An Assessment of Compliance with Energy-Efficient Construction Program Requirements in the Southeastern U.S.

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ABSTRACT ®

Advanced Energy recruited one hundred homeowners in three southeastern United States climate zones to participate in a three-part survey of their home. All the homes were built under one of two discontinued energy efficient residential construction programs used in the region over the past two decades.

The first objective was to evaluate whether each house met the requirements of the program under which it was built. The second objective was to perform a HERS rating on each house to evaluate whether it meets the EnergyStar™ benchmark score of 86. The final objective was to determine what upgrades would allow homes rated below 86 to become EnergyStar™ compliant while also addressing standards not mandated by EnergyStar™.

The home surveys and HERS ratings showed that only four homes comply with their original program requirements, but twenty-eight homes exceed the EnergyStar™ benchmark. Homes are clearly not performing as intended, highlighting the need for repair as well as strategies to ensure that ongoing programs do not repeat the failures of the past.

Background and Introduction

Previous Advanced Energy research (Katz 1997) found that homes built in 1994 under energy-efficient residential construction programs in the southeastern U.S. fell short of building performance goals and did not significantly outperform non-program homes. This survey included only program-built homes, but examined a broader set built from 1980 to 2002 and included homes built under a second program not included in the 1994 project. Others have found similar failure to meet program criteria across the country (Hoeschele, Chitwood and Pennington 2002) but we have not researched the national scope of this problem.

The purpose of this survey was to assess the status of the homes relative to their intended design requirements and performance, and then to benchmark them using the Home Energy Rating System (HERS) to assess EnergyStar™ compliance. The requirements for homes in the two programs we evaluated were prescriptive with the exception that the more recent program required certification testing of house and duct leakage on one house per year. For homes that did not meet the EnergyStar™ requirement of a HERS rating of 86 or more, we simulated improvements that would achieve compliance. This report describes our methods for sampling and surveying the homes, assessing compliance with specific requirements of each construction program, and analyzing EnergyStar compliance and upgrades. It also includes simple analysis of house- and duct leakage for homes grouped by program.

This survey did not seek to identify the reasons for the non-compliance with program requirements that we found. This would be a critical next step in the process of identifying whether ongoing energy efficient construction programs require operational changes to ensure their success.

Methods

Survey Population and Sample Design

Homes eligible for the survey were built under one of two new-construction energy efficient home programs, generically referred to as Programs A and B. Homes in each program are distributed across heating-dominated, balanced, and cooling-dominated climates in the southeastern U.S.

Of all homes built under the programs, a sub-set population of 34,120 was used to recruit homes into the survey. The percentages of residences in each region and each program type are listed in Table 1 for the population and the survey sample.

Table 1. Population and Survey Home Distributions by Program and Region

	Population Distribution (34,120 Homes)			**Surveyed Homes Distribution** (100 Homes)		
	Program A (%)	Program B (%)	Total (%)	Program A (%)	Program B (%)	Total (%)
Cooling	25.4	7.5	32.9	26	8	34
Heating	5.5	2.1	7.6	7	2	9
Balanced	46.3	13.2	59.5	45	12	57
Total	77.2	22.8	100	78	22	100

Dates of construction for the seventy-eight homes in Program A ranged from 1980 to 1999 and the median-aged house was built in 1993. Dates of construction for the twenty-two homes in Program B ranged from 1999 to 2002. House sizes ranged from 1330 ft2 to 4630 ft2, with a mean of 2220 ft2 and a median of 2170 ft2.

Survey Procedures

Each survey required the completion of field forms and a REMRate™ version 11.11 building file to generate a HERS rating. REMRate™ is a product of Architectural Energy Corp., Boulder, CO. Surveyors used field forms to record the characteristics of each home's heating, ventilation, and air-conditioning (HVAC) equipment, water heater, ductwork, envelope (including insulation, doors, windows, and foundation), and relevant appliances. Surveyors photographed elevations and recorded a scale drawing of the building including a window schedule and sketches of details such as sloped ceilings and dormer windows.

Surveyors performed a single-point blower door test, a single-point duct blaster test and measured bathroom exhaust fan airflows. We used Minneapolis Blower Doors, Minneapolis Duct Blasters, Exhaust Fan Flow Meters, and digital manometers from the Energy Conservatory, Minneapolis, MN, for all performance measurements. During the survey, we noted any items in need of repair (for example, a plumbing leak or standing water in a crawlspace) on field forms and immediately reported them to the homeowner.

Applying the HERS Rating Methodology to Existing Homes

HERS Ratings for the survey homes were developed in a manner consistent with the way Advanced Energy calculates HERS ratings for new homes. Most REMRate™ input variables are spelled out in documented HERS standards (RESNET 2003), but some require judgment by the surveyor. This section explains how certain "judgment calls" were handled for the survey homes.

When rating a new home, it is typically not known what, if any, vegetation may shade the building, so none is assumed. Shading is only credited for fixed elements of the building, like porch roofs or overhangs. Surveyors applied this rule to the surveyed homes.

The U-value and solar heat gain coefficient (SHGC) of windows are parameters that might require judgment. Many new windows come with U-value and SHGC ratings based on a nationally recognized rating procedure, but it is impractical, if not impossible, to determine these values for unrated windows in existing homes. The survey recorded frame type and number of glazing layers in the windows in each home, as well as whether the glass had a low-e coating. We determined the presence of a low-e coating using an E-Tekt+ Low-E Coating Detector, manufactured by EDTM, Inc., Toledo, OH. Then we selected the default values for U-value and SHGC in REMRate™ for the corresponding window type, number of glazing layers, and low-e status.

Ceiling and floor insulation R-values were de-rated from their nominal values if there was missing insulation or an obvious deficiency in installation, like consistent compression of floor insulation or insufficient depth of blown attic insulation. Wall insulation levels were not assessed during the field survey and were modeled at their nominal code-required values.

We determined mechanical system efficiencies by recording the manufacturer and model numbers of all equipment, and then used that information to look up the system efficiency rating as reported by the Air-Conditioning and Refrigeration Institute (ARI), which maintains an online database of ratings at www.ari.org. If the ARI database did not contain information on the equipment in question, we contacted the manufacturer directly. If the manufacturer could not provide the information or it was not possible to record the model number of the equipment, we searched the Preston's Guide, a CD-ROM database of system efficiencies available at www.prestonguide.com. As a last resort, if none of the above methods discovered the system efficiency then a default value was assigned based on the building code in effect the year the home was built or the equipment was installed.

We made an optimistic assumption by modeling the homes with nominal-rated mechanical system efficiencies because that assumes correct refrigerant charge and airflow. Advanced Energy field tests in 1994 identified that only three out of twenty-two newly-installed mechanical systems measured had correct refrigerant charge (Katz 1997). We did not measure refrigerant charge or airflow in this survey.

Twenty-nine homes had unvented gas fireplaces. These appliances were not modeled in REMRate™ as part of the homes' heating systems.

Methods of Assessing Program Requirements

Program A used a variety of prescriptive compliance measures, including standards for insulation, windows, and mechanical system types and efficiencies. Program B used many of the same prescriptive compliance measures along with minimum standards for duct and envelope tightness. Program B required that all combustion appliances be vented to outside, and required certification testing of house and duct leakage on one house per builder per year.

We did not assess all program requirements in the survey, and the method of assessment varies for different requirements. Appendix A contains a complete listing of the requirements for both programs with the method of assessment for each requirement.

Analysis and Findings

Program Compliance Analysis

Program A compliance. Only four of the 78 Program A homes met the program requirements, even when the requirements for door type and water heaters were ignored. Two more homes (six total) complied when the glazing ratio requirement was ignored. One more home (seven total) complied when the floor insulation requirement was ignored. Table 2 summarizes the percentage of homes that complied with each of the listed requirements:

Table 2. Compliance with Individual Requirements of Program A (78 Homes)

Requirement	Compliance	Homes
Window types	100%	78
Heat pump supplies ≥ 60% of load	91%	71
Electric water heater ≥ 40 gal	88%	69
Ceiling insulation with tradeoff	86%	67
Flat ceiling insulation ≥ R-30	79%	62
Glazing-to-floor ratio ≤ 15%	67%	52
Cooling efficiency ≥ SEER 11	51%	40
Door types	41%	32
Mastic used to seal ductwork	10%	8

Program B compliance. None of the twenty-two program B homes met the program requirements, even when the requirements for window type, door type, glazing ratio, floor insulation, and water heaters were ignored. Table 3 summarizes the percentage of homes that complied with each of the listed requirements:

Table 3. Compliance with Individual Requirements of Program B (22 Homes)

Requirement	Compliance	Homes
Window types	100%	22
Ceiling insulation with tradeoff	95%	21
Has an electric water heater ≥ 40 gal	95%	21
Heat pump supplies ≥ 80% of load	95%	21
Flat ceiling insulation ≥ R-30	86%	19
Glazing-to-floor ratio ≤ 15%	86%	19
House infiltration ≤ 0.40	82%	18
Cooling efficiency ≥ SEER 11	73%	16
Door types	68%	15
No unvented combustion appliances*	59%	13
Mastic used to seal ductwork	27%	6
Duct leakage ≤ 5% of floor area	5%	1

* The owners of the nine Program B homes that have unvented gas heaters were contacted to verify that the unvented heater was in fact original to the home. All but one responded "yes;" the ninth declined to answer the question.

EnergyStar™ compliance. Twenty-eight of the one hundred homes met the EnergyStar™ benchmark score of 86. The HERS ratings ranged from 76.2 to 88.7 with a mean of 84.5.

Thirteen of the seventy-eight (17%) Program A homes meet the EnergyStar™ benchmark. The HERS ratings of the seventy-eight homes ranged from 76.2 to 88.5 with a mean of 84.1.

Fifteen of the twenty-two (68%) Program B homes met the EnergyStar™ benchmark. The HERS ratings of the twenty-two homes ranged from 83 to 88.7 with a mean of 86.2.

Of the twenty-nine homes reported to have unvented gas fireplaces, nine meet the EnergyStar™ benchmark (four Program A homes and five Program B homes.)

Performance Testing

Duct leakage. We measured duct leakage in cubic feet per minute (CFM) at a pressure of negative 25 Pascals in the duct with reference to outside pressure (CFM_{25}). We calculated a duct leakage ratio by dividing the duct leakage by area of conditioned space in the home. Two Program A homes had damaged ductwork that could not be measured. We specified "Observable leakage pathways" as the REMRate™ input to generate the HERS rating, and excluded these homes from the calculations for Table 4 and Figures 1 and 2. Table 4 shows average duct leakage ratios by region and program:

Table 4. Average Duct Leakage Ratios By Region And Program

Region	Avg. Ratio	Construction Program	Avg. Ratio
Cooling (34)	10.8%	Program A (78)	15.6%
Balanced (57)	16.8%	Program B[1] (22)	11.0%
Heating (9)	15.2%	All Homes (100)	14.6%

[1] The performance requirement for duct leakage in program B homes was 5%.

The distributions of duct leakage ratios by program are illustrated in Figures 1 and 2. The number under each bar represents the upper limit of the ratio, e.g. the bar labeled "0.10" represents the number of homes that have a duct leakage ratio between 0.05 and 0.10. Notably, only one Program B home out of the twenty-two surveyed met the 5% duct leakage requirement.

Figure 1. Duct Leakage Distribution for Program A Homes (N = 76)

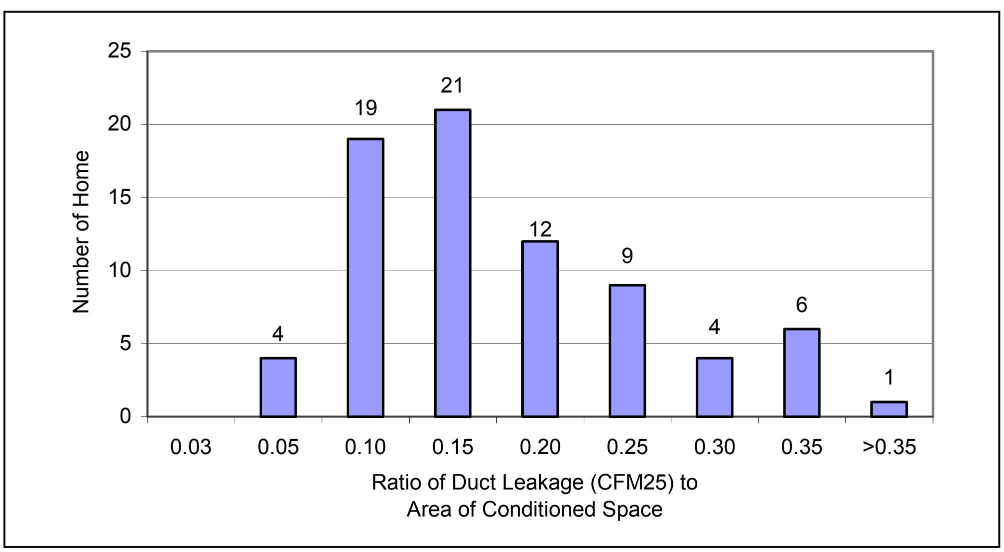
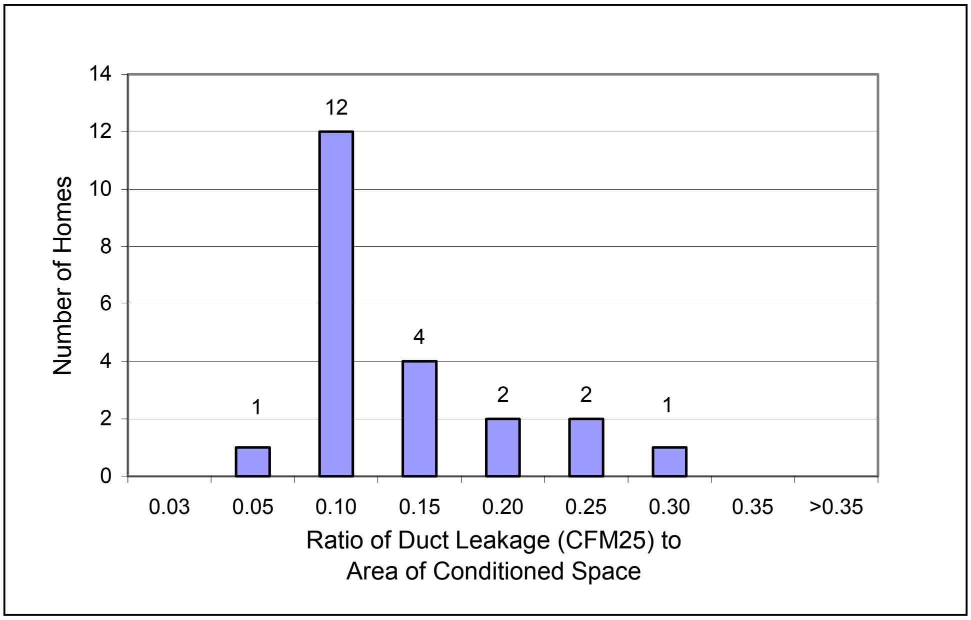


Figure 2. Duct Leakage Distribution for Program B Homes (N = 22)



House leakage. We measured house leakage in CFM at a pressure of negative 50 Pascals in the house with reference to outside pressure (CFM_{50}). We calculated a leakage ratio for each home by dividing CFM_{50} by the envelope area of the house. Table 5 shows the average house leakage ratios by region and program:

Table 5. Average House Leakage Ratios by Region and Program

Region (N)	Avg. Ratio	Construction Program	Avg. Ratio
Cooling (34)	0.31	Program A (78)	0.40
Balanced (57)	0.43	Program B[1] (22)	0.30
Heating (9)	0.40	All Homes (100)	0.38

[1] The performance requirement for house leakage in Program B was 0.40.

The distributions of the house leakage ratios by construction program are illustrated in Figures 3 and 4. The number under each bar represents the upper limit of the ratio, e.g. the bar labeled “0.35” represents the number of homes that have a ratio between 0.25 and 0.35.

Although this sample may be too small to draw the conclusion, the house and duct leakage data appear to indicate an improvement over time. The mean duct leakage is 15.6 % for Program A homes and 11.0% for Program B homes. The mean house tightness ratio for Program A homes in this survey is 0.40 CFM50 per ft^2 envelope area, which improves to 0.30 for Program B homes.

Figure 3. House Leakage Distribution for Program A Homes (N = 78)

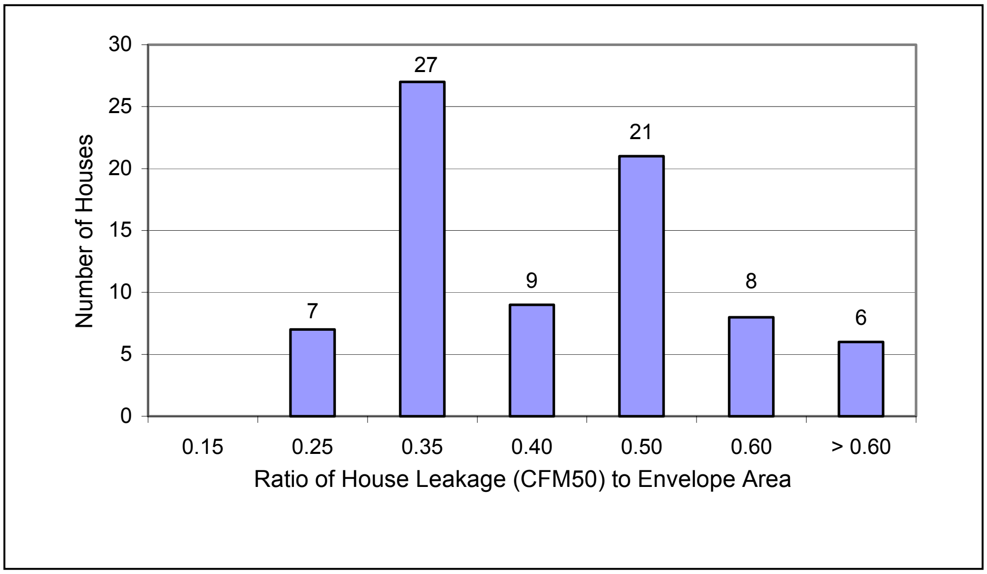
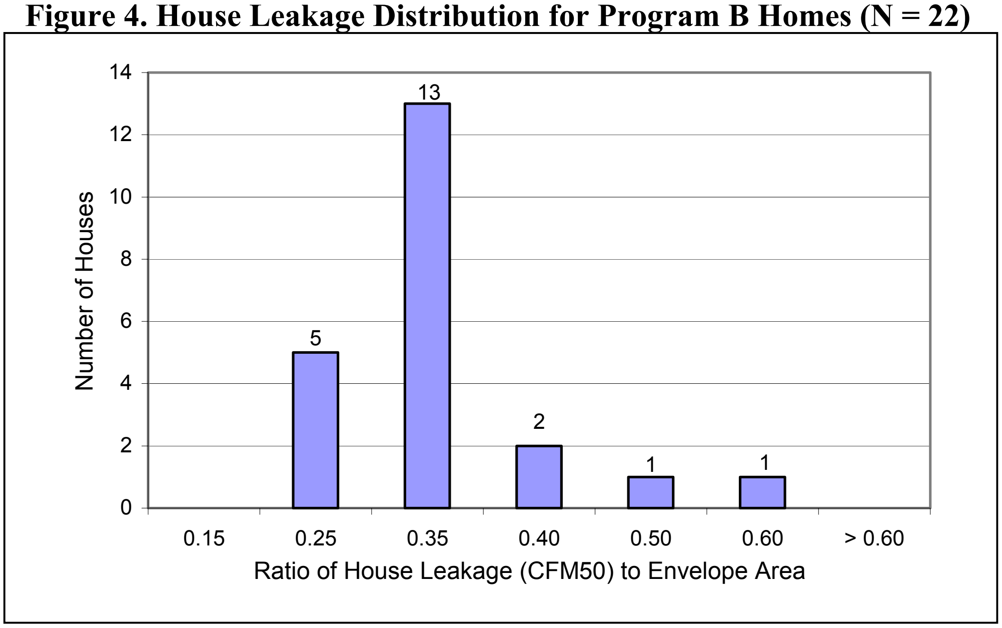


Figure 4. House Leakage Distribution for Program B Homes (N = 22)



Upgrade Analysis

We re-modeled the seventy-two homes with HERS ratings below 86 to identify upgrades that would bring each home to the 86 threshold.

We set the duct leakage improvement target to 100 CFM25 per duct system in each home (Tooley 1993). Duct systems were located in vented crawlspaces, attics, or basements, used metal boots, and included inline cooling coils. The target includes a 25 CFM_{25} allowance for the presence of the cooling coil in the air handler and the likelihood that some penetrations in the air handler will not be possible to seal.

We set the house leakage improvement goal to 0.35 times the envelope area of the house. This ratio is a current standard for new construction programs administered by Advanced Energy and we don't regard it as a difficult performance target to meet. The majority of program B homes and a significant portion of the program A homes already comply with this target as illustrated in Figures 3 and 4.

Fresh air ventilation decreases a HERS rating because it requires additional heating and cooling energy to condition the incoming air. However, Advanced Energy requires ventilation in its construction programs, so we modeled a ventilation flow according to the formula for the Environments for Living program (MCS 2003), in which Advanced Energy is a partner:

$$\text{Ventilation flow} = 7.5\ \text{CFM} \times (\text{Number of bedrooms} + 1) + 0.01\ \text{CFM} \times \text{Conditioned Area (ft}^2\text{)}$$

As a result, we specified building upgrades that allowed the inclusion of fresh air ventilation by ensuring compliance with EnergyStar™ even when the ventilation was added.

In general, we did not improve insulation as an upgrade measure except for homes that had a known insulation deficiency (e.g. attic insulation missing or having a nominal value less than R-30). In such cases, we upgraded the flat attic insulation R-value to R-30. We upgraded basement wall insulation in two homes that had uninsulated basement foundations.

If the home did not reach a rating of 86 with the duct leakage, house leakage, and ventilation upgrades, then we upgraded the mechanical systems. We set the following caps for equipment efficiency upgrades based on the most efficient technologies widely available:

- Heat pumps up to 14 SEER and 8.5 HSPF
- Furnaces up to 0.90 AFUE
- Air conditioners up to 14 SEER
- Electric water heaters up to 0.92 EF
- Gas water heaters up to 0.62 EF

Water heaters generally achieve small (0.2-0.3 point) improvements in HERS ratings and we applied them as a more cost-effective improvement than upgraded heating and cooling equipment in homes that were already close to the 86 rating. We upgraded heating and cooling equipment in homes with larger HERS deficiencies and in some cases achieved EnergyStar compliance without also upgrading the water heater.

If the building did not reach a rating of 86 with envelope and mechanical system upgrades, we upgraded windows either by conversion to a low-e window on east, west, and north exposures, or by applying shading to the southern exposure sufficient to block heat gain in the summer, yet allow heat gain in the winter.

We did not use radiant barriers as upgrades due to the small savings modeled by REMRate™ for this measure. We also did not use programmable thermostats as an upgrade due to recent studies indicating that replacing a manual thermostat with a programmable thermostat does not correlate with energy savings because savings are primarily dependent on occupant behavior, not thermostat type. (Connor & Lucas 2000; Nevius & Pigg 2000)

Table 6 summarizes the groups of upgrades used to achieve EnergyStar™ compliance and how many homes come into compliance using each group of upgrades.

Table 6. EnergyStar™ Upgrades with Count of Homes (N = 72 Homes)

Upgrades Needed to Achieve EnergyStar™ Compliance	Homes
Reduce duct leakage	4
Reduce duct and house leakage	7
Add window shading and reduce duct and house leakage[1]	1
Upgrade domestic water heater (DWH) alone	1
Upgrade DWH, insulation, and house and duct leakage	5
Upgrade HVAC equipment alone	1
Upgrade HVAC, plus duct and/or house leakage	30
Upgrade HVAC and insulation, plus duct and/or house leakage	4
Upgrade HVAC and DWH, plus duct and/or house leakage	15
Upgrade HVAC, DWH, insulation, duct and house leakage	2
Upgrade HVAC, DWH, duct leakage, and windows to low-e	2

[1] This house already had high-efficiency mechanical equipment, and upgrading the DWH was not sufficient to meet EnergyStar™.

Conclusions and Future Research

Surprisingly, while only 5% of the Program A homes and none of the Program B homes met the standards of their original program, 28% of the homes met the EnergyStar™ benchmark as they stand. Another 11% can be brought into compliance with EnergyStar™ by improving duct and shell leakage, without upgrading any mechanical equipment. Approximately 60% of homes would require major expenditure to achieve the EnergyStar™ benchmark.

The lack of compliance with program criteria makes it clear that new home construction programs require integrated quality assurance systems and processes to achieve their objectives. Identifying the causes of the non-compliance we found and eliminating any that continue to exist is certainly a part of the process to ensure the success of ongoing and future programs.

The 1994 Advanced Energy survey (Katz 1997) highlighted deficiencies in refrigerant charging and sizing of mechanical systems, which we did not evaluate in this survey. Quality assurance for mechanical system installations should be included in programs to ensure that the energy savings projected by the HERS modeling software will be achieved in the field.

This survey could also provide a lead-in to research on designing programs for improving existing homes and measuring the results. Developing retrofit upgrade strategies would require market research on what types of upgrades are most acceptable to homeowners, what contractors would charge to implement the repairs, and what the homeowners would be willing to pay for, or finance, based on projected cost savings or other perceived benefit. If the owners of homes in this survey would continue participation into a retrofit phase, contractors could provide estimated and actual costs to install the upgrades that have already been proposed. We could precisely evaluate actual energy savings due to upgrades if the study sub-meters the heating, cooling, and water heating energy consumption for a year while estimates and market data are generated, and then compares the sub-metered usage both pre- and post-upgrade. This very precise data could also be used to assess the accuracy of the cost savings projected by the HERS software in our region.

One thing is certain: we must develop thorough, effective processes to ensure that new home construction programs or retrofit programs deliver the energy savings and performance enhancements they promise.

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Appendix A

Table A.1 Requirements Shared by Programs A and B

Program Requirement	Description of Assessment
An electric heat pump shall be the primary source for both heating and cooling and is required to have a minimum SEER level of 11.	Pass/Fail assessment based on value(s) recorded for REMRate analysis file.
The HVAC air distribution system must be sealed with a permanent finish sealer such as mastic.	Pass/Fail assessment based on field survey observation. Mastic must be present on the majority of visible duct system connections to earn a "Pass" rating. Mastic sealing the inner liner of flexible duct to connections was judged acceptable even if the outer jacket was not sealed with mastic.
Ceilings will have an installed insulation thermal resistance value of R-30.	Pass/Fail assessment based on observed nominal value and deficiencies noted. A lower R-value may pass if other systems sufficiently exceed their minimum requirements.
Floors over crawlspaces will have an installed insulation thermal resistance value of R-19.	Pass/Fail assessment based on observed nominal value and deficiencies noted.
Exterior walls will have a total insulation value of R-16.	Closed cavity R-value is not assessed. Assessable knee walls are subject to Pass/Fail assessment based on observed nominal value and deficiencies noted.
All windows will be insulated double-pane glass or single-pane glass with storm windows.	Pass/Fail assessment based on the predominant window type recorded on the field form.
The area of all windows and glass area of exterior doors will not exceed 15% of the heated floor area.	Pass/Fail assessment. The glazing ratio is calculated by dividing the sum of all glass areas by the conditioned floor area as recorded in the REMRate analysis file.
All exterior doors will be insulated metal doors or wood with storm doors. Program B homes may also utilize fiberglass doors.	Pass/Fail assessment is recorded based on field form entries.
The home must have an electric water heater with a minimum capacity of 40 gallons.	Pass/Fail assessment based on field form entries.
Floors built on concrete slabs will have an installed perimeter insulation thermal resistance value of R-5.	Not assessed.
The water heater must have a minimum insulation value of R-12 installed.	Not assessed.
Construction techniques will be used that provide a continuous vapor retarder on exterior walls and around doors and windows.	Not assessed.

Table A.2 Additional Requirements for Homes in Program A

Program Requirement	Description of Assessment
An electric heat pump shall provide 60% or greater of the heating and cooling BTUh's for the structure.	Pass/Fail assessment. The percent of heating and cooling load for homes with mixed-fuel space conditioning will be prorated for each piece of equipment based on the percent of conditioned area served by each unit.
Adequate natural or mechanical attic ventilation will be provided	Not assessed for compliance. However, owners of structures with powered attic ventilators will receive a recommendation to discontinue their use.

Table A.3 Additional Requirements for Homes in Program B

Program Requirement	Description of Assessment
Air infiltration through the home's envelope must be less than 0.40 CFM50 per exposed square foot of the home.	Pass/Fail assessment. The house leakage ratio is calculated by dividing the house leakage determined during the field survey by the sum of areas representing foundation floor, cantilevered conditioned floor, exterior wall, knee wall and attic ceiling as recorded in the REMRate analysis file.
A heat pump must serve 80% or greater of the heating and cooling BTUh's for the structure.	Pass/Fail assessment. The percent of heating and cooling load for homes with mixed-fuel space conditioning will be prorated for each piece of equipment based on the percent of conditioned area served by each unit.
Duct leakage [CFM_{25}] must be less than 5% of the conditioned floor area.	Pass/Fail assessment. The duct leakage ratio is calculated by dividing the total duct leakage determined during the field survey by the conditioned floor area recorded in the REMRate analysis file.
Any combustible fuel appliances in the home should be vented to the exterior.	Pass/Fail assessment based on whether the structure has an original-equipment unvented gas or kerosene space heater, or a gas stove with a kitchen exhaust not vented to the exterior.
All insulation should be installed to allow the material to achieve its stated maximum R-value. Material should be installed absent of voids, gaps, compression and wind intrusion, and there should be no misalignment of the insulation and the air barrier.	Deficiencies are noted and used to pro-rate the R-values modeled in the REMRate analysis. Significant deficiencies result in a "Fail" assessment of the affected insulation.