Persistence of Savings in New Multifamily Buildings

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The Bonneville Power Administration (Bonneville) in cooperation with Tacoma Public Utilities, has conducted an evaluation of the impacts of the Model Conservation Standard (MCS) on the energy consumption characteristics of new multifamily buildings in the Pacific Northwest. In this project, continuous hourly measurements of apartment level end use consumption and other important energy performance parameters were made 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 analysis of MCS energy savings and cost-effectiveness for these building pairs for two years immediately after measure implementation.

This paper provides a brief overview of the methodology that was used to perform the rigorous energy savings analysis for the measure package and its individual measure components. The methodology involves an integrated approach that calibrated an hourly simulation with measured performance data. The paper describes the results of the energy savings analysis performed on both the first and second years after implementation for each pair. The paper compares the results between the two years with regard to the persistence of savings achieved by the measure package and its individual components. The paper ends with a discussion of the cost-effectiveness of the components of the MCS and the market transformation that may have occurred as a result of code implementation.

Introduction

The Bonneville Power Administration (Bonneville) in cooperation with Tacoma Public Utilities (TPU) has sponsored 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 Model Conservation Standard is a voluntary regional energy code that was adopted by the City of Tacoma to reduce energy consumption in new residential and commercial buildings. It was important for Bonneville to quantify the energy savings of the MCS buildings compared to non-MCS buildings to enhance its understanding of the impact and value of energy codes for new construction in the Pacific Northwest. This research addressed the energy impacts of the MCS in the multifamily sector.

The impact evaluation methodology employed in this study used a test-reference experimental design. To support the evaluation, 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 a hourly simulation.

Four of the primary objectives established for the evaluation included:

1. Estimation of the total energy savings achieved by the package of MCS features in each building pair.

2. Estimation of the energy savings achieved by the individual MCS features in each building pair.

3. Determination of the persistence of the MCS energy savings across multiple years.

4. Assessment of the value of the MCS to the region, in terms of the cost-effectiveness of specific MCS features and the implications of the findings on future energy code development.

Background

Code implementation has been a large and ongoing part of Bonneville's conservation efforts. In 1983 and 1986, the Northwest Power Planning Council (Council) Plans established the MCS as the primary means to capture savings in new construction. Bonneville responded by running three pilot programs and two full-scale MCS programs to encourage adoption of MCS-level conservation measures. The pilot programs consisted of the Code Adoption Demonstration Program (CAPP) and the Residential Standards Demonstration (RCDP). The fill-scale programs were the Early Adopter (EA) and Super Good Cents (SGC) Programs.

Washington has long been a proponent of code programs. As early as 1981 it passed a state-wide energy code. In 1984, the City of Tacoma, Washington (the primary site for this study) became the first local government in the BPA service territory to adopt MCS through the EA program. In 1986, an improved state-wide energy code was passed. By 1988, half of the EA jurisdictions in the BPA service territory that were enforcing the MCS code as a mandatory requirements for new and electrically heated buildings were in Washington. Washington followed the same pattern of adoption for the SGC Program implemented in 1984. By the end of 1987, 91 percent of the SGC homes constructed were in the State of Washington. Both programs promoted the same codes and by 1988 MCS became known as the Northwest Energy Code.

In January 1990, the Washington State Legislature passed a measure that directed the Washington State Building Code Council to develop energy efficiency standards and ventilation requirements for new residential and commercial buildings permitted after 1991. The new codes were modeled after the MCS and are called the Washington State Energy Code (WSEC) and the Ventilation and Indoor Air Quality Code. The MCS differs from the WSEC in that the former requires a more efficient building shell and the use of air-to-air heat exchangers to improve indoor air quality.

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 its service area. Selections based upon desired physical characteristics of the buildings and the willingness of the owners to participate in the study. 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 a 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 hourly 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 heat was achieved. The simulation was calibrated over a coincident one year period for the test and reference cases in each building pair. The calibration was repeated for a second coincident one year period to support the evaluation of savings persistence.

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:

   (a) *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.

   (b) *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.

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

6. **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.

7. **Comparison of the Multiyear Energy Savings Estimates** - The energy savings estimates produced under Tasks 5 and 6 above were compared between the two calibration years to evaluate the ongoing persistence of the energy savings.

Results

The methodology described above was successfully applied to the five building pairs. Major findings from the research are summarized below. The discussion begins with a summary of salient characteristics of the selected sample buildings, including a description of the MCS features in each building pair. The discussion also includes a summary of the results of the continuous hourly measurements made at each site. The discussion concludes with important findings from the first and second year savings and cost-effectiveness analyses performed on each building pair.

Summary of Building Characteristics

Salient physical characteristics of the ten sample buildings are summarized in Table 1. These characteristics were compiled from an examination of available construction plans and observations made during the detailed energy audit. The ten building sample contains a total of 84, all-electric housing units constructed in 1990 or 1991. The five test buildings were constructed in compliance with the Model Conservation Standards. The five reference buildings were, at a minimum, constructed to comply with the prevailing Washington State Energy Code. The sample contains one, two and three bedroom housing units. The sample buildings are either two or three stories in height. The gross floor areas range from 3,814 to 12,607 square feet, with the size of an average unit varying by almost a factor of two, from 639 to 1,246 square feet. In all cases the thermal integrity of the buildings comply with the respective code requirements. For some of the nonMCS buildings, the selected insulation levels and window types exceeded the minimum requirements of the Washington State Energy Code (WSEC). All housing units have zero clearance fireplaces and a washer/dryer set. There were no central laundry facilities in any of the buildings.

Conservation Measures. The conservation measures implemented in each building pair were defined as the difference in test and reference building features relevant to the MCS code provisions. The specific MCS features varied somewhat across the building pairs because the component performance path (instead of the prescriptive path) of MCS compliance was selected by the developers for all five test buildings. The component performance path provided more flexibility to the developers in selecting a combination of building envelope features that collectively met the thermal integrity requirements of the code.

The MCS features assigned to each building pair were influenced significantly by the thermal performance characteristics of the reference buildings. All of the reference buildings were constructed in compliance with the minimum requirements of the prevailing local energy code (i.e., the code that would have been used in the absence of the MCS), which was at least as stringent as the WSEC. However, in most cases the reference buildings implemented energy efficiency beyond the minimum code requirements, resulting in greater energy efficiency than expected. For building pairs where this occurred, the impact of the MCS appeared to be significantly reduced.

Table 2 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

Table 1. Summary of Building Characteristics

Building No.	Category	No. of Housing Units	Gross Floor Area Total (sq ft)	Gross Floor Area Avg Unit (sq ft)	Insulation Levels Roof & Ceiling	Insulation Levels Wall	Window Type
1	MCS	4	3813	954	R-38	R-19	Triple
2	Non-MSC	4	4532	1133	R-38	R-13	Double
3	MSC	6	7474	1246	R-38	R-19	Triple
4	Non-MSC	6	6900	1150	R-38	R-19	Double
5	MSC	8	7432	929	R-38	R-19	Double
6	Non-MSC	8	8067	1008	R-38	R-19	Double
7	MSC	12	7670	639	R-38	R-19	Dbl.w/argon
8	Non-MSC	12	12607	1051	R-38	R-19	Dbl.w/argon
9	MSC	12	10296	858	R-38	R-19	Dbl.w/argon
10	Non-MSC	12	10683	890	R-38	R-19	Double

Table 2. Summary of Conservation Measures

Conservation Feature	4 unit	6 unit	8 unit	12 unit (1)	12 unit (2)
Air-to-Air Heat Exchanger	X	X	X	X	X
Glazing:					
Double to Triple w/Thermal Break*	X	X			
Add Argon					X
Glass Area (13.4% to 11% of gross wall)				X	
Wall Insulation (R-13 to R-19):					
Same Framing (2x4)				X	
2x4 to 2x6 Framing	X				
Door Insulation (R-1.4 to R-10)					

* Includes adding thermal break to sliding glass door

building pair. This table shows that an air-to-air heat exchanger (AAHX) was installed in each test building, per the MCS requirements. The AAHX was included in the MCS specification to mitigate the hazard in apartments of insufficient natural ventilation. 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. Beyond the AAHX, the number of conservation measures included in the building pairs ranged from none in the 8-unit pair to three measures in the 4-unit pair. A net increase in energy consumption was expected in the 8-unit pair due to the impact of the AAHX. Significant savings were expected in the 4-unit pair with measures affecting three components of the building shell.

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. These measurements are summarized in Figure 1. The figure shows that 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” (lights and appliances) 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.

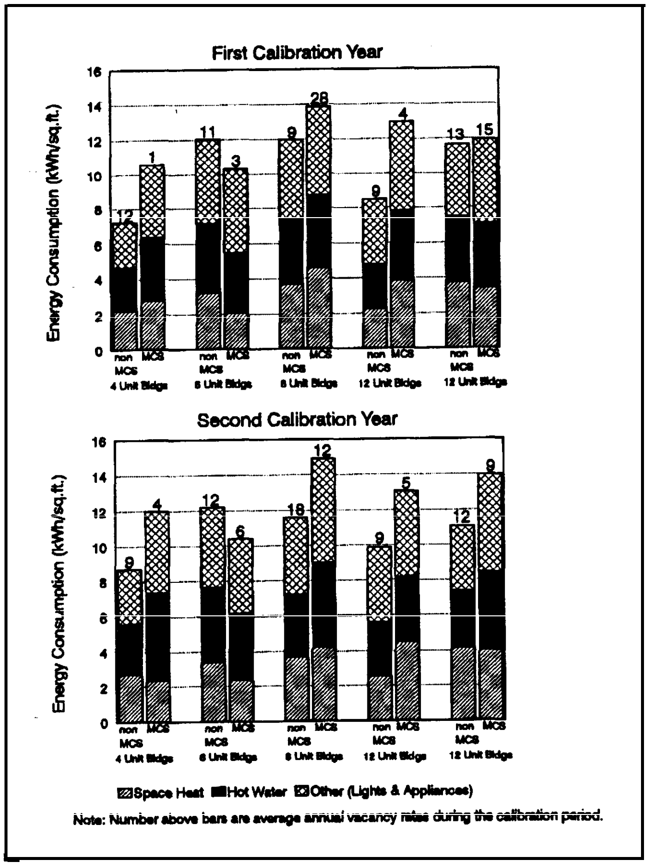

Figure 1. Measured Annual End Use Consumption

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 less energy for this end use in two of the five cases for the first calibration year and in three 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.

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 for both years.

The savings 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 was 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 2). 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 saving 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 all 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 AAHX performance, thermostat setpoint and internal gains between the two years. For the 4 unit 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 the 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 mills/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 mills/kWh, which is well below the Bonneville threshold.

Market Transformation

Implementation and adoption of the MCS code has resulted in a permanent increase in the energy efficiency of new. multifamily construction practices. The increase in efficiency, although somewhat obscured by Washington's long history of building to codes and often to standards higher than required codes, has resulted in measurable savings. These two factors render the MCS program synonymous with a market transformation project. That is, BPA has found it cost effective to invest, relatively short term, in code adoption programs resulting in a permanent change in efficiencies that the market will bear once BPA is no longer involved financially.

Conclusions

This study leads to a number of conclusions about the implementation of the Model Conservation Standards in new multifamily buildings in the Pacific Northwest:

1. Significant energy savings were realized from the MCS in several of the buildings, when comparisons are made to reference (non-MCS) buildings constructed in accordance with the prevailing energy requirements of the Washington Energy Code. First year savings ranged from .85 to 1.86 kWh/sqft hours per square foot, or seven to 15 percent of reference building consumption, with the AAHX excluded.

2. The air-to-air heat exchangers (AAHX) installed in the MCS apartments had a large negative impact on energy savings. With the effect of the AAHX removed, the MCS conservation packages and the individual measures within these packages were found to be cost effective. During the first year all of the measures had a cost-effectiveness of less than 39 mills per kilowatt hour saved, which is under Bonneville's 42 mill threshold. During the second year one measure was not economically justified, with a cost-effectiveness of 43 mills per kilowatt hour saved.

3. Excluding the impact of the AAHX, the energy savings associated with the MCS did persist through the second year of the study. In four of the five pairs, savings decreased slightly during the second year. No change was found in the fifth pair.

4. The air-to-air heat exchangers were included in the MCS specifications to compensate for the assumed decrease in natural ventilation due to more efficient building construction. They are, according to this field test, net consumers of energy and were of questionable value.

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