Multifamily Metering Study Impact Evaluation of the Model Conservation Standards Final Report

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Prepared by SBW Consulting, Inc.

Executive Summary

In 1989 the Bonneville Power Administration (Bonneville), in cooperation with Tacoma Public Utilities (TPU), began the Multifamily Metering Study to evaluate the impacts of the Model Conservation Standard (MCS) on the energy consumption characteristics of new multifamily buildings in the Pacific Northwest.

The impact evaluation methodology employed in this study used a test-reference experimental design. Up to three years of continuous hourly measurements of apartment-level end-use consumption and other important energy performance parameters were collected on each of 84 housing units in a ten building sample. The sample contained five matched pairs of test and reference (control) buildings. The measured data were used to support a rigorous, multiyear analysis of MCS energy savings using an hourly simulation.

Four specific objectives were established as the basis for the evaluation. They included:

- Estimation of the total energy savings achieved by the packages of MCS features in each building pair and their cost-effectiveness.
- Estimation of the energy savings achieved by the individual MCS features in each building pair and their cost-effectiveness.
- Determination of the persistence of the MCS energy savings across multiple years.
- Investigation of a simplified method for estimating space heat consumption and energy savings that
could be readily applied by utility planners without the need for detailed end-use metering.

Methodology

The analysis of the MCS was completed as a series of tasks that are summarized below.

1. Selection of Sample Buildings - The five test buildings were selected by TPU from available new construction sites within their service area. The five reference buildings were selected from candidates in the surrounding service areas of the Seattle City Light and Puget Sound Power and Light. The "matched" pairs included two sets of 12 unit buildings and one set each of 8 unit, 6 unit and 4 unit buildings

2. Data Collection - The selected study design employed analysis techniques that required the use of simulation that was calibrated with measured performance data. If the simulation could consistently and accurately predict space heat consumption under conditions that were directly measured, confidence was built in its ability to accurately predict consumption under conditions that were not measured. The simulation could then be used to estimate space heat consumption under any reasonable combination of weather, tenant mix and building physical characteristics.

The input data were collected from energy audits, professional judgment, one-time and short-term measurements. Continuous measurements were also made of lighting/appliance energy consumption, domestic hot water energy consumption, space heat energy consumption, total housing unit energy consumption, interior air temperature, outside air temperature, air-to-air heat exchanger (AAHX) supply and exhaust temperatures, AAHX on/off time and, in select cases, clothes dryer on/off time.
3. **Data Preparation** - The verified data set was manipulated in several ways to prepare it for analysis. Missing data were filled using a procedure that varied with both the type and length of the occurrence. Weather files were prepared by integrating the measured outside air temperature with the hourly weather data from the nearest NOAA weather station for the calibration periods. The filled data set was also aggregated to the building level. A separate aggregation of the individual housing units to the building level was made for each of the unit level measurements.

4. **Simulation Calibration** - The calibration process consisted of three major steps. First, the building characteristics data, derived profiles and aggregated energy measurements (except total and space heat consumption) were integrated into the simulation. Second, the simulation was run to calculate predicted space heat energy consumption under measured site weather conditions and these results were compared to measured space heat consumption. In the final step, adjustments were made to the simulation inputs until a satisfactory match of the predicted and measured space was achieved. The simulation was calibrated over a coincident one-year period for test and reference cases in each building pair.

A subtraction of calibrated test building and reference building consumption would not produce an accurate estimate of savings because of differences in microclimate weather conditions, tenant behavior and the physical properties of the two buildings. To obtain an accurate estimate of actual energy savings, corrections were made to account for these differences.

5. **Simulation Adjustments** - Adjustments were made to the calibration year savings estimates to account for the following factors:
• Weather Conditions - A weather adjustment was used to assess microclimate differences that existed between the test and reference buildings. An additional weather adjustment was used to compute energy savings under typical, long-term weather conditions.

• Tenant Behavior - A tenant behavior correction within each matched pair was required to account for variations in appliance mix, consumption patterns, thermostat setpoint and differences in vacancy rates.

• Physical Properties - Differences in physical properties that were accounted for included size of the housing units, infiltration rates, construction type and geometry.

Individual Conservation Measures - The simulation analyses were completed with the disaggregation of the adjusted energy savings of the conservation package into its individual components and an analysis of cost-effectiveness.

Simplified Analysis Techniques - In an effort to maximize the relevance of this research to utility planners, the detailed measurement of end use consumption were used as the basis for the application of simplified analysis techniques that might produce acceptable savings estimates at a significantly reduced cost.

The assessment of simplified techniques began with the application of PRISM to each of the sample buildings for the calibration period previously used in the simulations. An effort was made to improve upon the ability of PRISM to predict space heat consumption. Through a linear regression analysis a balance point was computed from the measured data and a revised space heat slope was computed as a function of the PRISM weather dependent slope. The results of the PRISM analyses were compared to the corresponding simulation analysis to assess the value of the simplified techniques.

Comparison of the Multiyear Energy Savings Estimates - The energy savings estimates produced under Tasks 6 and 7 above were compared between the two calibration years.
Results

The methodology described above was successfully applied to the five building pairs. Major findings from the research are summarized below.

Conservation Measures

The specific MCS features varied somewhat across the building pairs because the component performance path of MCS compliance was selected by the developers for all five-test buildings. Table S-1 provides a listing of MCS features that were present in each building pair. The MCS features impacted the space heating and other (i.e., AAHX) end-uses in each building pair. An air-to-air heat exchanger (AAHX) was installed in each test building, per the MCS requirements. Although it is listed as a conservation measure, this feature actually increased the consumption in each MCS housing unit due to increased space heat requirements (from the introduction of outside air) and the addition of fan energy consumption.

<table>
<thead>
<tr>
<th>Table S-1. Summary of Conservation Measures</th>
<th>4 unit</th>
<th>6 unit</th>
<th>8 unit</th>
<th>12 unit</th>
<th>12 unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conservation Feature</td>
<td>4 unit</td>
<td>6 unit</td>
<td>8 unit</td>
<td>12 unit</td>
<td>12 unit</td>
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<tr>
<td>Air-to-Air-Heat-Exchanger</td>
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<td>x</td>
<td>x</td>
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<tr>
<td>Glazing Double to Triple w/Thermal Break*</td>
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<td>Add Argon</td>
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<tr>
<td>Glass Area (13.4% to 11% of gross wall)</td>
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<td></td>
<td>x</td>
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<tr>
<td>Wall insulation (R-13 to R-19): Same Framing (2x4)</td>
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<td></td>
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<tr>
<td>2x4 to 2x6 Framing</td>
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<tr>
<td>Door Insulation (R-1.4 to R-10)</td>
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</tbody>
</table>
*Includes adding thermal break to sliding glass door.

**End Use Consumption Measurements**

Continuous hourly measurements of end use consumption were made during the first and second year calibration periods selected for each site. Space heat consumption was the smallest end use in all but one building representing 19 to 33 percent of total annual consumption, or from 2.0 to 4.6 kWh/sqft. "Other" end use consumption was the largest in all buildings representing 36 to 46 percent of total annual consumption, or from 3.3 to 5.1 kWh/sqft. Similar results were found for the second calibration year.

A comparison of total consumption (unadjusted) between the building pairs indicated that the MCS buildings consumed less total energy than their nonMCS counterparts in only one of the five building pairs during both calibration years. A similar comparison of measured space heat consumption indicated that the MCS buildings consumed energy for this end use in three of the five cases for the first calibration year and in two of the five cases for the second calibration year. In most cases the reference buildings implemented energy efficiency beyond the minimum code requirements, resulting in greater baseline energy efficiency than expected. For building pairs where this occurred, the impact of the MCS appeared to be significantly reduced.

**Energy Savings**

A calibrated simulation was prepared for each sample building using the procedures described above. A separate calibration of space heat consumption was successfully performed for the test and reference buildings in each pair.

The values for each pair were corrected for variations in weather, tenant behavior and physical properties that were unrelated to the MCS. During the first calibration year, energy savings for the complete MCS package
(including AAHX) ranged from -3.2 to 12.1 percent (-0.41 to 1.55 kWh/sqft) of total annual consumption. For the 8 unit pair, the negative savings estimate of -3.2 percent was expected since the addition of an AAHX was the only MCS feature included in the pair. While providing improved indoor air quality, air-to-air heat exchangers increased energy consumption. For the 6 unit and one of the 12 unit pairs, a negative savings is also observed. In both cases the energy savings were computed at -1.6 percent (-0.17 to 0.19 kWh/sqft) of total annual consumption. This result was not expected because the MCS features included more than just the AAHX (see Table S-1). The increased consumption (negative savings) associated with the AAHX was slightly greater than the positive savings associated with the other MCS features. The reference buildings in the three pairs with negative savings were constructed by the same builder. In all three cases the expected savings from the MCS were reduced because the reference buildings were more energy conserving than they had to be. With a total sample of only five building pairs, the actions of this single builder had a pronounced effect on the magnitude of the savings attributed to the MCS in this study. The estimates of savings are therefore more conservative than what might be expected in the entire building population.

For the 4 unit and other 12 unit pairs significant positive savings were observed. Fully adjusted savings for the entire MCS package in these two buildings ranged from 3.5 to 12.1 percent (0.45 to 1.55 kWh/sqft) of total annual consumption, respectively. With the AAHX excluded, the fully adjusted savings in these two building pairs increased significantly. Savings increased to 14.6 percent (1.86 kWh/sqft) in the four unit pair and 6.6 percent (0.85 kWh/sqft) in the first of the twelve unit pairs. Savings ranged from no savings in the 8 unit pair to 4.6 percent (0.48 kWh/sqft) savings in the 6 unit pair. Average savings across all five building pairs with the AAHX excluded, was 5.3 percent (0.65 kWh/sqft) of total annual consumption.

Similar results were produced from the second year analysis. The fully adjusted energy savings for the full MCS conservation packages persisted into the second year but were reduced by .02 to .29 kWh/sqft for four building pairs. Savings remained unchanged in the remaining case (8 unit). The reduction in savings was caused by the
combined affects of changes in the AAHX performance, thermostat set point and internal gains between the two years. For the 4 units building the primary cause was differences in internal gains and/or thermostat setpoint. For both 12 unit buildings the reduced savings were attributed primarily to a degradation in the performance of the AAHX. For the 6 unit building all of these factors contributed to the lower savings. With the AAHX excluded, energy savings increased slightly for the 6 unit and both 12 unit pairs, decreased slightly for the 4 unit pair and remained unchanged at no savings for 8 unit pair. Average savings across all five building pairs, with the AAHX excluded, was slightly greater than the first year at 0.70 kWh/sqft of total annual consumption.

Cost-Effectiveness

Examination of the levelized cost data reveals that the full MCS package (including the AAHX) was not cost-effective in any building pair for either calibration year. In all cases the levelized cost was either undefined (i.e., negative savings) or greater than the 42 mill/kWh threshold established by Bonneville. However with the AAHX excluded, the MCS package was cost-effective in all building pairs for both years. For the first year the levelized cost ranged from a low of 2.6 mills/kWh for the first 12 unit pair to a high of 32.3 for the second 12 unit pair. For the second year the package became slightly more cost effective in the 6 unit and both 12 unit pairs. The package became slightly less cost-effective for the 4 unit pair and remained unchanged for the 8 unit pair. The cost-effectiveness ranged from 2.2 to 28.4 mill/kWh, which is well below the Bonneville threshold.

PRISM Analysis

The PRISM model accurately modeled temperature dependent consumption. However, the standard PRISM methodology consistently overestimated the space heat slope. These findings are in agreement with previous PRISM research. As a result, the standard PRISM methodology overestimated space heat consumption in all but one building for both years. The average over prediction of space heat consumption was .80 kWh/sqft (26 percent) in the first year and 1.2 kWh/sqft (33 percent) during the second year. These results showed that it was
inappropriate to assume the temperature dependent consumption and space heating consumption were equivalent. The temperature dependent consumption included a significant amount of seasonal consumption in the other and hot water end-uses. These findings are also in agreement with previous PRISM research.

The adjusted PRISM model produced results that compared more favorably, on average, to the measured data. The average over prediction of space heat consumption for adjusted PRISM was 0.2 kWh/sqft (5 percent) for the first year and 0.5 kWh/sqft (14 percent) for the second year. This represents a significant improvement from the unadjusted model. Using long term weather conditions, the energy savings from the adjusted PRISM model ranged from 1.5 to 1.7 kWh/sqft for the first year and 0.8 to -0.2 kWh/sqft for the second year.