house and duct air tightness with calibrated pressurization fans (Minneapolis Blower Door and Duct Blaster™). These measurements were used as inputs into the revised simulations of heating energy use discussed later in this paper.

Primary findings from the occupant survey and set-up review were as follows:

- MAP homeowners were overwhelmingly satisfied with their homes. Less than 10% of respondents reported comfort problems or high bills after the first full heating season.

- Homeowners displayed uneven knowledge of their whole-house ventilation system. Over half did not understand the purpose of whole-house ventilation and did not know how their ventilation system worked.

- On average, about three-quarters of the approximately 20 on-site punch-list compliance requirements were met. The most common violation had to do with deficiencies in the crossover heating duct installation. The crossover duct is a 12" round flex duct that connects one section of a multi-section home with the other. (About 70% of the homes constructed during the MAP were double-section homes, and about 10% of MAP homes were triple-section.) This violation was of particular concern since duct losses have been found to have considerable impact on heating energy use (Davis et al. 1996).

Table 1. Summary Ventilation Statistics
(ACH and CFM averages)

Measure	ACH[1]	CFM (ft^3/min)	% failing Standard 62 (0.35 ACH)
Natural ventilation (n=177)	0.218	42.2	94
Fan-added ventilation (n=173)	0.042	8.1	--
Combined ventilation	0.260	50.2	87

[1] ACH values are found by dividing the blower door results at 50 Pa depressurization by a divisor ranging from 22 to 27, depending on where home is sited. This process is based on the procedure discussed in Sherman (1987) and informed by data gathered by Palmiter et al. (1992).

Air-tightness of the field sample homes was also evaluated with a blower door test. Blower door results were of interest both for purposes of refining simulations of heating energy usage (since air infiltration is a major portion of heating requirements in energy-efficient homes) and to assess the performance of the homes versus accepted air quality standards. Tracer gas measurements of natural and mechanical ventilation in manufactured homes made during RCDP (Palmiter et al. 1992) had shown that a majority of the homes had ventilation levels less than those recommended by ASHRAE Standard 62 (ASHRAE 1989). This was true even though these homes had mechanical ventilation systems (usually consisting of spot ventilators controlled by a 24-hour timers).

Field review of the MAP homes found ventilation levels had not changed appreciably since the RCDP study. Mechanical ventilation rates had increased slightly because of longer exhaust fan operation times; however, natural ventilation rates decreased enough (because of tighter air sealing) to offset the gain in mechanical ventilation. Nearly 90% of the home in the sample did not meet the ventilation level recommended by ASHRAE Standard 62.

The primary reason for this failure has to do with fan run-time. Median combined fan run-time for these homes was 4 hours per day, which was the most common timeclock setting for homes leaving the factory. (The most common MAP ventilation system consists of two 50 CFM fans connected to 24 hour timers.) Each fan would have to run more than 12 hours/day to push the average ventilation rate close to 0.30 ACH. While there is still considerable debate on what level of ventilation is needed to ensure acceptable air quality, it is clear that this set of homeowners did not take action to run their ventilation system beyond the level required by the program specifications and therefore set in the factory. Annual costs of operation for increased run times are modest (under $100), but many new homeowners are not accustomed to living with and utilizing whole house ventilation systems. Education of homeowners on the issue of whole-house ventilation remains a major challenge in the promotion of energy-efficient homes.

Billing Analysis Overview

The billing analysis conducted for the MAP evaluation relied on a combination of techniques. One of these techniques is familiar to energy evaluators: a variable-base degree-day regression analysis. An in-house program similar in form to the Princeton Scorekeeping Method (PRISM) was employed. A more simplified technique, using the median low bill to determine non-heating ("base load") consumption, was also used. Results from the billing analysis were combined with field audit data to recalibrate engineering simulations of program performance and facilitate determination of overall program impacts.

Variable-Base Degree-Day Regression Analysis

The most common of the methods for estimating residential heating energy use is PRISM (Fels 1986). The method used in this report is adapted from PRISM, and relies on a variable-base degree-day method, in which individual bills are paired with the average temperature conditions for the billing period, expressed as heating degree-days. A regression is established using these points, and the fit (as described by the correlation coefficient, or R^2) indicates the relationship between space heating energy and weather conditions. The actual procedure consists of an iterative process; degree-days are calculated to various bases between 50 °F and 72 °F. (Note that because these homes are well-insulated and are of light-frame construction, their balance point (defined as the temperature below which the thermostat will call for heat) averages below 60 °F.) A separate regression is run for each degree-day increment, and the best fit is selected as the estimate of space heating for that particular home.

For most Pacific Northwest weather sites, there are months in which no heating degree-days occur and therefore no space heating occurs. In western Washington and Oregon, for example, it is not unusual for space heating to be completely absent between May and October in homes built to MAP specifications. The regression algorithm derives space heating estimates only for those months in which heating degree-days occur. Remaining bills are used to derive non-space heating energy use.

A balance-point degree-day base is selected for the best fit of energy consumption to degree-days. The regression using the best-fit degree day base produces a slope that expresses heating requirements per degree-day (kWh/DD) as the heat loss rate for the house. An intercept is also produced, representing the point at which the heating degree-days and heating load equal zero. The intercept represents home energy use when there is no space heating. When multiplied by the number of months in the analysis, this becomes a first-order estimate of the home's non-space heat energy use ("base load").

There is a difficulty with this method: base load energy usage varies seasonally, depending upon ground temperature and hours of daylight. Fels et al. (1986) noted this shortcoming in a critique of standard PRISM, and suggested a periodic mathematical function be applied to the regression constant to adjust the base load. Otherwise, PRISM could be expected to over-estimate space heating energy by including some portion of the base load consumption. In Fels' dataset, the constant from the PRISM regression was taken as the minimum non-heating consumption, and the maximum non-heating consumption was described by a cosine function with an amplitude of approximately 1.15.

This method became the basis of the work undertaken in this report. The cosine adjustment proposed by Fels et al. could not be applied without further review, given the differences in house type between Fels et al.'s work and MAP homes. Roos and Baylon (1993) had already used the cosine adjustment in evaluating the energy usage of a set of manufactured homes built to thermal standards similar to MAP's. (These homes have already been described above as "RCDP" manufactured homes, so labeled for the research project under which they were studied.)

The RCDP manufactured homes were submetered so that both space heating and non-space heating electricity consumption could be studied. Roos and Baylon found a cosine function with amplitude 1.12 provided the best agreement between metered space heating consumption and estimates from the regression. This seasonal variation was applied to the constant from the regression, resulting in about a 14% average reduction in space heating energy estimate for the 97 MAP cases which met the PRISM R^2 cut-off of 0.70 or greater.

Simplified Billing Analysis: The Median Low Bill Method

An additional method was used for estimation of space heating energy. No regression analysis was conducted in this case. The procedure was developed by Kennedy (1994) and begins with the selection of the three lowest bills in the annual billing cycle. The median of these three bills is selected as a first-order estimate of non-space heating consumption. The Roos and Baylon adjustment is applied and the result is the monthly estimate of the home's non-space heating energy usage for each month. The difference between the base load calculated in this manner and the total bill for the month becomes the monthly space heating energy consumption estimate.

Seasonal variation in non-space heating consumption is directly accounted for with the Median Low Bill method. However, any temperature-based variation is not measured directly, since the procedure does not normalize by ambient temperature or heating degree-days. The Median Low Bill method is less complex than the regression analysis, but it cannot be easily applied across climate zones and different years' weather conditions.

Data Attrition

At least one year's worth of utility bills was obtained for 162 of the 178 homes. The set of usable bills was reduced by 10 cases because of unresolvable data problems such as multiple estimated bills or uncertain billing dates because of intermittent reporting (common in some rural areas). Another 17 cases were excluded because of substantial wood heat use. Finally, 20 heat pump cases were left out of the analysis because of reasons discussed below.

The final analysis set included 115 buildings. Variable-base degree-day regressions were run on these cases, and 97 had correlation coefficients (R^2) of 0.7 or greater, which is the usual cut-off point for "good" PRISM results.

The R^2 value was thus unacceptably low in about 15% of the 115 cases. The bulk of these cases involved utility customers in western Washington and Oregon, where bi-monthly billing periods are used, resulting in only half as many points for the regression analysis. Use of the Median Low Bill method allowed an additional 18 cases to be included in the final estimate of heating consumption, and an added benefit was that the results were somewhat more transparent to the analyst. (That is, results were not embedded in a regression-based program with a correlation coefficient acting as final arbiter.)

The presence of cooling equipment and heat pumps also limits the effectiveness of a variable-base degree-day methodology such as PRISM. In order to estimate the base load, the program assumes there is no cooling energy usage for a billing period in which cooling might otherwise be expected. The presence of undetected cooling in months with relatively low temperature variations will reduce the R^2 value and reduce the number of acceptable regression estimates of space heating energy usage.

Billing Analysis Results and Engineering Simulation Recalibration

The regression results and Median Low Bill results were in substantial agreement for the billing period studied. When the Median Low Bill space-heating estimates were plotted against the regression estimates, the correlation coefficient came out to 0.985. The Median Low Bill results are used in summarizing program impacts (Table 2).

Once the heating consumption was estimated for individual cases, the overall program impacts could be determined. This process relied on a combination of earlier engineering simulations and the results of the billing analysis. A combined approach was used in order to broaden the limited applicability of the billing analysis results to the more diverse MAP population. That is, billing results were necessary to estimate program cost-effectiveness, but they alone were not considered sufficient for the task.

The *SUNDAY*® building simulation analysis program (Palmiter et al. 1987) was employed at the outset of MAP to estimate energy savings which could be expected from the program. A special version of the program was also used to construct optimal conservation measure packages and dictate program specifications. These simulations allowed BPA and participating utilities to determine appropriate financial incentives to offer manufacturers for their participation in the program.

SUNDAY® is a one-node building energy simulation program, which has been used extensively in estimating conservation program impacts. *SUNDAY*® has been benchmarked with other simulation programs, and with billing and submetered data. When *SUNDAY*® inputs (internal gains, building thermal mass, window orientation, etc.) are properly specified, *SUNDAY*® agrees within a few percentage points on an annual basis with other detailed simulation programs and submetered heating energy data.

The major variables in estimating long-term energy usage in MAP homes are building heat loss rate (UA), thermostat setpoint, internal gains, solar contributions, duct efficiency and ambient temperature. The building heat loss rate for these homes was fairly tightly determined by the program specifications, and ambient temperature conditions were described by long-term TMY data. Thermostat set point and setback data were gathered during the field audit, and internal gains were re-estimated based on occupancy levels. Some adjustment to solar contributions was also performed, based on a review of a selected number of buildings. Duct efficiency was estimated based on detailed fieldwork performed on MAP homes during the 1994 and 1995 heating seasons (Davis et al. 1996).

Table 2. Annual Space Heating Energy Comparison For Selected Climates Zones
(Averages)

Climate Zone	Weather Site	N	Annual Heating Energy (kWh – yr)		Normalized Heating Energy (kWh/ft² - yr)	
			Bills	*SUNDAY®*	Bills	*SUNDAY®*
1	Portland, OR	6	4968	5038	4.32	4.22
	Salem, OR	6	4414	4428	3.94	3.40
	Seattle, WA	9	6602	6553	4.25	4.36
2	Boise, ID	9	5849	5776	4.16	4.03
	Pocatello, ID	5	7712	7713	5.50	5.35
	Spokane, WA	13	6918	6986	5.77	5.75
3	Kalispell, MT	6	9848	9837	7.84	7.84

Results of the billing analysis are presented in Table 2 for weather sites containing at least 5 homes (54 in all). Averages for the sites, as found from analysis of individual homes assigned to these sites, are compared to revised *SUNDAY®* simulations. A perfect match is not expected, given remaining uncertainties in *SUNDAY®* inputs and vagaries of the individual sites used in the billing analysis.

Pacific Northwest climate zone designations are based on heating degree-days to base 65 °F. Note the climate zones are described in terms of heating degree-days to base 65 °F, even though the balance point degree days for most of the homes in this study was considerably below this temperature. Zone 1 includes weather sites with less than 5000 HDD_{65}, Zone 2 has 5000-8000 HDD_{65}, and Zone 3 has more than 8000 HDD_{65} (based on Typical Meteorological Year data from 1951-1980).

Table 3 shows the savings of the prototype MAP home versus a prototype of the same size built to the 1994 HUD thermal standards. Prototype analysis using *SUNDAY®* was employed in all estimates of MAP savings (Baylon, et al. 1991; Baylon & Davis, 1993). This sort of analysis is especially appropriate, given the uniform construction standard for this type of housing.

The HUD minimum thermal standards were revised while the MAP was underway, and this revision had a significant effect on both estimates of program savings (since the baseline home changed relative to the 1976 HUD thermal standards) and on the incentives paid to manufacturers to produce MAP homes. The savings from MAP conservation, as revised based on the results of the field audit and billing analysis, were substantial relative to the 1994 HUD standards, ranging from about 3900 kWh in milder climates to over 6500 kWh in western Montana. Levelized cost of conservation was also very favorable, ranging from about $0.02 to $0.03 per kWh saved.

Table 3. MAP Savings Relative To HUD 1994 Standards
(Based On Prototype 1493 Ft² Home With 179 Ft² Glazing)

Climate Zone	Annual Heating (kWh) MAP	HUD 1994	Savings (kWh/yr)	Cost of conservation (mills/kWh[1])
1	4808	8714	3906	28.8
2	8677	14390	5713	19.7
3	10255	16877	6622	17.0

[1] Levelized cost of conservation based on discount rate of 4.8% and measure life of 45 years. One mill = $0.001. Includes administrative and evaluation costs.

The Big Question: Will the Transformation Stick?

From April 1992 through July of 1995, nearly 100% of all manufactured homes produced in the Pacific Northwest were built to Model Conservation energy standards. A cash incentive paid to manufacturers for each complying home was sufficient to cover the added cost of insulation, better windows, and improved air sealing.

In many rural parts of the region, manufactured homes accounted for more than 75% of the new homes sited during these years. In Idaho, manufacturers marketed their product aggressively and captured more than 30% of the single-family market by the end of the program.

A follow-on program was initiated in July of 1995. Homes built to MAP standards are now certified under the marketing label Super Good Cents (for electrically-heated homes) or Natural Choice (for homes heated with a fossil fuel). Cash incentives were not included in this program. However, manufacturing associations within each state in the region began paying a small flat fee (about $30 per home) to the manufacturers as partial reimbursement for the increased costs related to inspection and certification of compliance with Super Good Cents standards.

The consumer demand for a product, which delivered better thermal performance, than achieved using the basic HUD requirements remained high throughout 1995. For the entire year, 77% of the nearly 19,000 manufactured homes produced in the region were certified as Super Good Cents or Natural Choice homes. By the end of 1996, however, Super Good Cents/Natural Choice penetration slipped to 62% of total production (18,300 homes).

Many observers of the industry are very concerned that it is on the verge of a "race to the bottom", with only a few manufacturers believing their produce can take away market share from site builders.

There are efforts afoot to resurrect the technical assistance and marketing programs with the aid of pooled conservation monies from a variety of sources. However, it is not clear whether this effort will ultimately be successful. It is clear, however, that MAP was an impressively successful program while underway, which combined public and private interests for joint benefits. Utilities and BPA successfully acquired reliable conservation, and homeowners in a traditionally neglected sector got even better value for their money.

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