A TALE OF TWO CITIES: BOOSTING ENERGY EFFICIENCY IN MULTIFAMILY NEW CONSTRUCTION

Marc Schuldt, SBW Consulting, Bellevue, WA
Debra Okumo Tachibana, Seattle City Light, Seattle WA
Pamela Brandis, Bonneville Power Administration, Portland, OR
Jeffrey Romberger, SBW Consulting, Bellevue, WA

Introduction

In 1983, the City of Tacoma, Washington adopted a mandatory energy code for multifamily residences that requires energy efficiency beyond the Washington State Energy Code. All electrically heated new apartment buildings greater than five units must comply with this greater efficiency level. In a parallel effort, Seattle City Light in 1992 implemented the Super Good Cents (SGC) conservation program that also provides for energy efficiency beyond the state code through incentives that are offered to the builders of new multifamily buildings with more than five housing units. In both cases the efficiency improvements were patterned after the Model Conservation Standard (MCS), a voluntary regional energy code that was developed by the Northwest Power Planning Council to reduce energy consumption in new multifamily buildings.

The Bonneville Power Administration (Bonneville) has sponsored an impact evaluation of the energy code changes implemented by Tacoma to quantify their energy savings and cost-effectiveness. The code changes evaluated included enhanced thermal integrity of shell components, such as glazing, external walls and external doors. The evaluation also considered the energy impacts of air-to-air heat exchangers that are required by the code to mitigate possible air quality problems. The evaluation methodology employed in this study used a simulation approach that created a site-specific model for each building in the participant and non-participant samples. The simulations were supported by up to three years of extensive hourly measurements of apartment level end use consumption, and other energy performance parameters that were collected on each of 84 housing units in a 10 building sample of participants and non-participants.

Seattle City Light (Seattle) has sponsored an impact evaluation of the SGC program to quantify the energy savings achieved by the program participants. The program features evaluated included a package of shell efficiency improvements, efficient exterior lighting (common area and outside) and efficient interior lighting (bathroom and kitchen). This study also used a simulation based approach to estimate energy savings for the shell and lighting measures; however, the simulations represented a much larger participant sample (1,314 housing units in 19 projects) with prototypical models rather than individual building models. Two prototypes were developed with an hourly simulation model to represent the consumption characteristics of the two categories of buildings found within the participant sample. Separate estimates of savings were produced for each building classification. The simulations were supported by one year of Seattle utility billing records, the Bonneville hourly end use consumption profiles, program records and building plans, and on-site surveys.

The two studies shared similar objectives that included: (1) Determining the as-built energy consumption characteristics of the classifications of new multifamily buildings represented by the participant population; (2) Determining the baseline energy consumption characteristics of the classifications of new multifamily buildings that represent the corresponding non-participant population; and, (3) Determining the energy savings associated with the installed conservation measures.

The major impetus for the MCS research in Tacoma was the inconclusive results from previous BPA research on the MCS in new multifamily buildings. The previous statistical analysis of billing records had provided a wide range of estimates for energy savings. Multiple regression analysis at the housing unit level had indicated space heat savings of 25 percent (1.8 kWh/sq.ft. per year), while building level analysis indicated 15 percent (0.8 kWh/ sq.ft.). Due to the uncertainties of the previous methods, it was concluded that an approach based on end-use measurements would provide an exceptional opportunity to improve on the savings estimates. It was important to the BPA to quantify the MCS energy savings in order to enhance its understanding of the impact and value of energy codes for new construction in the Pacific Northwest.

The Seattle SGC study benefited from the findings of the MCS study. Besides using a similar simulation approach, Seattle mined the MCS study for reliable parameters on typical infiltration, internal loads, thermostat setpoints, and hourly load curves. Like the BPA, Seattle found the DOE-2 tool to be robust for predicting space heat consumption, making adjustments to typical weather conditions, estimating energy savings, and disaggregating savings by measure type. Seattle has used the SGC study findings to develop new specifications and terms for the program to replace Super Good Cents. The Built Smart program for energy and resource efficiency in multifamily new construction projects began operation in spring 1997.

Methodology

The two studies used a similar five-step methodology to evaluate as-built and baseline energy consumption characteristics and to estimate both gross and net energy savings attributed to the conservation measures. Common elements of the respective methodologies are summarized below.

Sample Selection

Both studies selected a sample of participants and non-participants as the basis for the estimation of energy savings. For the Bonneville study, the sample consisted of five "matched" pairs of all-electric participants and non-participants. The five participant buildings were selected by Tacoma Public Utilities (TPU) from available new construction sites within their service area. All of the participants complied with the MCS. The five non-participants were selected from candidates in the service areas of the surrounding electric utilities. All of the non-participants were in compliance with the less stringent Washington State Energy Code.

For the Seattle City Light study, separate participant and non-participant samples were selected for the shell improvements and lighting measures. Each building in the sample was a newly constructed apartment complex in the Seattle City Light service area, completed in 1993 or 1994. The participants were required to have electric space heat and to have installed one or more of the SGC provisions that were being evaluated. Buildings that were participants for one measure type were allowed to be a non-participant for another measure type. The participants were classified into two basic categories (in-unit versus common laundries), based on their thermal characteristics. Each of these categories became the basis for the development of a prototype building.

Data Collection

For both studies the calculation of energy savings required the collection of building characteristics and energy system performance data for the selected one-year study period. These data were used to formulate the inputs to the hourly simulation models used in both studies. In both cases, total building consumption data were required to serve as a reference to judge the adequacy of the simulation models. For the Bonneville study, the hourly measurements of housing unit consumption were used as the reference. For the Seattle City Light study, the reference was provided by electric utility bimonthly billing records.

Building Characteristics Data: Building physical and operational characteristics data were necessary to satisfy the inputs to the simulation model prepared for individual buildings or prototypes. For both studies the primary sources of these data were construction drawings, and observations and measurements made during an on-site survey. Project files, developed during program implementation, were also available for the Seattle City Light study.

End-Use and Energy System Performance Measurements: The Bonneville study also collected up to three years of extensive hourly measurements of apartment level end use consumption and other energy performance parameters on each of 84 housing units in the ten building sample of participants and non-participants. The measurement strategy included continuous hourly measurements of lighting/appliance energy consumption, domestic hot water energy consumption, interior air temperature, outside air temperature, air-to-air heat exchanger (AAHX) supply and exhaust temperatures, AAHX on/off time and clothes dryer on/off time. Short term PFT tracer gas measurements of the air exchange rate were also made on a sample of housing units. These data were used directly in the Bonneville study to develop site-specific inputs to the individual building simulations. These data were also used indirectly in the Seattle City Light study (referencing the Bonneville study as a secondary resource), to support the derivation of typical end-use profiles required as inputs to the prototypes.

Participant Model Development

Inputs to the hourly simulation were prepared for each building or prototype based upon the analysis of the data collected in the above step. For the Bonneville study, separate simulations were prepared for each of the five participant sites. For the Seattle City Light study, as-built simulations were prepared for each of the two prototypes. The simulations were run under the weather conditions that occurred during the study period. The energy consumption predicted by the simulation was compared, on a monthly basis, to the 1995 consumption targets prepared for each building or prototype from measured end use data or electric billing records. Adjustments were made to the simulations until a satisfactory match of the predicted and measured consumption was achieved. The adjustments were made to parameters with the highest degree of uncertainty, such as thermostat setpoints and equipment capacities. References 2 and 3 provide more detailed information on the simulation calibration process.

Non-participant Model Development

Non-participant model development differed somewhat between the two studies. For the Bonneville study, separate calibrated simulations were prepared for each of the five non-participant buildings using the same procedures as the participant simulations, discussed above. For the Seattle City Light study, the non-participant models for each prototype were developed by changing the parameters in the as-built model (developed in the above step) relevant to the energy performance of the shell and lighting conservation measures. This less rigorous treatment of the non-participants was necessary due to resource limitations. The parameters were modified to reflect typical baseline (i.e., standard building practice) characteristics compiled from the non-participant sample within each prototype. The models were rerun under these conditions and the results were compared to the respective as-built models for reasonableness.

Energy Savings

Energy savings were computed in both studies as the difference between participant and non-participant consumption under typical weather conditions. For the Bonneville study, adjustments had to be made to the calibrated simulations for each of the ten buildings to adjust for typical weather conditions, and for differences in tenant behavior and building physical properties between the participants/ non-participants pairs that were not relevant to the conservation measures. Reference 2 provides more detailed information on these adjustments. For the Seattle City Light study, both the as-built and baseline models for each prototype were rerun under typical weather conditions and an assumption of full occupancy. Vacancy adjustments were applied later during the estimation of program level savings.

For both studies the analysis was completed with the disaggregation of total savings for each building or prototype into the individual conservation measures. For the Bonneville study, savings were computed for each of the MCS features included in the matched pairs. For the Seattle City Light study, separate savings were computed for the shell measures, the kitchen/bath lighting measures and the common/exterior lighting measures. While the Bonneville study normalized energy consumption and savings to the rentable square footage, the Seattle study normalized to the envelope-enclosed floor area, including both rentable and interior common areas.

Cost-Effectiveness

Both studies examined the cost-effectiveness of the conservation measures. The Bonneville study computed the cost-effectiveness of the conservation package and individual components in each matched pair using the standard Bonneville levelized cost methodology. Whenever possible, the cost-effectiveness was based on incremental capital cost data from the participant and non-participant builders. A measure was cost-effective if its levelized cost was less than or equal to 42 mills/kWh in 1993 dollars. The Seattle study considered the cost-effectiveness of the entire SGC program, including administrative expenses as well as the incremental cost to the utility and the participant of measures. These costs are compared with the costs of energy alternatives, whether internal (Seattle City Light generation) or from external markets. During 1996, spot market and power prices were in the neighborhood of 15 to 20 mills, while low-cost gas and combined-cycle combustion turbines drove Seattle's 1996 average avoided costs to below 32 mills per kWh.

Results

The methodology described above was successfully applied to the participant and non-participant samples. Major findings from both evaluations are summarized below.

Comparison of Building Samples

The sample for the Bonneville study contained five matched pairs of participants and non-participants. The ten-building sample contained a total of 84 all-electric housing units constructed in 1990 and 1991. The sample contains one-, two- and three-bedroom housing units that ranged in size from all one-bedroom units to all three-bedroom 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 average unit size varying from 639 to 1,246 square feet. In all cases the thermal integrity of the buildings complied with the respective code requirements. For some of the non-participant buildings, the selected insulation levels and window types exceeded the minimum requirements of the Washington State Energy Code (WSEC). All housing units had zero clearance fireplaces and a washer/dryer laundry set. There were no central laundry facilities in any of the buildings.

A total of 39 buildings were included in the Seattle City Light study. Twenty-six of the buildings were to some degree SGC participants. Many of the buildings served as non-participants for aspects of the SGC program in which they did not participate. Thirteen of the buildings were pure non-participants because they did not participate in the program in any way.

The portion of the Seattle study sample that was used in the analysis of shell measures included 19 participant projects (with 22 buildings) and 15 non-participant projects (with 23 buildings). In-unit laundries were found in 17 of the shell-measure participants (20 buildings); these were used to define the first prototype. These buildings ranged in size from 7 to 245 housing units. They had predominantly one and two bedroom housing units, whose average size ranged from 650 to 1,164 square feet. This size range is very similar to the Bonneville study. However, nearly all SGC sample buildings had, in addition, internal common areas averaging 13 percent of the gross envelope-enclosed floor area. Most of this space was unconditioned but shared interior walls with the rentable area within tenant units, and hence benefited from thermal transfer and the shell efficiency measures.

The remaining two buildings in the SCL sample had common area laundries and, therefore, were used to define the second prototype. These two buildings ranged in size from 100 to 200 housing units that were predominantly studio apartments. The average size for these units ranged from 412 to 606 square feet (excluding common areas), which was significantly smaller than the first prototype.

The internal common areas averaged 14 percent of the gross envelope-enclosed floor area in these two buildings.

Comparison of MCS and SGC Features

For both studies the conservation measures were defined as the difference in the features, relevant to SGC or the MCS, between the participants and non-participants. For the Bonneville study, 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 all participant developers. 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. Under the MCS, the wall U_o (including glass and doors) had to be equal to or less than 0.125 Btu/sq.ft.ºF. This value is significantly lower than the 1986 Washington State Energy Code U_o requirement of 0.144 Btu/sq.ft.ºF. Table 1 summarizes the MCS conservation measures found in the five matched pairs.

The MCS features defined for each building pair were influenced significantly by the thermal performance characteristics of the non-participants (used to define baseline conditions). All non-participants were constructed in compliance with the minimum requirements of the prevailing local energy code, which was at least as stringent as the Washington State Energy Code. However, in most cases the non-participants 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 was significantly reduced. A single builder constructed the three non-participant buildings that were most energy efficient.

The table shows that an air-to-air heat exchanger (AAHX) was installed in each participant 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 heating requirements.

Table 2 provides similar information regarding the SGC conservation measures for the Seattle City Light study. The table shows the prescriptive requirements of the SGC program that all participants were required to meet. It also provides a comparison of the average observed as-built and baseline conditions. The table shows that, on average, the participants met or exceeded the prescriptive requirements of the SGC program, while non-participants varied somewhat from code in most measure areas. The table shows that, for all but two provisions (floor-above PT slab and outside lighting), the baseline conditions estab-

Table 1. Summary of Conservation Measures (Bonneville Study)

	Building Type				
MCS Conservation Measure	**4 unit**	**6 unit**	**8 unit**	**12 unit (1)**	**12 unit (2)**
Air-to-Air Heat Exchanger (AAHX)	X	X	X	X	X
Glazing: Double to Triple w/ Thermal Break*	X	X			
Add Argon					X
Glass Area (% of 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)	X				

• Includes adding thermal break to sliding glass door

Table 2. Summary of SGC Provisions and Baseline Values (Seattle Study)

Provision	**SGC Conservation Measure**	**SGC Prescriptive Requirement**	**SGC As-Built Condition**	**non-SGC Baseline Condition**
Thermal Shell	Thermostats	Heat Anticipator	Dead Band: 2°F	Dead Band: 5°F
Ceilings:	Attics	R-49	R-49, U-0.020	R-37, U-0.028
	Vaulted	R-38	R-38, U-0.027	R-36, U-0.030
Walls:	Above-Grade	R-26	R-26, U-0.041	R-19, U-0.062
Floors:	Above Post Tension Slab	R-15	R-17, U-0.045	R-17, U-0.045
	Pinned Under PT Slab	R-30	R-30, U-0.049	R-21, U-0.064
Glazing		U-0.35	U-0.35	U-0.45
Infiltration:	Assumed Rate	0.35 ACH	0.30 ACH	0.40 ACH
Lighting	Kitchen	Fluorescent	1.95 W/sqft	2.53 W/sqft
	Bathroom	Fluorescent	3.37 W/sqft	4.74 W/sqft
	Unconditioned Common Area	Fluorescent	0.28 W/sqft	0.64 W/sqft
	Outside Exterior	Fluor. or HPS	0.02 W/sqft	0.02 W/sqft

lished by the non-participants were less efficient than the corresponding participant as-built conditions. There are three notable differences between the MCS and SGC measures: (1) the Seattle program did not install air-to-air heat exchangers, (2) SGC incorporated a significant lighting component, concentrating on interior common areas; and (3) SGC also provided incentives for high-efficiency refrigerator and water heat appliances (not shown in Table 2.)

Energy Consumption

A calibrated simulation was prepared for each participant and non-participant building in the Bonneville study and for both prototypes in the Seattle City Light study using the procedures described above. For all buildings and prototypes an acceptable match between simulated and actual (measured or billed) consumption was achieved. Table 3 shows the annual end use consumption estimates for each building in the Bonneville study that reflects the as-built configuration under typical weather conditions. The participant in each building pair is labeled as MCS and the non-participant is labeled as non-MCS. The table shows a range of 2.7 to 4.1 kWh/sq.ft. for space heating, which is the end-use impacted by the conservation measures. For some building pairs, the MCS condition consumes more or an equivalent amount of energy for space heating as the non-MCS condition, indicating that there were significant differences between the participant and non-participants in these pairs other than the MCS features.

Table 4 provides information comparable to the Table 3 totals, for the two prototypes in the Seattle City Light study. The simulation models were calibrated to within one percent of actual 1995 annual energy use for the aggregate of buildings included in each prototype. The final estimates of as-built annual consumption for the in-unit laundry and common laundry prototypes, under typical weather conditions, were 10.26 kWh/sq.ft. and 8.32 kWh/sq.ft., respectively. As expected, estimated annual baseline consumption for both measure types in each prototype is greater than as-built consumption, indicating energy savings were achieved from the conservation measures. Baseline energy consumption increased in the simulations for both the in-unit laundry and the common laundry prototypes. The Table 4 findings represent the characteristics of 22 participant and 23 non-participant buildings.

Energy Savings and Cost-effectiveness

Table 5 summarizes the energy savings achieved by the MCS in the five matched pairs of participants and non-participants in the Bonneville study. The table shows that energy savings for the complete MCS package (including AAHX) ranged from -3.2 to 12.1 percent of total consumption, or -0.41 to 1.55 kWh/sq.ft. 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 (see Table 1). While providing improved indoor air quality, air-to-air heat exchangers in-

Table 3. Simulated End-Use Consumption (Bonneville Study)

Building Type	Category	Annual Energy Consumption (kWh/sqft)			
		Space Heat	Hot Water	Lts. & Appls.	Total
4 unit	MCS	3.05	3.84	4.36	11.25
	Non-MCS	3.06	3.18	3.25	9.49
6 unit	MCS	2.70	3.35	4.72	10.77
	Non-MCS	3.17	4.05	4.91	12.14
8 unit	MCS	4.11	4.28	5.09	13.48
	Non-MCS	3.78	3.75	4.51	12.05
12 unit (1)	MCS	3.47	3.84	5.09	12.39
	Non-MCS	3.59	2.54	3.69	9.82
12 unit (2)	MCS	3.50	3.72	4.86	12.07
	Non-MCS	3.67	3.68	4.20	11.55

Table 4. Simulated Energy Consumption and Savings (Seattle Study)

Prototype	SGC Conservation Measure	Consumption kWh/sqft	Energy Savings		
			kWh/year	kWh/sqft	% Total
In-unit	As-Built under SGC	10.26			
Laundry	Baseline Thermal Shell	11.69	1,239	1.43	12
	Baseline Kitchen & Bath Lighting	10.34	61	0.07	1
	Baseline Common Area Lighting	11.77	1,300	1.50	13
	Total Package Savings		2,600	3.00	26
Common	As-Built under SGC	8.32			
Laundry	Baseline Thermal Shell	9.57	647	1.25	13
	Baseline Kitchen & Bath Lighting	8.45	67	0.13	2
	Baseline Common Area Lighting	10.03	885	1.71	17
	Total Package Savings		1,599	3.09	32

creased 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 of total annual consumption, or -0.17 to -0.19 kWh/sq.ft. This result was not expected because the MCS features included more than just the AAHX (see Table 1). The increased consumption, or negative savings, associated with the AAHX was slightly greater than the positive savings associated with the other MCS features. In all three cases the expected savings from the MCS were reduced because the non-participant buildings were more energy conserving than was required by the State Energy Code.

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 of total annual consumption, or 0.45 to 1.55 kWh/sq.ft. With the AAHX excluded, the fully adjusted savings in these two building pairs increased significantly. Savings increased to 14.6 percent (1.86 kWh/sq.ft.) in the four unit pair and 6.6 percent (0.85 kWh/sq.ft.) in the first of the 12 unit pairs. Savings ranged from no savings in the 8 unit pair to 4.6 percent (0.48 kWh/sq.ft.) savings in the 6 unit pair. Average savings across all five building pairs, with the AAHX excluded, was 5.3 percent (0.65 kWh/sq.ft.) of total annual consumption.

The results from the cost-effectiveness analysis in the Bonneville study showed that all of the individual measures were economically justified except the AAHX. In all cases the levelized cost was less than the 42 mills/kWh threshold established by Bonneville. The cost-effectiveness of the shell measures ranged from 6.7 to 39.3 mills/kWh. The measure package, without the AAHX, was also cost-effective for the four pairs where shell measures were considered. Cost-effectiveness ranged from 2.6 to 32.3 mills/kWh.

Table 4 also summarizes the energy savings achieved by the shell and lighting measures in Seattle's SGC program. The table shows that significant energy savings were achieved by the SGC provisions in both prototypes. Annual energy savings of 1.43 kWh/sq.ft. (1,239 kWh/apartment) were estimated for the thermal shell package in the in-unit laundry prototype. Energy savings of 1.57 kWh/sq.ft. (1,361 kWh/apartment) were estimated for the lighting measures. These values represent 12 and 14 percent of baseline consumption, respectively. Only half of the units in this prototype received kitchen or bath lighting measures.

Most of the savings from the lighting measures are found in the common area lighting, since it is operated 24 hours per day. The effect of heat/light interactions is included in the lighting savings estimates for the kitchen/bath measures, since these were in conditioned spaces. The interactive effect degraded the lighting savings to account for an increase in space heat consumption necessary to meet the higher space heat load caused by the reduced lighting capacity. No savings were found from the outside lighting component of the exterior lighting measure because the baseline and as-built conditions were determined to be the same. The program addressed few outside lighting fixtures due to BPA reimbursement limits. The thermal shell savings occurred mainly during the utility's peak months (60 percent during November through February), when winter rates are higher.

Annual energy savings of 1.25 kWh/sq.ft. (647 kWh/apartment) were estimated for the shell package in the common laundry prototype. Energy savings of 1.84 kWh/sq.ft. (953 kWh/apartment) were estimated for the lighting measures. These values represent 13 and 19 percent of baseline consumption, respectively. Again, most of the lighting savings are found in the common area

Table 5. Summary of MCS Energy Savings (Bonneville Study)

Building Type	MCS Conservation Measure	Energy Savings kWh/year	kWh/sqft	% Total
4 unit	Wall Insulation	2,536	0.66	5.2
	Glazing	2,718	0.71	5.6
	Entry Door Insulation	1,857	0.49	3.8
	Air-to-Air Heat Exchanger (AAHX)	-1,216	-0.32	-2.5
	Total Package with AAHX	5,895	1.55	12.1
6 unit	Glazing	3,623	0.48	4.6
	Air-to-Air Heat Exchanger (AAHX)	-4,871	-0.65	-6.1
	Total Package with AAHX	-1,248	-0.17	-1.6
8 unit	Air-to-Air Heat Exchanger (AAHX)	-3,064	-0.41	-3.2
	Total Package with AAHX	-3,064	-0.41	-3.2
12 unit (1)	Wall Insulation	2,553	0.33	2.6
	Glass Area	3,955	0.52	4.0
	Air-to-Air Heat Exchanger (AAHX)	-3,083	-0.40	-3.1
	Total Package with AAHX	3,425	0.45	3.5
12 unit (2)	Glazing	866	0.08	0.7
	Air-to-Air Heat Exchanger (AAHX)	-2,812	-0.27	-2.3
	Total Package with AAHX	-1,946	-0.19	-1.6

lighting system, which is run continuously; and the majority of thermal shell savings (61 percent) came during winter peak months. All units in this prototype received kitchen and bath lighting measures.

Based on the findings of this study, the SGC 1992-1994 program acquired energy savings in 1995 at the cost of 14 mills per kWh to the Utility. If one assumes that the program incentive has covered 80 percent of the incremental cost of prescribed measures, then the cost to Participants was 3 mills per kWh and the Service Area cost was 17 mills per kWh. A sensitivity analysis of this service area levelized cost ranges from 15 mills (at a 90% incentive coverage rate) to 23 mills (at 70 percent). These costs are very competitive with the 1996 costs of energy alternatives, whether from Seattle City Light generation (at an avoided cost of 32 mills per kWh) or from external markets (where spot market and power prices have been around 15 to 20 mills).

Market Transformation

The policy goal for the Tacoma Energy Code and Seattle's Super Good Cents program is to move the market toward more efficient construction practices. Market transformation of this nature was facilitated in two ways, by encouraging early adoption of new building practices and technologies (as did the Model Conservation Standards), and by creating market demand for energy-efficient apartments and condominiums. Early adoption incentives are offered to builders, while recognition and demand are promoted with building owners and tenants.

The SGC study concluded that Seattle's program designers should develop ways to underscore the value of improved energy efficiency in participating buildings through follow-on services. This type of service would provide building owners and tenants with ongoing information about energy bills and savings. Assistance with operations and maintenance (O&M) could ensure that the proper lamps are replaced in high-efficiency lighting fixtures. Follow-on services also serve the utility, by supporting the persistence of impacts and reinforcing consumer demand, along with the opportunity to provide non-energy customer services.

The two studies described in this paper portray two approaches to new construction market transformation. The SGC program shows how incentives can help builders acquire the accumulative experiences that demystify super-efficient design and practice. The MCS study demonstrates the effect on one builder in particular of repeated experience in building to a higher standard, which carried over to their construction practice outside the MCS service area.

Conclusions and Recommendations

From this work several conclusions were reached concerning the value of the MCS as an efficiency standard, and the merits of energy codes and utility DSM programs as alternative delivery mechanisms.

Bonneville Study

1. Significant energy savings were realized from the MCS in the two building pairs where the non-participant building was constructed close to the energy efficiency requirements of the prevailing Washington State Energy Code (WSEC). First year savings ranged from 0.85 to 1.86 kWh/sq.ft. or 7 percent to 15 percent of reference building energy consumption, when the impacts of the air-to-air heat exchanger (AAHX) were excluded.
   Less savings or no savings from the MCS were realized in the remaining three pairs due primarily to the fact that the non-participant buildings included energy efficiency beyond WSEC requirements
2. The AAHX installed at the MCS site in each building had a large negative impact on energy savings. The results of the infiltration tests made on the sample buildings, and the fact that the AAHX is no longer a requirement of the MCS, provide indications that the AAHX may have been an unnecessary requirement in the test buildings.
3. With the effects of the AAHX removed, the conservation packages and the individual features within these packages in each pair were found to produce significant energy savings that were cost-effective. All measures had a regional levelized cost of less than 39 mills/kWh saved, which is under the Bonneville economic threshold of 42 mills/kWh saved.
4. The continuous measurements of end-use consumption in the sample buildings provided valuable information regarding the consumption patterns of new multifamily buildings in the Pacific Northwest. The measurements indicated that the combined lighting and appliance end-use ("other") was the largest in nearly every housing unit, while the space heat end-use was the smallest.
5. Although the building selection process attempted to match buildings within each pair (except for the MCS features), significant non-programmatic differences were found between buildings. In most cases these differences had a significant impact on energy savings and therefore had to be accounted for in the impact evaluation. The impact of these effects was large enough for this sample of buildings that the use of utility billing records (or even weather adjusted billing records) as the basis for estimating savings would have led to very misleading conclusions regarding the MCS energy savings.

6. The DOE-2 simulation was found to be a robust tool for estimating the energy consumption impact of the MCS. The strengths of this tool include the ability to (1) accurately predict space heat consumption that was measured by a data acquisition system; (2) adjust space heat consumption for differences in weather conditions, tenant behavior, and building physical properties; (3) provide accurate estimates of the energy impacts of the MCS; and (4) disaggregate total package energy savings into its individual measure components, including the negative impact of the AAHX.

Seattle City Light Study

1. Annual energy savings to tenants from the shell measures were generalized to weighted annual energy savings of 1.40 kWh/sq.ft. of floor area, where floor area includes all envelope enclosed spaces, both rentable and common area. Added to these impacts were findings of energy savings to tenants from kitchen and bath lighting measures that averaged 0.15 kWh/sq.ft. of total building floor area, in buildings where this measure was installed.
   Normalized by rentable square footage, the SGC tenant energy savings (from thermal shell and unit interior lighting) were 1.61 kWh/sq.ft. without water heaters (1.78 kWh/sq.ft., with), in the sample of 19 buildings. This compares to the MCS findings ranging from 0.0 to 1.86 and averaging 0.65 kWh/sq.ft. Another comparison may be drawn from an evaluation of PacifiCorp's Oregon Long-Term SGC 1992-1993 program. Their study found savings of 1.70 kWh/sq.ft. of rentable space, where units average 890 square feet. PacifiCorp measures included thermal shell insulation, windows, some water heaters (in one-third of units) and some heat exchangers (also in one-third of units).
2. Annual energy savings from common-area lighting measures were generalized to weighted annual energy savings of 1.53 kWh/sq.ft. of floor area, where floor area includes all envelope enclosed spaces, both rentable and common-area. Normalized by the square footage of the areas actually affected by the common area-lighting measures (interior common areas plus parking garage), the owner's energy savings were 2.90 kWh/sq.ft.
3. Overall, weighted energy savings from the lighting and shell measures were over 3.0 kWh/sq.ft. of envelope-enclosed floor area, or 2,500 kWh per residential unit (28 percent of baseline energy use). These savings are more than double what was expected based on Northwest Power Planning Council and BPA projections at the time of initial program design.
4. Program participants with buildings completed in 1993-1994 received 1995 bill savings of about $75 per unit to tenants and $50 per unit to building owners. The typical 60-unit building from this group thus saves about $7,500 on energy bills each year ($4,500 shared by tenants and $3,000 to the owner).
5. Based on the findings of this study, the SGC 1992-1994 program produced significant energy savings that were cost-effective. The cost to the Utility was 14 mills per kWh, the cost to Participants was 3 mills per kWh, and the Service Area cost was 17 mills per kWh. These costs are very competitive with the 1996 costs of energy alternatives, whether from Seattle City Light generation (at an avoided cost of 32 mills per kWh) or from external markets (where spot market and power prices have been around 15 to 20 mills).
6. Seattle should revise the multifamily new construction program to improve the incentive structure for shell measures, calculating thermal shell incentives based upon the envelope-enclosed square footage, rather than upon number of residential units. The excellent performance of SGC common-area lighting measures is noteworthy, and future opportunities to build on the strength of this measure should be captured wherever possible, including in gas heat buildings.

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