Cost-Effectiveness of Greening Affordable Housing

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ABSTRACT

Enterprise Community Partners launched the Green Communities Initiative in 2004, the first national green building program developed for affordable housing. This paper describes the evaluation of the cost-effectiveness of building affordable housing to the Green Communities Criteria by looking at three aspects of the program. The first was a survey and statistical analysis of incremental construction costs to meet the specific Green Communities Criteria. The second was a benefit-to-cost analysis comparing the lifetime operational cost savings to the total incremental cost for a development to meet all mandatory criteria. This used simulation to evaluate the predicted benefits for meeting the energy and water criteria. The final aspect was a comparison of the predicted operational performance to the measured performance.

Key findings show that the 17 housing developments in this study met all mandatory Green Communities Criteria with an average increase to the total development cost of only 1.4%. Based on their design, these developments had an average predicted energy and water savings above 20%, with much of the energy savings coming from domestic hot water, lighting, and appliances and little from building envelope. On average, these savings proved to pay for the additional cost to meet the Green Communities Criteria, however, there was too much variability, due to regional diversity, in both the cost and savings data to draw a definitive conclusion. About half of the nine developments that were analyzed for post-construction performance had measured savings that tracked well to the modeled-predicted savings with an acceptable coefficient of variance.

Introduction

According to the US Dept. of Housing and Urban Development, an estimated 12 million renter and homeowner households now pay more than 50 percent of their annual incomes for housing. The lack of affordable housing is a significant hardship for low-income households preventing them from meeting their other basic needs, such as nutrition and healthcare, or saving for their future and that of their families (CPD 2010).

There are many challenges to building green affordable housing such as perceived risk, lack of documented success, and budget constraints to minimize first-time costs (Bradshaw 2005). To overcome these barriers and to encourage changes in construction practices, information on price signals related to green construction is needed. Financial institutions, investors, and developers want to know three things.

- How much more does it cost to build to green standards?
- Will the green improvements create cost-effective savings?
- What is the on-going cost-effectiveness and confidence in achieving the savings?

There are many financial, sociological, and environmental benefits to building to green standards. Previous publications have taken the financial benefits to include: energy savings, emissions savings, water savings, operations and maintenance savings, productivity and health benefits (Kats 2003). Of these financial benefits, the only ones that are currently directly measurable in dollars are the energy and water savings. Finally, for financial accountability and to increase investor confidence in green affordable housing, the predicted economic savings should be validated against measured performance. This paper attempts to address the three questions above by focusing on the analysis of the data from the Enterprise's Green Communities Initiative.

Background

Performance Systems Development (PSD) was contracted by Enterprise Community Partners, Inc. from 2005 to 2009 to compile and analyze the development cost and building performance data for their Green Communities Initiative. Green Communities homes are built according to the Green Communities Criteria (Green Criteria), the first national framework for healthy, efficient, environmentally smart affordable homes. The Green Criteria were developed with the goal of creating a holistic approach to delivering significant health, economic and environmental benefits to residents, owners and low-income communities. The Green Criteria addresses aspects of design, development and operations, such as: integrated design, location, site improvements, water conservation, energy efficiency, materials that benefit the environment, healthy living environments, and operations and maintenance of affordable housing.

To measure the impact of the Green Communities Criteria, Enterprise, in partnership with PSD, developed a cost benefit survey tool and obtained data points on costs and utility cost savings from 53 housing development projects. While a total of 53 affordable housing developers provided data, only 42 submissions were completed. Certain anomalies in data reporting — e.g., failure to provide cost data — forced Enterprise to eliminate those developments from the survey population. PSD calculated the predicted long-term energy and utility cost savings resulting from applying the Green Communities Criteria for the developments that provided complete submissions. The baseline for calculating utility usage, costs and savings for each development was a model simulation of the development built to the minimum construction code requirements of that locality. As utility bills became available for occupied developments, PSD performed weather normalized regressions to compare measured building performance to the predicted performance. The results have been published by Enterprise (Bourland 2010).

While there have been three updates to the Green Communities Criteria (i.e., 2005, 2006 and 2008), the majority of the developments for this analysis comply with the 2005 version. This is the version of the criteria that Enterprise's report and this analysis are based on (Enterprise 2008).

To clarify, this paper used a different development population set than what was used in Enterprise's report and only focused on the costs of the mandatory criteria. While the Green Communities Initiative included new and rehabilitation construction, and single family and multifamily developments, this paper focused on the developments there were comprised of new, multifamily construction. Therefore, the results of this paper will be different.

Methodology

Cost Comparison at the Individual Criteria Level

The first part of this study determined the overall cost premium for constructing an affordable housing development that met the Green Communities Criteria. The developer was asked to report the incremental cost spent for each criterion met. The incremental cost was defined as the cost spent to meet a criterion minus the cost would have spent if building the same affordable housing development to typical construction practices or local code. These incremental costs were self-reported by the developer. It was understood that the accuracy of these figures depended on the level of detail the developer used in tracking costs and knowledge of what typical construction practices would have cost. All cost data were normalized by the total development square footage and checked for outliers. For any outliers, the developers were asked to verify that these reported incremental costs were associated with the correct criterion and that they were calculated or estimated correctly.

Determining Cost-Effectiveness

Of all of the individual mandatory criteria in the 2005 version of the Green Communities standard, the energy and water criteria (specifically 4.1, 5.1 through 5.6) were analyzed for cost-effectiveness as they had a directly measurable monetary benefit. This was determined by comparing the incremental costs to the present value of the lifetime operational cost savings of the technology installed to meet the criteria. For the purposes of this study, the operational cost savings include the energy and water costs but not the potential maintenance and servicing cost savings as they are not directly measurable. As these developments are new construction buildings, the operational costs were unknown and therefore had to be predicted. Once the housing developments became occupied, monthly utility bills were then used to determine how well the models predicted the measured performance.

The predicted energy savings were determined by comparing the predicted usage of the Green Communities proposed design to a baseline design using whole-building energy simulation software models. A ‘tracking’ energy model was built using TREAT software for each of the 27 developments that had submitted as-designed drawing sets and/or energy modeling reports with sufficient information. Enterprise did have a third party document the compliance of the as-built developments to the as-designed drawings; however, this data was not available for all developments during the energy modeling process. For consistency, these data were not used. The baseline model was built as a change set applied to the as-designed energy model reflecting the building characteristics of the local construction code of that development. The energy simulation ran the as-designed model against the change set to determine the predicted energy savings. Details on the energy modeling procedure and the assumptions used for inputs not found in the drawing sets have been documented in Enterprise’s report (Bourland 2010, 65-71).

Similarly, the predicted water savings for meeting the Green Communities interior water criterion (4.1) were calculated using a spreadsheet analysis as compared to a baseline. The values for the water using appliances and devices for the as-designed building came directly from the Cost Benefit Survey.

The predicted cost savings were calculated from the energy and water savings by applying the cost per unit of electricity, fuels, and water that the developer submitted in their Cost Benefit Survey. Unit costs that were missing or appeared to be outside of normal ranges were investigated and corrected by referencing rate schedules from the utility serving that development.

The predicted lifetime operational cost savings were determined using the present value of the predicted annual cost savings over the life of the measure. This study used the same discount rate of 6% along with fuel and water inflation rates of 5% and 4.7%, respectively, as Enterprise's report (Bourland 2010, 23). This study also used the same measure life for the various building components with the exception that 10 years was used in this study for the measure life of "Water conserving appliance and fixtures" to account for this study focusing only on multifamily buildings. (Bourland 2010, 24). The lifetime operational cost savings was then converted into a benefit-to-cost ratio (BCR) by dividing it by the total incremental cost to meet all mandatory criteria.

Comparing Predicted and Measured Performance

To measure the validity of the calculated cost-effectiveness of meeting the Green Criteria, the predicted performance was compared to the measured performance. The measured performance of the development came from analyzing the post-construction monthly utility bills. These utility bills were compared with the monthly predictions from the as-designed energy and water models. This comparison can provide first-level 'commissioning' as to whether or not the systems and equipment were installed and operate as called out in the construction design documents. It can also give feedback on the usage schedule assumptions made in the energy and water prediction models.

In accordance with EVO IPMVP Vol. III, the energy savings were calculated as the difference between the projected baseline and the post-construction energy usages. Following Option D, the baseline was defined as a modification to the as-designed energy simulation model. However, a modification of Option D was used to convert the monthly utility bills into long-term weather normalized values that were subtracted from the weather normalized output of energy simulation modeling. This was done for each development that had at least 12 months of contiguous utility bills. The monthly utility bills were regressed against the local daily weather for the period analyzed. These regression equations were then used to calculate the weather-normalized monthly energy usages by running them with long-term average weather (TMY2) of the development's location. TREAT also used this same TMY2 files to calculate the predicted monthly energy usages of both the as-designed and baseline models. Because of this weather normalization, direct comparisons could be made of the model predictions and monthly utility bills.

Results

From the 42 developers who submitted completed Cost Benefit Surveys, drawing sets, and/or energy savings reports for new affordable multifamily developments, there were sufficient data from:

- 24 developments with incremental construction costs

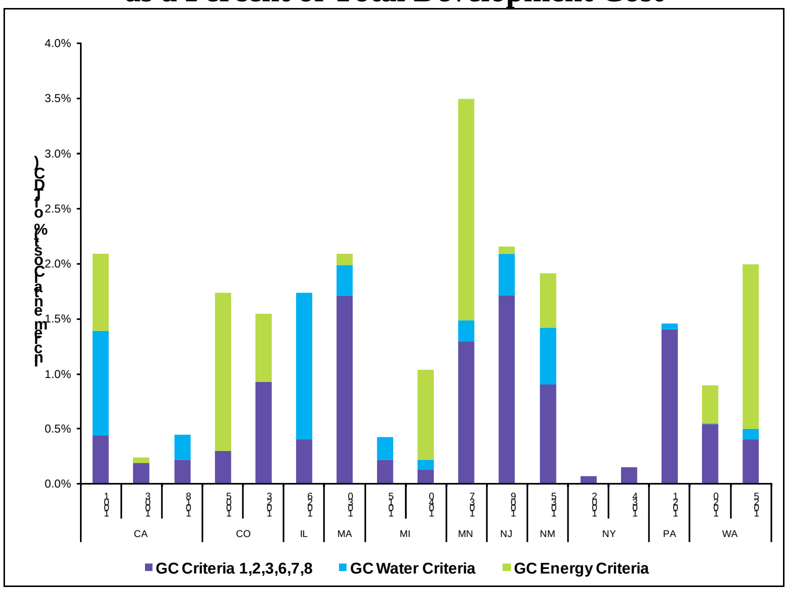
- 29 developments with predicted annual energy savings in dollars
- 24 developments with TREAT modeled energy savings using a local code baseline
- 34 developments with predicted annual water savings in dollars
- 17 developments with incremental construction costs, predicted annual energy cost savings from TREAT, and water cost savings

For consistency between the incremental costs analysis and the operational savings analysis, the smaller subset of 17 developments was used for this study.

Incremental Cost Analysis

The incremental cost to meet the mandatory criteria as a percent of total development cost (TDC) for the 17 development subset is shown in Figure 1. Because this study focuses on the cost-effectiveness of the water and energy saving criteria, these criteria were broken out separately. Correlation regressions were run between total incremental cost and the following: location, square footage, number of units, or building type. No significant correlation was found.

Figure 1. Incremental Cost to Meet all Mandatory Green Communities Criteria as a Percent of Total Development Cost



The findings show that it cost $3.15/SF or $2,890/unit to meet all of the mandatory Green Communities criteria, based on the mean of the 17 development subset, with a standard deviation of $2.29/SF or $1,920/unit (Table 1). Additionally, from comparing the mean to median values, there was more variation in the energy and water cost data than in all other criteria. This suggests a wide range of experience or access to lower cost, high performance solutions for meeting these criteria. It may also be a result of the variation in the local construction codes developers were used to building to and therefore different levels of effort to achieve the energy savings goals of criterion 5.1.

In terms of percent increase to the total development cost (TDC), the mean was 1.4% with a median of 1.6% and standard deviation of 0.92%. This is slightly lower than what was reported in the New Ecology study (Bradshaw 2005). Additionally, there was less variation in the green premium as a percent of TDC in this study than the New Ecology study. This was probably due to the fact that this study focuses only on new affordable multifamily developments all built to the same mandatory green criteria.

Table 1. Incremental Cost Data

	Criteria 1,2,3,6,7,8 ($/SF)	Water Criteria ($/SF)	Energy Criteria ($/SF)	All Mandatory Criteria ($/SF)	All Mandatory Criteria ($/unit)	Criteria 1,2,3,6,7,8 (% TDC)	Water Criteria (% TDC)	Energy Criteria (% TDC)	All Mandatory Criteria (% TDC)
Mean	$ 1.40	$ 0.77	$ 0.97	$ 3.15	$ 2,890	0.65%	0.25%	0.48%	1.40%
Median	$ 0.98	$ 0.18	$ 0.27	$ 3.24	$ 2,770	0.41%	0.10%	0.10%	1.50%
Std Dev	$ 1.07	$ 1.48	$ 1.24	$ 2.29	$ 1,920	0.57%	0.37%	0.63%	0.92%

Predicted Operational Cost Savings

Figure 2 shows the predicted annual energy and water savings from meeting all mandatory Green Communities criteria. These percentage results were based on energy costs of normalized model predictions of the as-designed Green Communities developments compared to a local code baseline.

Figure 2. Predicted Annual Energy and Water Savings

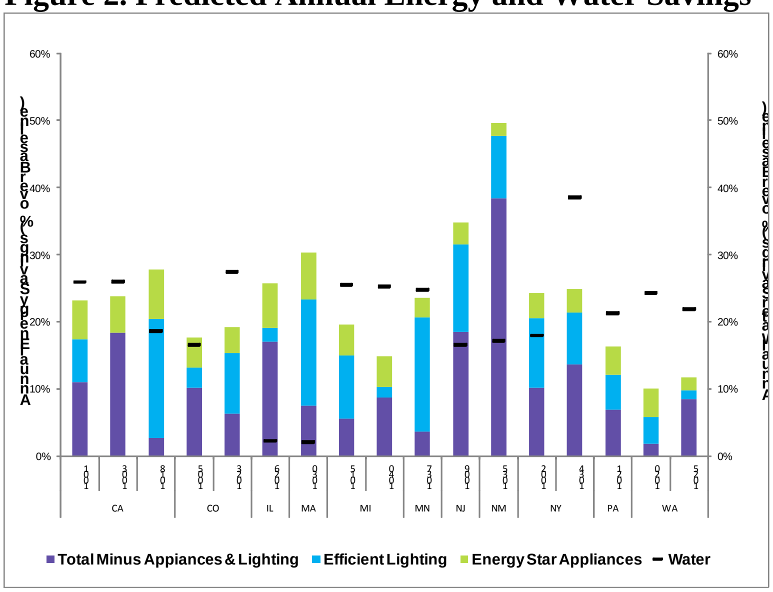


Table 2 below shows that there is a lot of variation in the predicted energy and water savings over the baseline, percentages based on costs. The average total energy savings was 26% with a standard deviation was 13%. The high variation in total energy savings is expected as criterion 5.1 is a performance requirement and each development was compared to its local construction code baseline models for savings calculations. There is less variation in the appliance and water savings which is likely due to both of these criteria being prescriptive and low cost to implement.

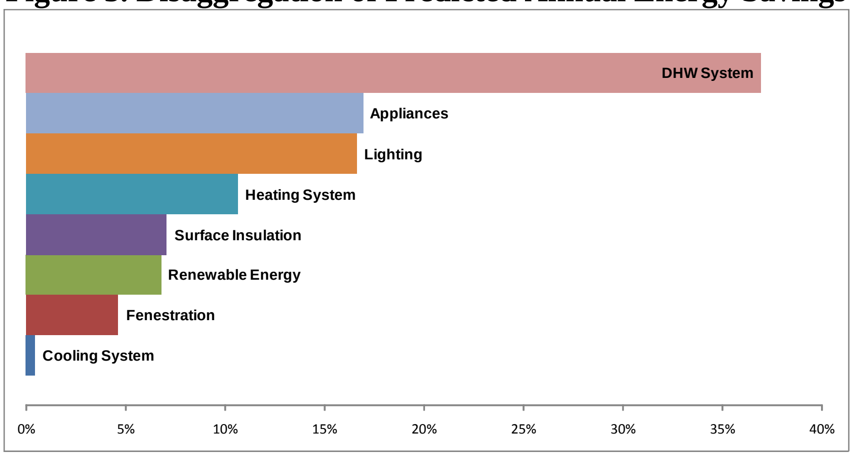
To determine if any correlations exist, the predicted annual energy savings were plotted against a variety of development characteristics. The only correlation found was a slight increase in energy savings for an increase in design costs, however, the R^2 was 0.18 making it insignificant.[1]

Table 2. Predicted Annual Energy and Water Savings

	Total Energy Savings minus Appiances & Lighting	Efficient Lighting Savings	Energy Star Appliances Savings	Total Energy Savings	Water Savings
Mean	11%	7.8%	4.4%	26%	21%
Std Dev	8.4%	5.5%	1.5%	13%	8.5%

From the energy models built with TREAT, savings were tagged by building component to allow for savings disaggregation. Figure 3 shows the distribution of predicted savings by component over the baseline as a percentage of site Btu's among the 17 development population. The majority of the modeled energy savings were achieved through lighting, appliances, and domestic hot water (DHW) reductions, while less savings were achieved through the building envelope. It should be noted that the modeled DHW energy savings includes that from the low-flow water fixtures which accounted for between 10% and 60% of the total modeled DHW energy savings. The small building envelope related savings is possibly due to energy modeling scenarios not being fully utilized during the design process. This is a huge educational opportunity to encourage cost-effective building envelope efficiencies. Upgrades to the building exterior typically do not happen within the first 10 years or more. Additionally, the savings benefit from highly-insulated surfaces has a much longer useful lifetime than equipment, lighting and appliances.

Figure 3. Disaggregation of Predicted Annual Energy Savings

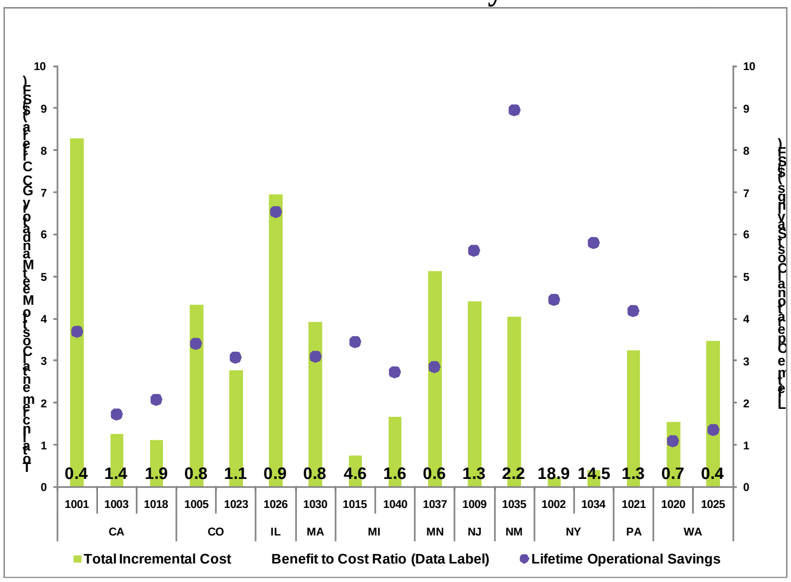


[1] R^2 is a measure, ranging from 0 to 1, of the relationship between one variables dependence on the other.

Predicted Cost-Effectiveness

Figure 4 shows the incremental cost to meet all mandatory Green Communities Criteria, the lifetime operational cost savings, and the benefit-to-cost ratio (BCR) for each development. BCR of 1.0 or better is sound investment as the benefits over the lifetime of the technology will pay for the first cost.

Figure 4. Comparison of Lifetime Operational Cost Savings and Incremental Cost to Meet All Mandatory Green Communities Criteria



The mean BCR for the 17 development subset was 3.14 with a standard deviation of 5.36 which cancels out the mean. However, if the three developments that had a BCR outside of two standard deviations of the mean, based on the 14 development subset, were eliminated, the BCR for this population drops to 1.10 and the standard deviation is reduced to 0.54 (Table 3). The BCR was also calculated based on only the incremental costs associated with meeting the energy and water criteria and the results shown for the 14 development subset in Table 3. On average, the savings proved to pay for the additional cost to meet the green criteria; however, the standard deviation was still too large to draw a definitive conclusion.

Comparing standard deviation as a percent of the mean for the incremental costs (Table 1) and operational savings (Table 3), it appears that there is more variation in the incremental costs, making it the bigger driving factor for the variation of the BCR. This is logical as the incremental costs to meet the criteria were self-reported and greatly affected by regional diversity of the development's location, whereas the energy and water cost savings were all produced with the same modeling software and procedures.

Table 3. Benefit-to-Cost Ratio (BCR)

	Lifetime Operational Savings	Std Dev of Lifetime Operational Savings	BCR (All Mandatory Criteria)	Std Dev of BCR-All	BCR (E & W Criteria)	Std Dev of BCR - E & W
Mean of 17 developments ($/SF)	$ 3.76	$ 2.03	3.14	5.25	5.36	8.79
Mean of 17 developments ($/unit)	$ 3,610	$ 2,070				
Mean of 14 developments ($/SF)	$ 3.59	$ 2.16	1.10	0.54	3.19	2.69
Mean of 14 developments ($/unit)	$ 3,490	$ 2,250				

Predicted to Measured Performance

Utility data were collected from all of the developments that were fully occupied. Of the 42 developments, 14 provided at least 12 contiguous energy utility bills for all meters in that development. The original intent was to compare the predicted cost savings to the measured cost savings for the 17 development population subset to attempt to validate the predicted cost-effectiveness shown in Table 3. However, only four of the 17-development subset had submitted energy utility bills in time for this study, and only two of this subset had submitted water bills. Therefore, a smaller subset of nine developments that submitted energy billing data and had a TREAT energy model with a local code baseline was used to demonstrate how measured energy performance was tracking to predicted energy performance.

Figure 5 shows monthly data from one of the developments and demonstrates why the savings were compared in source energy and why a goodness of fit measure was needed for determining if a building's performance was tracking to its prediction. In Figure 5, the first year electricity performance tracked well while the natural gas performance did not during the heating season. The goal was to determine if the development as a whole was tracking well to the prediction, on a cost basis. However, energy cost rates vary both seasonally and by location which makes a cost-based analysis difficult. Tracking savings by source energy allowed for the combining of multiple fuel types to a common unit, took energy generation into account, and is the method used in EPA's Portfolio Manager (EPA 2010). The source energy chart within Figure 5 gives feedback on how the development's measured performance is tracking to the prediction and allows for one goodness of fit metric to be used (e.g., net mean bias, coefficient of variance, etc).

The results in Figure 6 show that the first year energy performance of about half of the developments tracked well with the as-designed energy models, on an annual source energy basis, all normalized to average long-term weather, and for development size. The author did not investigate the differences between the predicted and measured performance as to whether they were due to the quality of implementation, incorrect assumptions in the energy models, or a combination of both. Therefore, the as-designed energy models were not calibrated to the utility bills, as specified under Option D (EVO 2006, 29).

Figure 5. Typical Model Predictions and Monthly Utility Reads

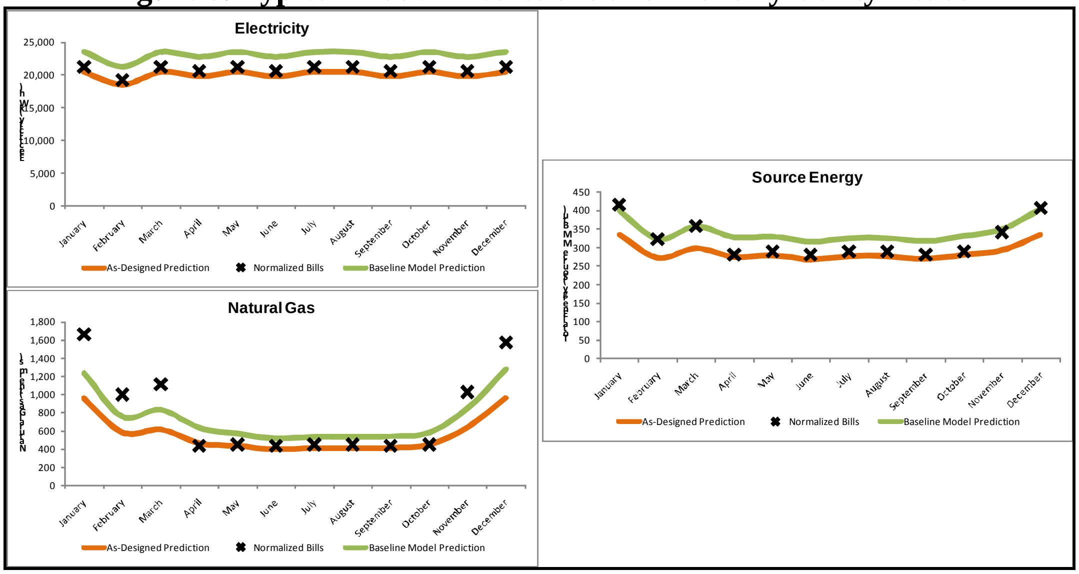
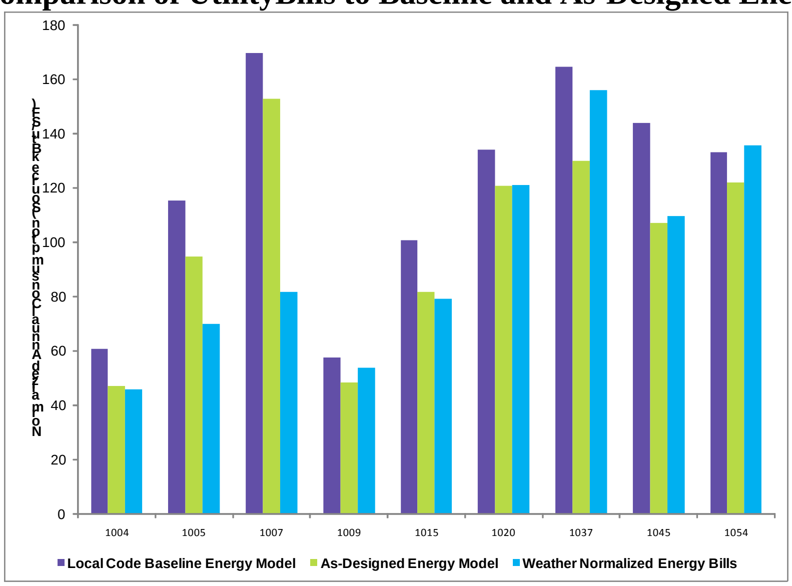


Figure 6. Comparison of UtilityBills to Baseline and As-Designed Energy Models



The comparison of performance was also put into terms of weather normalized savings as a percentage of source energy, shown in Table 4. Additionally, the CV(RMSE) is included in the table to give feedback on the goodness of fit between the monthly utility bills and the predicted monthly energy usage from the simulation.[2] For the savings to be valid and in compliance with whole building simulation guidelines, the CV(RMSE) must be no greater than 15% (ASHRAE 2002, 20). The measured savings tracked well to the predicted savings in only four developments. The others were less than the predictions and/or had a CV(RMSE) greater than 15%.

[2] CV(RMSE) is the coefficient of variation of the root mean squared error. It indicates the uncertainty of the modeled values to the actual values.

Table 4. Comparison of Predicted to Measured First Year Energy Savings

Development	Predicted Savings (Source Btu)	Measured Savings (Source Btu)	CV(RMSE) Model to Bills (Source Btu)
1004	22%	24%	13%
1005	18%	39%	41%
1007	10%	52%	99%
1009	16%	6.3%	14%
1015	19%	22%	6.4%
1020	10%	10%	22%
1037	21%	5.2%	17%
1045	25%	24%	12%
1054	8.3%	-2.1%	12%

Conclusions

The purpose of this study was to determine the cost-effectiveness of new construction affordable multifamily housing developments being built to the Green Communities Criteria. Of the 42 developments, a subset of 17 was selected for consistency of cost and savings data. This study found that the average incremental cost to meet all mandatory Green Communities Criteria was $3.15/SF, or a 1.4% increase to the total development cost.

The second part of this study looked at the predicted operational cost savings from achieving the mandatory energy and interior water criteria. The average modeled energy and water savings were 26% and 21%, respectively, compared to the modeled baseline. Furthermore, about 33% of the modeled energy savings, based on site Btu's, came from meeting the Energy Star appliance and efficient lighting criteria, while only 7% of energy savings came from surface insulation. This was a missed opportunity that could have brought more savings with long service life, and reduced HVAC equipment size and cost.

The average benefit-to-cost ratio was 1.10 for a 14 development subset of the 17. However, the 0.54 standard deviation drops this ratio below 1.0. Supporting this calculation, it was found that there was more variation in the incremental costs than there was in the modeled energy savings. The concluded reason was that the incremental costs were self reported and greatly affected by regional diversity of the development's location, whereas the energy and water cost savings were all produced with the same modeling software and procedures.

The energy savings of nine developments was tracked for one year post-construction. Of these, four developments had annual energy savings that tracked well to the predicted savings. For these four, the monthly utility reads compared with the monthly modeled predictions had a CV(RMSE) of less than 15%, which complies with whole building simulation measurement and verification guidelines (ASHRAE 2002, 20).

Recommendations

The calculation of new construction energy savings for the developments discussed in this paper should be completed following Option D of IPMVP Vol. III. This should include updating the prediction models with the third party field verification of as-built performance data as well as calibrating them to the post-construction utility data. These developments should continue to be tracked for both energy and water performance using the first year's utility data as the new baseline to compare future monthly data. This can provide the building owners and operators with valuable, low-cost feedback about their development's performance. Additionally, water utility data for these developments needs to collected and compared with the predictions. The outcome of these steps should help identify energy and water usage modeling assumptions that need to be adjusted for future developments and identify patterns around as-built performance that differs from the design.

Based on the evaluation of Green Communities developments, Enterprise has integrated relevant parts of the cost benefit survey tool into their green development plan template and certification workbook to encourage standardized benchmarking to measure and monitor improvements based on integrated design, construction, rehabilitation, operations and maintenance of green methods and materials. Understanding the costs and associated lifetime savings will inform decisions and help transfer knowledge across the affordable housing sector as data on the cost-effectiveness of green methods and materials becomes more widely shared.

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