Residential New Construction Baseline Study Best Practices: Lessons Learned from Long Island, New York

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ABSTRACT

The term “baseline study” might be translated in more-common parlance as “knowing your enemy” when strategizing how to promote energy efficiency improvements in residential new construction. ENERGY STAR® Labeled Homes programs, energy-efficiency organizations, utilities, and others increasingly require comprehensive residential new construction baseline data to identify current practices, efficiency opportunities, and evaluate program success. Baseline studies provide an important snap shot of the current building practices and serve as the standard to measure future market effects of ENERGY STAR homes programs. This paper presents an overview of the current best practices for residential new construction baseline studies. We present highlights from a baseline study completed in the fall of 2003 for the Long Island Power Authority (LIPA). A brief overview of the major study findings are presented along with a detailed presentation of the key results. With greater adherence to the suggested methodologies detailed in this paper, baseline study results and cross-baseline study comparisons will be improved.

Introduction

In 2004, the Long Island Power Authority (LIPA) launched the New York ENERGY STAR Labeled Homes (NYESLH) Program on Long Island, NY. In 2001 over 5,600 new homes[1] were built on Long Island, with a median sales price of approximately $250,000. Homes participating in the ENERGY STAR program are estimated to use approximately 20% less energy than comparable new buildings constructed to current Long Island baseline standards. Participants in the NYESLH program will reduce load growth on LIPA’s electric system, and reduce their annual energy bills. In addition, the program results in higher performing buildings that improve comfort and durability.

In preparation for the launch of LIPA’s NYESLH Program, 63 newly constructed single-family detached homes on Long Island, New York (Nassau and Suffolk counties) were visited in 2003 and comprehensively tested to gather sufficient information to characterize typical residential baseline new construction practices.[2] Based on building permit and U.S. Census data, we estimated Long Island residential building starts by location and house type and targeted our sample to proportionally match new building trends (Faesy et al. 2004).[3] Given survey

[1] 74% single-family detached, 4% two-family, 22% buildings of three-family and more units.
[2] Baseline study design, survey preparation, sample selection, and data analysis was completed by Vermont Energy Investment Corporation (VEIC) and Optimal Energy, Inc. (OEI). The in-field portion of the study was completed by certified Energy Raters from Conservation Services Group (CSG).
[3] The study also examined 11 single-family attached and two multi-family buildings, however, given the small sample sizes, this paper focuses exclusively on single-family detached homes.

participation was voluntary, self-selection bias was inevitable. However, it is unclear whether those with particularly inefficient or efficient homes were more likely to volunteer for the study. Homeowners of inefficient homes may have wanted to document problems for their builder, while those who built efficient homes may have wanted their achievements substantiated. Overall, we surveyed homes built by 41 different builders with no single builder exceeding five percent of the total survey sample. Only homes built and occupied after January 1, 2001 were included in the study.

The LIPA study was comprehensive in scope and addressed the following areas:

- Housing starts, transactions, pricing and other market-based information;
- House size, areas, R-values, air leakage and other energy-related characteristics;
- Heating, cooling and domestic hot water energy efficiency, consumption, and system types, sizing, and duct characteristics;
- Lighting and appliance characteristics;
- Home Energy Rating System (HERS) scores;
- Analysis of code compliance, cost to achieve ENERGY STAR and impacts based on adjusted SEER; and
- Occupant satisfaction.

For complete information about the study, please see the "Long Island Residential New Construction Baseline Technical Study" (Faesy et al. 2004). This paper will present an overview of the most important components of the study, with illustrative results of key baseline performance indicators.

Major Findings

Overall, the average single-family detached house was 2,696 square feet with an estimated annual energy consumption of 145.4 MMBtu/yr. As shown in Figure 1, space heating accounted for 69% of total energy consumption, followed by domestic hot water, 12%, lights and appliances, 12%, and space cooling, 7%.

Table 1 highlights the characteristics of the average single-family detached houses found on Long Island. Most of the overall home performance characteristics presented in Table 1 are detailed further in the full study (Faesy et al. 2004).

As shown in Table 2, participation in the ENERGY STAR homes program will on average save Long Island homeowner's approximately 21% or $400 per year in energy costs compared to the current baseline home.

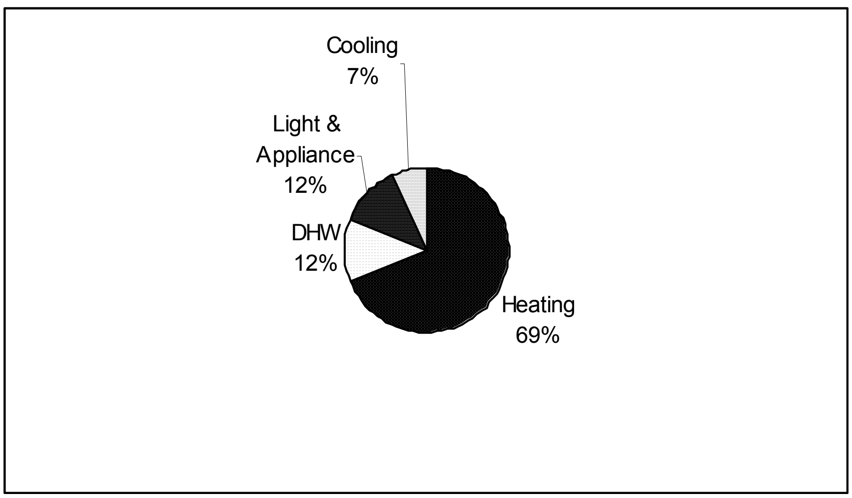
Key Study Components

Certain components of this baseline study are more revealing than others, either due to the comprehensiveness of the analysis or the surprising results. As such, given the limited space, we focus on those areas that we feel are most emblematic and noteworthy for a residential new construction baseline study. Each sub-section begins with an introduction and overview of the component analyzed, justification, relevance, and the results.

Adjusted Seasonal Energy Efficiency Rating (SEER)

Central air conditioners (CAC) on Long Island account for approximately $200 per year or 22% of total household energy costs (see Table 2). Given the significance of the CAC electrical costs to the homeowner and the coincidence of CAC operation with utility summer peak load, both homeowners and the electric utility benefit by increased equipment efficiency. CAC efficiency is rated according to a Seasonal Energy Efficiency Rating (SEER) test that is conducted in laboratory conditions. This factory "nameplate" efficiency is usually much higher then the actual in-field "adjusted" SEER rating as a result of three primary factors: 1) CAC equipment oversizing, 2) improper refrigerant charge levels, and 3) inadequate airflow levels over the cooling coil. The magnitude of the actual SEER efficiency reduction is directly influenced by the HVAC contractor's skill to properly size and commission the CAC unit. As such, efforts to work with the HVAC community to promote proper installation and sizing of systems, along with installation of ENERGY STAR qualified systems will yield significant kWh reductions.

Figure 1. Average Consumption in MMBtu by Major End Use Category



Cooling system oversizing has a number of energy, comfort, and first-cost impacts. Larger units have a greater kW impact. On Long Island, cooling coincides with system peak, so efforts to reduce peak demand generate sizeable financial savings for the utility. In addition, when CAC systems are oversized, the larger unit will cycle more often than a properly-sized unit, thereby increasing electrical consumption, household noise, and discomfort. Oversized CAC systems also do a poor job of dehumidifying the air, which impacts comfort and increases the potential for mold and mildew growth. Lastly, oversized CAC systems represent a lost opportunity to reduce the initial purchase costs of the equipment, tying up funds that could have been directed to other energy-saving measures in the house.

Table 1. Summary Average House Characteristics for Single-Family Detached

Feature	Units	Single-Family Detached
House Size	Square feet	2,696
Central Air Conditioning	% with CAC	81%
Space Heating Fuel		
Natural Gas	% present	62%
Fuel Oil	% present	35%
Propane	% present	3%
Domestic Hot Water Fuel		
Natural Gas	% present	60%
Fuel Oil	% present	36%
Propane	% present	2%
Electricity	% present	3%
Air Leakage		
Blower Door Tested	CFM-50	3,099
Natural Air Changes per Hour	Nat. ACH	0.56
Duct Leakage		
CFM-25	CFM-25 to outside	383
% of Total System Flow	% leakage to outside	30% (from 49 homes)
Windows		
Thermal Properties	U-Value	0.47
Shading Properties	SHGC	0.54
Glazing Percentage	% Window to Wall Ratio	17.7%
Walls	R-Value	13.8
Ceiling (Flat & Sloped)	R-Value	27.5
Distribution System		
Ducted	% present	59%
Hydronic	% present	41%
Heating Efficiency		
Furnaces	AFUE	83.4%
Boilers	AFUE	81.1%
Cooling Efficiency		
Unadjusted SEER	Rated SEER	10.3
Adjusted SEER	Adjusted SEER	7.0
Energy Rating		
Unadjusted HERS Score	Unadjusted	83.6 (63 homes)
Adjusted SEER HERS Score	Adjusted for charge, air-flow and CAC sizing	81.6 (28 homes)
Composite HERS Score	Based on Average Composite User-Defined Reference Home	82.5

Table 2. Long Island, NY ENERGY STAR Home Savings

End Use	Long Island ENERGY STAR Labeled Home	Long Island Conventional New Home	Annual Savings	Monthly Savings
Space Heating (Natural Gas)	$1,037	$1,185	$148	$12
Space Cooling (Electric)	$189	$392	$203	$17
Water Heating (Natural Gas)	$171	$198	$27	$3
Total Energy Costs	$1,397	$1,775		
Net Energy Savings			$378	$32
Lights and Appliances	$647	$623	$24	$2
Total Savings			$402	$34

Note: Estimates are based on projected energy consumption using REM/Rate software with March 2004 Long Island energy costs for a 2-story, 2,696 sq. ft. home with basement, central A/C, and gas furnace used for space heating, water heating, and LIPA electricity rates of approximately $0.13/kWh. Natural gas is estimated at $1.12 / therm. The ENERGY STAR Labeled Home is the same home upgraded to Program standards (86 HERS score, mechanical ventilation, and ENERGY STAR lights). Conventional new home is the composite baseline study home.

For this study we calculated the adjusted SEER rating for a sub-sample of 28 CAC systems in single-family detached homes.[4] Only 4% of the CAC units tested were ENERGY STAR qualified, all of which were installed as part of LIPA's COOL HOMES program. The adjusted SEER ratings reveal that the impact of improper installation of cooling equipment is significant. As Table 3 shows, there is an average 23% reduction in SEER, from 10.5 to 8.1 for the subset of units tested, when taking into account improper installation (i.e. charge and air flow).[5] CAC systems were found to be typically 1.7 tons (or 55%) oversized.[6] With the inclusion of improper sizing, the total average SEER reduction is 33%, to 7.0 SEER. We estimate the difference between the average rated SEER and adjusted SEER is approximately a 1,000 kWh increase in annual consumption. These test results underscore the efficiency penalty due to improperly sized and installed CAC systems.

Table 3. Adjusted SEER Summary Results

Unadjusted Rated SEER	Charge/Airflow Adjusted SEER	Overall Adjusted SEER (charge/airflow and oversizing	Overall % Reduction in SEER
10.5	8.1	7.0	-33%

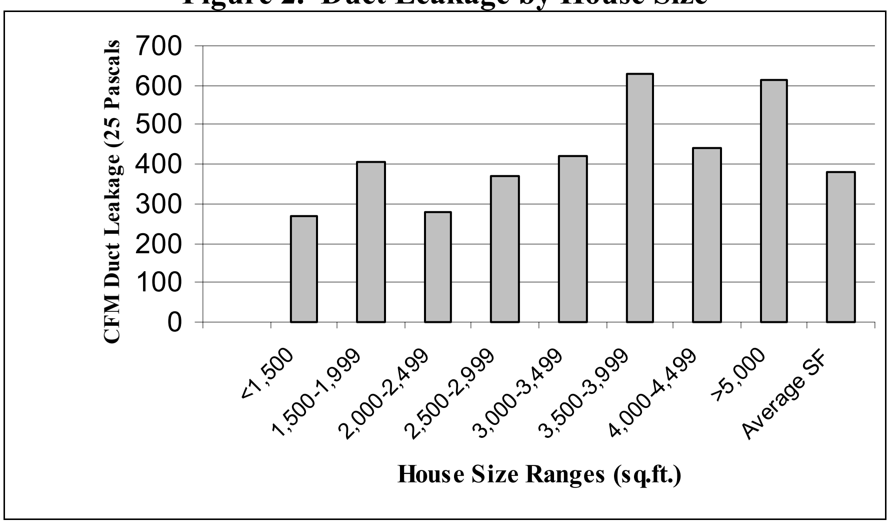
[4] This is a subset of the entire 63 home single-family detached survey. Therefore some of the findings (e.g. "rated SEER") will show numbers that are slightly different than the average value for the entire sample.
[5] Analysis of the HVAC systems was performed by the Proctor Engineering Group (PEG) using PEG's central air-conditioner charge and airflow CheckMe software and other analysis tools.
[6]CAC system sizing was determined through a Manual J cooling design load test using Right-Suite Residential J8 v. 5.8.41 software.

Duct and Air Leakage

Investments in space heating and cooling equipment efficiency are severely compromised if the ducted distribution system leaks warm or cool air to unintended locations such as crawlspaces, unconditioned basements, or attic areas. Additionally, if the whole house has serious air leakage problems due to improper air-sealing, then energy dollars are being spent to needlessly heat or cool the outdoors. To test the air-tightness of the ducts, a duct blaster was used on 25 homes to record the total duct leakage to the outside. The overall house air leakage to the outdoors was tested with a blower door for all 63 single-family detached homes in the study.

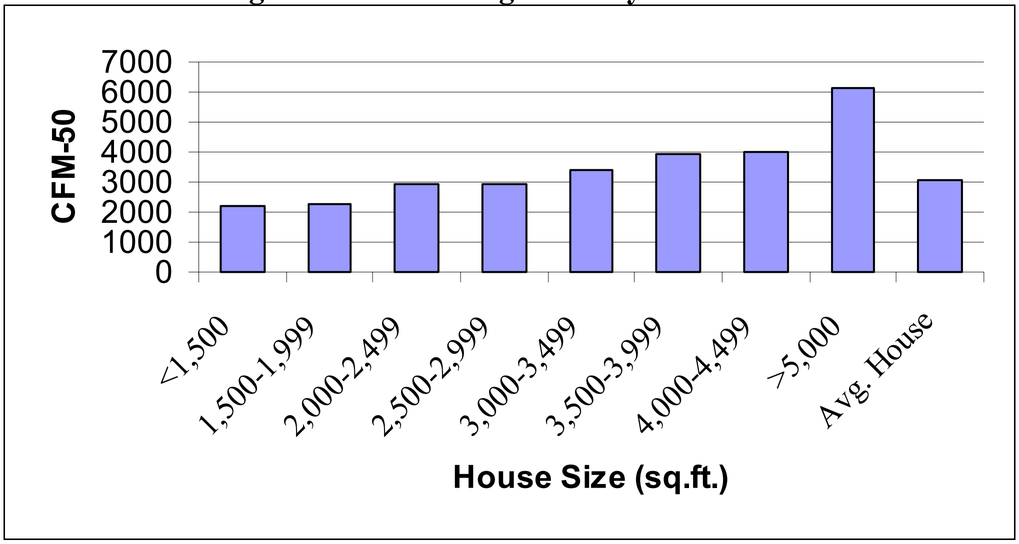
On average, ducts leaked 383 cubic feet per minute (CFM) at 25 Pascals of pressure to outside. This is equivalent to approximately 30% of all the conditioned air leaking to the outside. As a point of reference, typical industry standards focus on target duct leakage in the range of 6% of total system capacity. Homes in this baseline study have ducts that are approximately five times leakier than this standard. As shown in Figure 2, the larger the homes, the greater the duct leakage.

Figure 2. Duct Leakage by House Size



Additionally, the blower door test results further demonstrate that Long Island homes are not being built to industry air tightness standards. Homes had an average air leakage rate of 3,099 CFM at 50 Pascals pressure. As shown in Figure 3, as house size increased, so did the amount of air-leakage. Converting the air leakage rates at CFM-50 to natural air changes per hour (ACH) resulted in an average rate of 0.56 ACH. These air leakage rates are well in excess of the ASHRAE Ventilation Standard 62.2.

Figure 3. Air Leakage Rate by House Size



Home Energy Rating System (HERS)

Home energy rating system (HERS) ratings provide an easily understandable quantitative metric for builders and homeowners to gauge the overall energy efficiency of a home. For a home to receive an ENERGY STAR label, it needs to score at least 86 points (on a 0 to 100 scale). This level is set at 30% more efficient than the national standard energy code which would score at 80[7]. For each 5% savings relative to the 80-point, one point is earned. For this study we used REM/Rate, version 11.2 for the HERS analysis. This rating provided detailed results on the building design characteristics (e.g. R-values, U-values), mechanical system efficiencies (e.g. AFUE, E.F., SEER), and overall building performance comparisons (e.g. to ENERGY STAR and New York State energy codes). As described earlier, blower door and duct blaster tests were completed to determine house air leakage and duct leakage rates. In addition, we calculated the impact of the adjusted SEER scores on the overall HERS score and presented the results. Based on the field inspections, a composite average building was created, known as the "User-Defined Reference Home" that has the average characteristics of the sampled homes. The HERS score for this composite single family detached home serves as the initial baseline reference home for current and future program evaluation purposes.

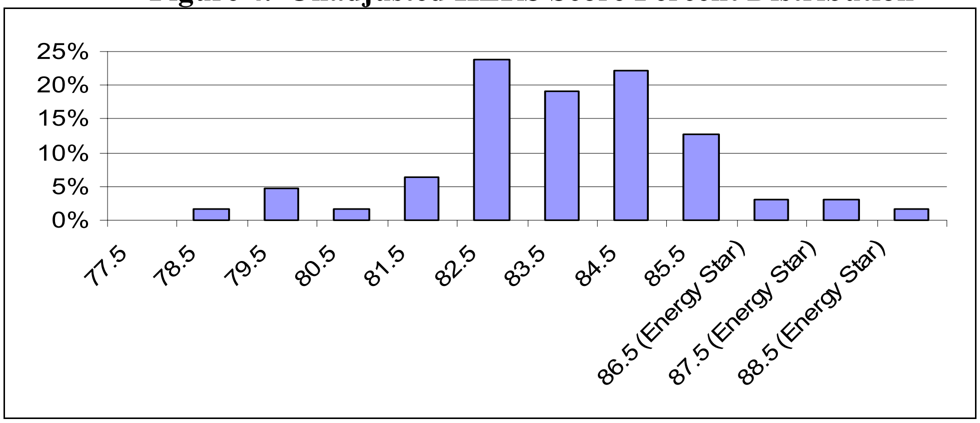
Although HERS ratings currently assume that all equipment is properly installed and provide full credit given that assumption, there are proposed changes to the national HERS standards (through the Residential Energy Services Network or RESNET) that will only allow full credit if equipment is tested and demonstrated to be properly installed. In anticipation of this new scoring in 2005, we ran the energy rating scores both under the current scenario assuming the equipment is properly installed ("unadjusted") and with the lower efficiencies using the "adjusted" SEER ratings (resulting in the "adjusted" HERS scores for the 28 homes that had the cooling systems tested).

The average HERS scores came in higher than expected given significant inefficiencies found in some system components. Overall, 8% of homes attained 86 points and qualified for

7We compared the Long Island home performance to the national baseline energy conservation standards of the 1993 CABO Model Energy Code (MEC).

ENERGY STAR status. The average unadjusted HERS score is 83.6, +/- 0.5 at a 95% confidence level. However, when taking into account the adjusted SEER ratings due to improper sizing, charge and air flow, the "adjusted" HERS score is 81.6, +/- 1.4 at a 95% confidence level. This represents a 2 point reduction in the average HERS score, or a 10% reduction in heating, cooling and hot water energy use; a sizeable amount when trying to reach the ENERGY STAR 86 point level. Figure 4 portrays the unadjusted HERS score distribution.

Figure 4. Unadjusted HERS Score Percent Distribution



Energy Code Comparison

Baseline studies provide valuable information, not only to determine what percent of homes meet ENERGY STAR standards, but the percent that comply with state building codes. Using Residential Energy Code (REScheck™) software, we found that the composite average home failed to meet the 2002 New York State Energy Conservation Construction Code. On average, homes failed code by approximately five percent. We also conducted an analysis of the 2001 International Energy Conservation Code (IECC 2001)[8] compliance for the composite single-family detached "User-Defined Reference Home" using REM/Rate software. Based on the composite home test results, over 75% of single-family detached homes in the study fail to meet the IECC 2001 code. These results show that the promotion of the New York ENERGY STAR Labeled Homes Program will should have a noticeable effect on code compliance as builders gradually change practices and incorporate improved building science methods, in both ENERGY STAR and non-ENERGY STAR homes.

Lighting and Appliances

As part of the study, we collected detailed information on the make and model of the major household appliances in each home. We also recorded the number of incandescent and fluorescent hard-wired fixtures in each room. On a positive note, there were quite a few ENERGY STAR appliances going into new homes. Much of this is likely due to the existing LIPA appliance program and its influence on builder and homeowner choices. As shown in Table 4, 46% of refrigerators, 28% of clothes washers, and 73% of dishwashers were ENERGY

[8] The 2002 New York Energy Conservation Code is based on the IECC 2001 with state-specific amendments.

STAR. Compared to the rest of New York and the nation, it is clear that the existing LIPA appliance program is positively impacting the market for ENERGY STAR appliances.

Table 4. Percent of Homes with ENERGY STAR Appliances

Appliance	Long Island, NY	New York State	All States
Refrigerator	46%	23%	20%
Clothes Washer	28%	18%	16%
Dishwasher	73%	34%	36%

Note: New York State and All States Averages from D&R International (2003).

Unfortunately, the positive trend with efficient appliances did not carry over to efficient lighting. Only 3% of all fixtures in the homes were fluorescent (pin-based) fixtures. This equals on average just one fluorescent fixture installed (out of an average 29 total fixtures per home). By way of comparison, Table 5 demonstrates the comparative presence of fluorescent lighting to other baseline studies; for example, in Vermont 14% of fixtures in new homes are fluorescent.

Table 5. Comparison of Fixture Type By Residential New Construction Study

Baseline Study	Fluorescent	Incandescent	Other	Fixture Sample
Vermont, 2002	14%	79%	7%	5,310
New Jersey, 1997 (PSE&G)	4%	96%	n/a	1,355
Long Island, NY 2003 (LIPA)(SFD)	3%	97%	n/a	1,404
Connecticut, 2002 (CLP & UI)	1%	99%	n/a	n/a

Least Cost ENERGY STAR Homes Upgrade Analysis

To encourage builders to meet ENERGY STAR standards, program administrators can help by providing guidance on those measures that will most cost-effectively yield the greatest energy savings. As such, the purpose of the least-cost upgrade analysis is to determine those combinations of measures that are most cost-effective to reach the designated ENERGY STAR home levels of 86, 88, and 90 points. The results of this study yield information that will assist planners with program design and setting of incentive levels that will move the market toward higher levels of ENERGY STAR residential new construction while not unduly depleting program budgets. In addition, the analysis demonstrates which measures are generally more cost-effective per HERS point gained.

The methodology used to conduct this least-cost analysis consists of several parts. Based on the overall average characteristics of the homes in the sample, a composite user-defined reference home (UDRH) was created in REM/Rate to represent the average characteristics of the typical single-family detached home on Long Island. Second, as previously discussed, the CAC SEER ratings (and correspondingly the HERS scores) were adjusted downward to reflect the actual performance of air-conditioning systems. Third, through an iterative process, efficiency upgrades to the entire house (building shell, mechanical equipment, etc.) were input into the REM/Rate model of the UDRH in ascending order of lowest-cost-per-HERS-points earned. Through this iterative process, the most cost-effective combination of measure upgrades to reach 86, 88, and 90 points were selected. The incremental costs for measure upgrades were based on existing information collected from an extensive survey of builders and wholesale retailers in New Jersey[9].

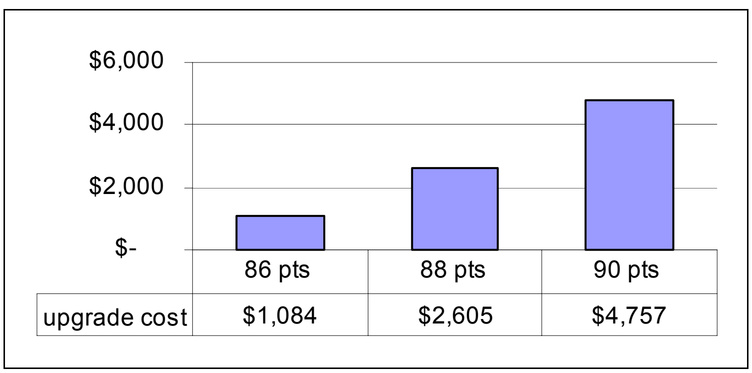
Consistent with the NYESLH program requirements, all least-cost modeling included mechanical ventilation systems. In addition, also modeled were measures that will be strongly encouraged by the NYESLH program, including six ENERGY STAR interior fixtures, programmable thermostats, and duct sealing. All equipment included as part of an upgrade was assumed to be properly installed (per program requirements) and achieved the full rating credit (e.g. SEER 13 equipment was modeled at SEER 13). Cost credit was given for right-sizing equipment and for the elimination of a chimney when installing a sidewall-venting high efficiency furnace.

In general, across the three house types (single-family detached, single-family attached and multifamily), the most cost-effective measures in terms of HERS points gained per measure type installed, not including the required components (discussed above), in order of cost-effectiveness were the following:

- Furnace upgrades to an AFUE of 90% and 92%;
- SEER 13 or higher central air-conditioner units.
- Water heater upgrades to an energy factor of 0.61, 0.64, and 0.84;;
- ENERGY STAR windows (U=0.39, SHGC=0.53 and U=0.37, SHGC=0.46); and
- Air sealing to 0.25 ACH and 0.35 ACH.

As Figure 5 demonstrates, the incremental cost to achieve 86, 88, and 90 points for the average new home in Long Island was $1,084, $2,605, and $4,757 respectively.

Figure 5. Single-Family Detached Least-Cost ENERGY STAR Upgrade Analysis Results



This least-cost analysis provides useful guidance for program planning. Because the LIPA new home baseline HERS score is relatively high already, the cost to reach ENERGY STAR at 86 points is relatively modest. In fact the current LIPA incentives of $1,270 are about in line, considering the estimated incremental cost to reach 86 points is $1,084. By design, the LIPA incentive structure does not cover the full incremental costs to build an ENERGY STAR home as the builder also incurs a HERS rating fee (approximately $400 to $500).

[9] Faesy et al. 2003. New Jersey ENERGY STAR Homes Program Incentives and Smart Growth Analysis. Prepared for New Jersey Utilities Collaborative.

If LIPA wishes to offer incentives to builders to achieve higher HERS scores in the future, this analysis provides some useful guidance about the approximate "least-cost path" to achieve 88 and 90 points.

Homeowner Survey

In addition to collecting data on the building characteristics, the raters asked homeowners general questions about the energy performance of their homes, overall satisfaction, and noted aspects of the home that were in need of energy improvements. The results were quite revealing. Long Island builders are not currently satisfying homeowners with respect to the energy performance of their homes. In one set of open-ended questions, 68% of homeowener's made comments critical of their builder's workmanship and the home energy performance. Further, in the recommendations section, raters named practically every component of the homes as needing attention and upgrading. Windows, ceiling and wall insulation, and duct and air leakage were frequently mentioned.

Conclusion

We estimate the costs for a comprehensive baseline study like the one presented in this paper to range from $200,000 to $300,000. The LIPA residential new construction baseline study clearly indicates that there are significant, cost-effective opportunities to improve the efficiency of residential new construction on Long Island. This is not unusual as virtually all residential new construction markets present opportunities for the promotion of cost-effective, market-transformation oriented, energy efficiency programs. Consistent with this general observation, the research findings presented here indicate that new homes built on Long Island in 2001 and 2002 on average perform relatively poorly. In fact, the average home examined in this study did not meet New York's energy code. On a positive note, the penetration of ENERGY STAR appliances is high.

Comprehensive baseline studies are valuable tools. Only through documentation of current building practices can efficiency programs target the most important areas for efficiency gains and evaluate market effects. We recommend incorporating the following key ingredients in future baseline studies:

- Housing starts, transactions, pricing and other market-based information;
- Careful house sample selection processes to minimize self-selection bias;
- House size, areas, R-values, leakage and other energy-related characteristics;
- Heating, cooling and domestic hot water fuel and system types, sizing, duct characteristics and consumption;
- Lighting and appliance characteristics;
- Home Energy Rating System (HERS) scores;
- Analysis of code compliance, cost to achieve ENERGY STAR and impacts based on adjusted SEER; and
- Occupant satisfaction.

By establishing an ENERGY STAR homes program, LIPA is taking a significant and positive step forward to improve overall home building practices in Long Island, NY and electric load reduction. We believe LIPA's promotion of ENERGY STAR homes and in-field program support will have an overall positive influence on building practices on the island, even for those builders who decide not to join the program. Thus, overtime a win-win situation will result in benefits to all homeowners through reduced energy bills, to the electric utility through reduced peak load consumption, and to builders through fewer home performance complaints.

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