FLORIDA SOLAR ENERGY CENTER®

CONTRACT REPORT

Comparing Apples, Oranges and Grapefruit:

An Analysis of Current Building Energy Analysis Standards for Building America, Home Energy Ratings and the 2006 International Energy Conservation Code

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ABSTRACT

The purpose of this work is to determine the relationship between the U.S. Department of Energy's *Building America* (BA) Benchmarking Analysis methods and the energy-efficiency analysis methods used by the International Energy Conservation Code (IECC) and the Residential Energy Services Network (RESNET) and the Home Energy Rating Systems (HERS) industry for similar purposes. Analysis for three different home sizes conducted in seven different climate zones revealed no correlation between the analysis methods. Pros and cons are presented for different policy options for maintaining or changing the BA benchmark.

EXECUTIVE SUMMARY

The overall purpose of the work presented in this report is to determine the relationship, if any, between the U.S. Department of Energy's *Building America* (BA) Benchmarking Analysis methods and the energy-efficiency analysis methods used by the International Energy Conservation Code (IECC) and the Residential Energy Services Network (RESNET) and the Home Energy Rating Systems (HERS) industry for similar purposes. The IECC allows code compliance through a performance-based comparative analysis method and the HERS industry uses very similar standards and methods to determine a relative measure of energy-efficiency performance called the HERS Index.

The simple goal of the work is to be able to say with certainty that a whole-building HERS Index of 'x' corresponds to a BA whole-building % savings of 'y.' Similarly, the goal is to be able to also say with certainty that this BA % savings of 'y' corresponds to a savings of 'z' with respect to the IECC minimum code standard.

The study is accomplished using homes of three different sizes (intended to represent 'typical' small, medium and large home plan options), on three different foundation types (slab-on-grade, vented crawlspace and conditioned basement), using both 1-story and 2-story models, in all 7 of the contiguous U.S. climate zones identified by the 2006 IECC.

The analysis is conducted using version 2.5, release 9 of EnergyGauge® USA, RESNET accredited software, produced and marketed by the Florida Solar Energy Center, for Home Energy Ratings, IECC performance-based code compliance and federal tax credit qualification. The basis for the analysis was the *Building America* Benchmarking Analysis procedures and all home cases were evaluated in accordance with the methods of this procedure for the purposes of creating an apples-to-apples comparison.

The results of the analysis are informative, showing not only the differences between the 3 methods of comparing the energy-efficiency performance of buildings, but also the origins of these differences and their impact on the primary goal of the analysis.

Every effort is made to accomplish the analysis using a consistent set of "rules" for all three methods, one that results in the ability to state with certainty that on an apples-to-apples basis, system A corresponds to system B in the following way. However, as the title of the report suggests, this goal is not achieved. The analysis results and findings do not support any consistent correlation between the *Building America* Benchmarking Analysis procedure and the HERS or IECC analysis procedures. The analysis does show a reasonably consistent relationship between HERS and IECC but the relationship ends at that point. Hence, the title of the report, indicating that while two of the analysis methods are, in fact, citrus fruits, the other is not.

Perhaps the most illustrative example of this finding – the inability to relate one system to another – comes from the analysis of *Building America* prototype homes that are 30% more energy efficient than the *Building America* Benchmark home standard, as evaluated against the alternative standards examined in this study.

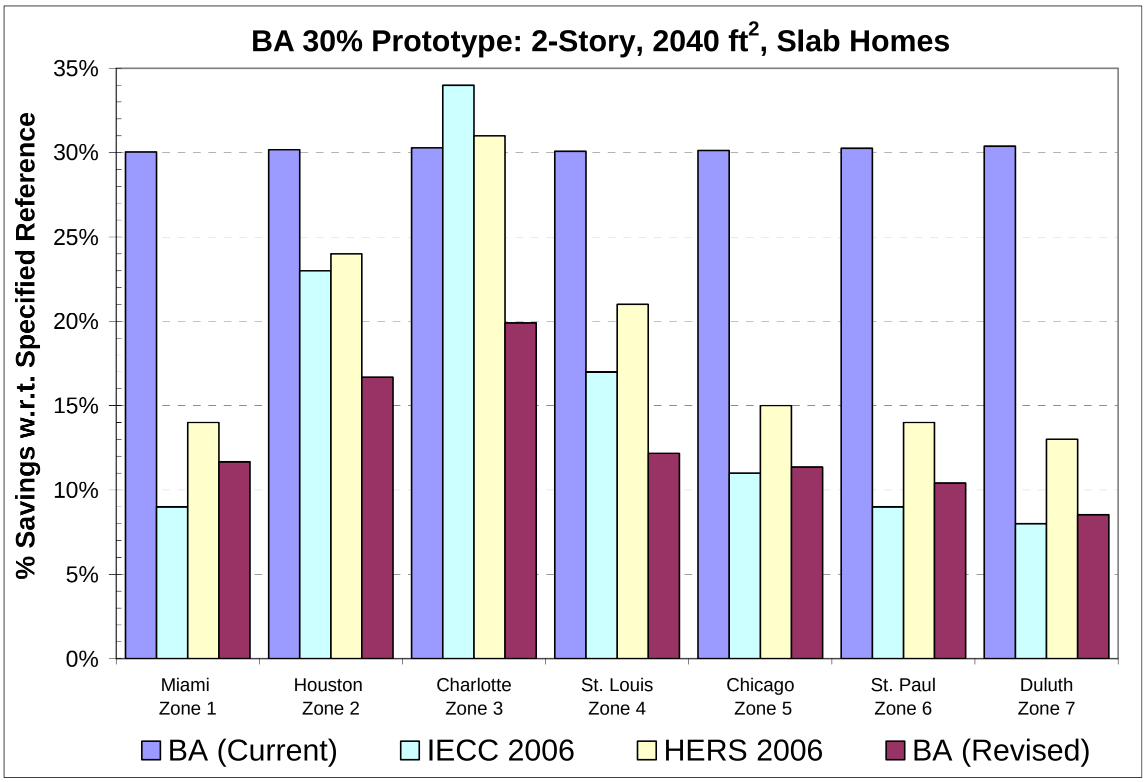

Figure 1 Bar chart showing the *Building America* "30% Prototype" home evaluated using the various performance analysis standards that were examined by this study.

Figure 1 above provides one example of why it is not possible to state with certainty how the 30% better than Benchmark home compares with either the IECC or with HERS or even with a hypothetical revised *Building America* standard [BA (Revised)]. One can calculate the HERS Index for these homes from the yellow bars as 1-the % savings. They illustrate that the HERS Index for the homes range from 87 in Duluth (not meeting ENERGY STAR standard, which requires a HERS Index of 80 or lower in cold climates) to 69 in Charlotte, which is significantly better than ENERGY STAR and, as a matter of fact, which qualifies for the $2,000 tax credit!

While the BA (Current) standards are very consistent at 30% savings across all climate zones, as Figure 1 shows, there simply is no correlation between that BA figure of merit and any of the other figures of merit evaluated by this study.

This study provides additional examples of differences among the standards that are equally disparate. For example, Section 3.3 of the report highlights differences among the standards for number of stories, foundation type, fuel type and home size that illustrate that BA % savings can not be well correlated to the HERS Index, even within the same climate.

It is difficult to make recommendations based on this analysis. There can be pros and cons for any given methods used to project energy savings. For example, the BA method was originally developed to measure progress toward a set of U.S. DOE energy savings milestones called Joules. The intent was to have a consistent standard of performance tied to mid 1990's era home standards. However, in the mid 1990's there were no definitive code standards for windows that are analogous to those that became effective in 1998. In addition, there were no standards or methods in the mid 1990's for the evaluation of distribution system efficiency, mechanical ventilation or lighting and appliances in homes.

Since the original objective of this study – to establish a correlation between the BA % savings value and the HERS Index value – could not be accomplished, there appear to be three potential options for moving forward. While options may not be considered recommendations in the conventional sense of the term, they, along with their advantages and disadvantages, are presented below:

I. <u>Maintain the current BA rule set</u>. This option allows BA program milestones to continue to be measured from a constant reference point. While this reference point can not be directly correlated to current codes or to the HERS Index, it does allow program goals to remain consistent with past objectives. However, this advantage also works as a disadvantage. Potential builder partners can not be told with certainty how much better than code their homes will be as the savings with respect to minimum code standards varies greatly with climate. Thus, builder partners are left in a bit of a quandary as to how they can advertise these homes in a way that can be simply explained to their potential customers.

II. <u>Revise the BA rule set</u>. While revising the BA rule set may bring it more in line with alternative, more current rule sets, the analysis presented here did not show that this would result in a complete correlation between the revised BA % savings values and the HERS Index (or Code e-Ratio). The revised BA rule set examined here consistently resulted in lower % savings values than the HERS rule set. Thus, adopting the revised BA rule set used in this analysis would cause the BA program goals to appear significantly more difficult than code-based programs.

III. <u>Migrate to the HERS Index</u>. A large disadvantage of migrating to the HERS Index is that it would change the basis of BA program savings goals and milestones. Of course, the previous option, revising the BA rule set, would do the same. There are, however, some advantages of this option. The HERS Index is widely used as a performance metric. It is used as the basis for the ENERGY STAR new homes program and other emerging national programs like USGBC's pilot LEED-H program. The HERS rule set also forms the basis for the EPAct 2005 federal tax credit for highly efficient new homes.

As a metric, the HERS Index includes all of the energy uses of a home. This is one of the basic tenets of the BA program – that whole home energy use forms the basis of the program. While changing the BA program standard to the IECC rule set would violate this tenet, changing to the HERS rule set standard would not. The HERS rule set a methodology to "score" the use of on-site energy production, whether by solar, wind or other "free" fuel resources or by highly efficient on-site conventional fuel technologies like micro-turbines and small combined heat and power plants. A significant advantage of the HERS rule set standard is that it is a consensus-based national standard.

A disadvantage of the HERS Index is that the "scoring method" used by the rule set does not use energy use as the metric. The metric used by the HERS rule set is called the normalized modified loads method.[1] It was derived as a compromise consensus method of avoiding the fight between site energy use and source energy use. It can be shown to reasonably reflect energy cost in a market where the ratio between site costs for electricity and natural gas are near the ratio of 3 to 1.

Finally, one advantage of using the HERS Index is that it can be explained fairly simply – the "American Standard New Home" has an index of 100 and a home that uses no purchased energy has an index of 0. In other words, zero is zero and anything greater than 100 probably doesn't meet current minimum energy standards.

[1] Fairey, P., J. Tait, D. Goldstein, D. Tracey, M. Holtz, and R. Judkoff, "The HERS Rating Method and the Derivation of the Normalized Modified Loads Method." Research Report No. FSEC-RR-54-00, Florida Solar Energy Center, Cocoa, FL, October 11, 2000.

1 INTRODUCTION

1.1 Background

The U.S. Department of Energy's (DOE) *Building America* (www.buildingamerica.gov) has adopted the theme "Research Toward Zero Energy Homes." As part of the process of achieving this long-term goal, DOE's *Building America* team members evaluate their progress using the Building America Benchmarking Analysis process.[2] This process is based on a comparative analysis procedure developed by the National Renewable Energy Laboratory (NREL) in collaboration with the U.S. DOE and their *Building America* research team members. The current analysis method is approximately based on the 1993 Model Energy Code (MEC 93) as the performance basis for comparison and was adopted and published by NREL in December 2004 (see footnote 1).

During the 13 years since MEC 93 was promulgated, model energy codes have undergone numerous changes, including changing their moniker to the International Energy Conservation Code (IECC). The most recent promulgation of the IECC is the 2006 version. In addition, in late 2005, the Residential Energy Services Network, Inc. (RESNET) adopted and promulgated revised standards for Home Energy Rating Systems (HERS).[3] Both the IECC and RESNET have updated their standards to become more or less aligned with each other and to reflect current market products and building practices.

In September of 2005, the U.S. Congress passed the Energy Policy Act of 2005 (EPAct 2005), which contained tax credit provisions for new, highly-efficient homes. The standards used for determining qualification for this new home tax credit are the same as the standards used by RESNET accredited programs for the determination of HERS ratings.

1.2 Objectives

The U.S. DOE, their contractors and research team members have questioned how the above standards, which are currently used in different realms for comparative analysis of building energy efficiency performance, are related to one another. The objective of this study is to provide the analysis needed to help answer this question. The stated tasks to accomplish this objective are as follows:

1. Compare the Building America (BA) 30% and 50% goals with the 2006 "expanded" whole-house HERS Index.
2. Determine the performance of IECC 2006 minimum code Standard Reference Design homes relative to the BA Benchmark Home.
3. Analyze the 2006 ENERGY STAR® reference home to determine the level at which BA prototype homes meet the ENERGY STAR homes criteria.

[2] See http://www.eere.energy.gov/buildings/building_america/pa_resources.html
[3] *2006 Mortgage Industry Notional Home Energy Rating Systems Standards*, Residential Energy Services Network, Oceanside, CA, August 21, 2006.

2 METHODS

2.1 Home Selection

The process of creating a set of building simulation files with their respective envelope components that is representative of Building America (BA) prototype construction practices can be a complex one. The % of new housing starts by BA climate zones (Figure 2.1) complicates it further. During the beginning of the study, four sources of data were searched in an attempt to simplify the process. These sources of building construction data are as follows:

- The Building America data base under the DOE-EERE Buildings Technologies Program (http://www.eere.energy.gov/buildings/building_america/)
- U.S. Census Bureau internet site. (http://www.census.gov/)
- Energy Gauge (FL) and Energy Gauge USA database files at FSEC
- Sample of EGUSA files (.enb) submitted by other BA teams

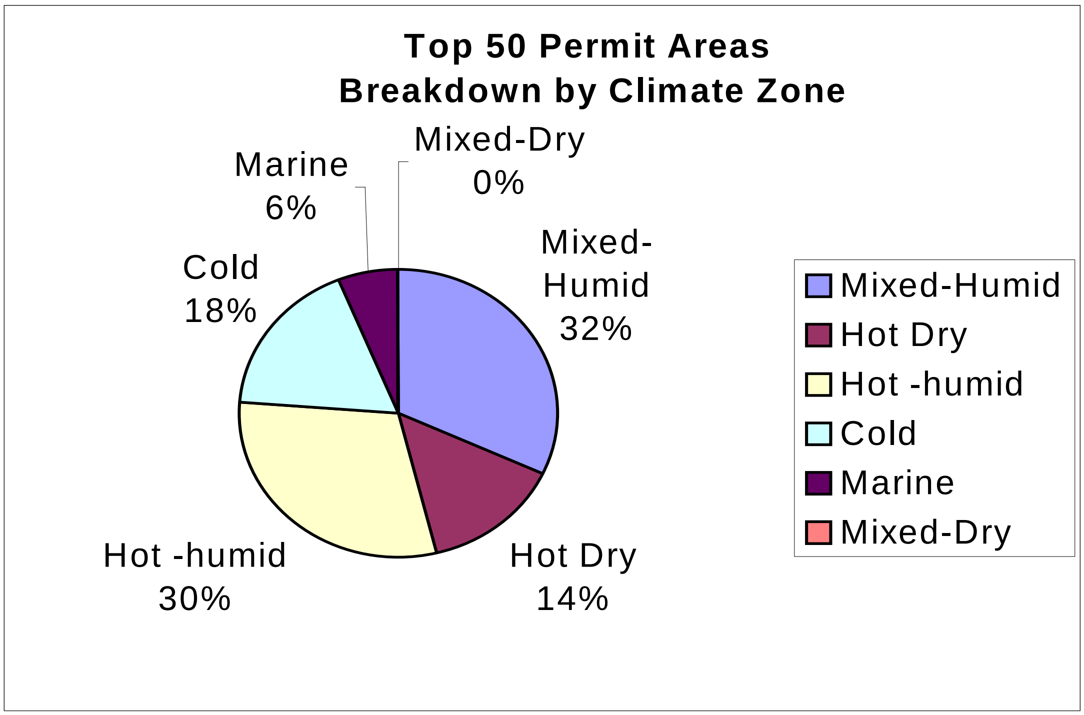

Figure 2.1 Percentage of Top 50 construction cities by climate zones ending on June 2005

The BA database under the DOE-EERE Buildings Technologies Program website was searched to help determine building parameters such as average home size and equipment efficiency among other variables. Although the database is easy to navigate and informative, we found that it could not provide all of the statistics and building envelope variables needed for the project. The Energy Gauge residential building database at the

Florida Solar Energy Center (FSEC) was also utilized due to its unlimited query options. However, a majority of the records found mostly apply to Hot-Humid climate and are not representative of BA building practices in other climate zones. Prototype building files submitted by three other BA teams were also scrutinized, which help identify current building envelope measures being used on BA single-family homes. These 18 benchmark building cases covered all climate zones except for the Marine climate.

To simplify the building file creation process, data sources such as the U.S. Census Bureau, provided information that can be related to building sizes utilized. For example, Figure 2.2 presents a breakdown of completed single-family homes by size. The range of home sizes used throughout this report was further reduced by generating three building size cases (1200 ft^2, 2000 ft^2, and 3000 ft^2) those of which fall within the boundaries of the ranges shown on the plot.

Other statistical data plots generated from data found at the Bureau of Census which are representative of current building construction can be found in appendix B of this report. Charts related to square footage by region, number of stories, foundation, wall envelope and heating fuel type are included in the appendix.

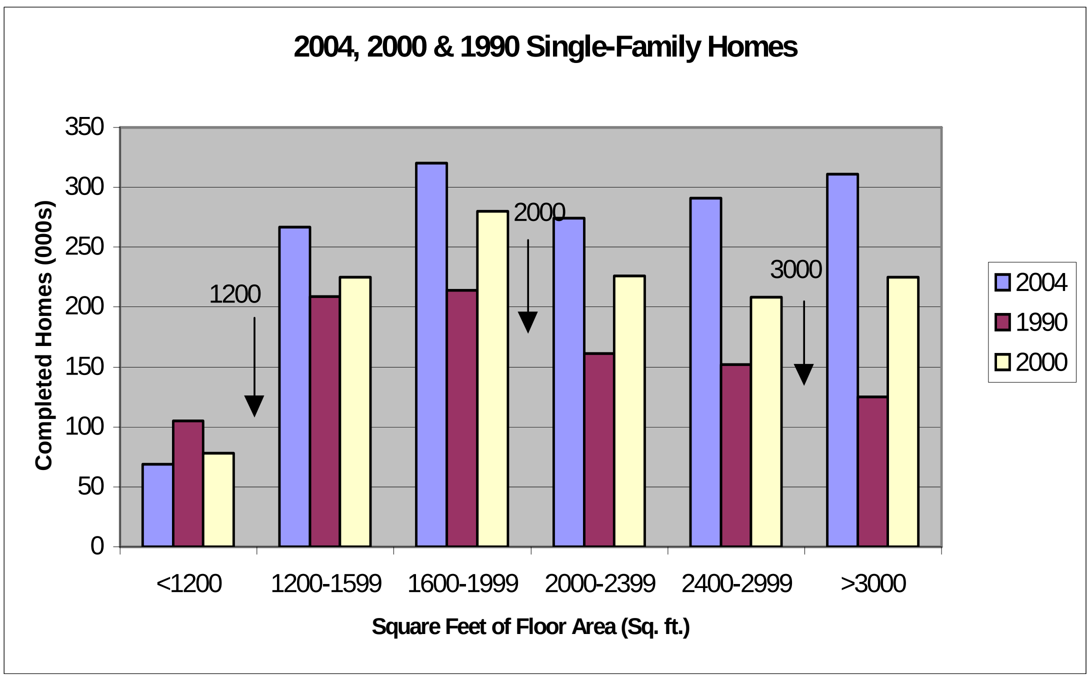

Figure 2.2 Breakdown of sizes for single family homes completed

2.2 Performance Comparison

2.2.1 Comparative Analysis Rule Sets

A "rule set" is a set of specific instructions as to how a comparative building energy analysis is to be performed. In general, comparative building energy analysis procedures require 3 different building configurations, as follows:

1. *Actual Home*: This is the building exactly as it is planned to be built or as it is actually built.
2. *Evaluated Home:* This is the Actual Home with specific changes that are required by the rule set. Usually such changes are specified by the rule set in order to eliminate lifestyle influences from the building analysis. For example, the Actual Home may have a thermostat setting of 75 ^{o}F year around but the rule set may require that the Evaluated Home have thermostat settings of 78 ^{o}F and 68 ^{o}F for cooling and heating respectively.
3. *Reference Home:* This home is normally a “geometric twin” of the Actual and Evaluated Homes that is configured to have envelope and equipment energy features that are equal to some standard such as a national energy code.

It is important to recognize that different comparative evaluation systems have chosen different names for these three buildings. For example, the BA comparative analysis procedure refers the Evaluated Home as the “Prototype” and the Reference Homes as the “Benchmark.” Likewise, the IECC procedure refers to the Evaluated Home as the “Proposed Design” and the Reference Home as the “Standard Reference Design” and the HERS procedure refers to the Evaluated Home as the “Rated Home” and the Reference Home as the “HERS Reference Home.”

For the purposes of this document, and from this point forward, the terms *Actual Home, Evaluated Home and Reference Home* will be used to refer to these three buildings in order to ensure consistency of meaning throughout this document.

2.2.2 Rule Set Differences

There are a number of major differences between the Building America (BA) Benchmarking rule set and the 2006 HERS and 2006 IECC rule sets. They may be summarized as follows:

- Thermostats: The BA rule set requires that thermostats in both the Evaluated Home and the Reference Home be set to 76 for cooling and 71 for heating. The HERS and IECC rules sets require that they be set to 78 for cooling and 68 for heating in the Evaluated Home and the Reference Home.

- Windows: The BA rule set uses Reference Home window characteristics that are considered typical of 1993 practice. This is prior to the IECC separating window and wall U-factors and establishing minimum standards for window SHGC, which occurred in 1998. As a result, the BA rule set for windows in the Reference Home are substantially different from the HERS and IECC rule sets for windows in the Reference Home.

- Infiltration and mechanical ventilation: The BA rule set uses a Reference Home specific leakage area (SLA=0.00057) that is 18.75% greater than the HERS rules set (SLA = 0.00048) and 58.3% greater than the IECC rule set (SLA = 0.00036).

Mechanical ventilation is also treated substantially different between the different rule sets. For the BA rule set, both the Reference Home and the Evaluated Home are required to incorporate mechanical ventilation, with the Reference Home required to have balanced mechanical ventilation meeting ASHRAE 62.2 Standards. For the HERS and IECC rule sets, there is no requirement for mechanical ventilation, however, where mechanical ventilation is present in the Actual Home, it is incorporated in the Evaluated Home at the ASHRAE 62.2 minimum ventilation rate.

However, the HERS and IECC Reference Homes are treated differently than the BA Reference Home. In both the HERS and IECC rule sets, the Reference Home does not have increased air exchange over and above the natural infiltration air exchange resulting from the Reference Home SLA requirement. To account for the fact that mechanical ventilation in the Evaluated Home will result in an increase in fan energy compared with no mechanical ventilation, the Reference Homes for the HERS and IECC rule sets have an added fan energy use that is equivalent to a mechanical ventilation fan energy use of 0.45 watts/cfm of air flow. The BA Reference Home uses the same additional fan energy for mechanical ventilation.

Unlike the HERS and IECC rule set requirements, the BA Reference Home rule set requires that the minimum ASHRAE 62.2 mechanical ventilation be provided to the Reference Home through a balanced mechanical system, which supplies and exhausts the same amount of air mechanically. This requirement is in addition to the infiltration resulting from SLA = 0.00057 for the BA Reference Home. This means the ventilation air is added to the infiltration air in the BA Reference Home as straight addition, rather than in quadrature, as would be the case for unbalanced mechanical ventilation.

The result of these differences in the treatment of infiltration and mechanical ventilation can be significant. For example, for a 2040 square foot, 2-story, 3-bedroom home, located in Chicago, IL, the BA Reference Home would have an overall air exchange rate (infiltration + mechanical ventilation) of 0.82 air changes per hour (ach). However, the same home, when configured according to the HERS and IECC Reference Home rule sets would have overall air exchange rates of 0.55 and 0.41 ach, respectively. In very cold climates, these differences in Reference Home air exchange rates can result in substantial differences in the comparative results.

- Distribution System Efficiency (DSE). The BA Reference Home distribution system efficiency rule set differs from the HERS and IECC Reference Home rule sets. For HERS and IECC the DSE for the Reference Home is characterized by a single value (DSE=0.80), regardless of home type. However, for the BA Reference Home, the efficiency of the distribution system is dependent on the foundation type and number of stories of the Actual Home. For example, if the Actual Home is a one-story, slab on grade home, the BA Reference Home duct system is specified to be 100% in the attic of the home and to have air leakage to outdoors equal to 15% of the AHU fan flow. However, if the Actual Home is a two-story, slab on grade home, then the BA Reference Home duct system is specified to be 35% in the conditioned space and 65% in the attic and to have air leakage to the outdoors of 15% * 65% = 9.75% of the AHU fan flow.

- NAECA Equipment Standards. The BA rule set specifies Reference Home equipment efficiencies that are different than the current NAECA minimum standards. The BA rule set specifies equipment efficiencies that predate the 2004 NAECA water heater efficiency modifications and the 2006 air conditioning and heating system modifications. On the other hand, both the HERS and IECC rule sets specify that the "prevailing federal minimum standard" equipment efficiencies be used for the Reference Home.

- Water Heating. The number of gallons per day (gpd) for water heating is dependent only on the number of bedrooms for the IECC and HERS rule sets but is dependent on other additional factors for the BA rule set.

In addition to the above there are significant differences between the treatment of internal gains in the BA rule set and the HERS and IECC rule sets. The HERS and IECC rule sets call for the application of internal gains that are a function of only the conditioned square footage and the number of bedrooms of the home [iGain = 17,900 + 23.8 * CFA + 4104 * Nbr (Btu/day per dwelling unit)]. The BA rule set calls for the application of internal gains which vary by the location of the home, with location multipliers for the miscellaneous electrical uses that range from a low of 0.77 to a high of 1.11. Additionally, the BA rule set treats internal gains in homes with gas devices differently than all electric homes, with greater internal gains in gas homes.

2.3 General Analysis Methods

The first step of the analysis process was to select a representative set of proposed BA home plans and specification for small, medium and large homes. For the most part, homes were selected from actual builder models. The medium sized home is used as the basis for much of the analysis. Significant care was taken to create both a 2-story and a 1-story medium sized model, having the same conditioned square footage, with the same envelope and equipment characteristics, the same window-to-floor-area ratio and the same window orientation percentages so that differences in these characteristics would not confound the analysis of the impact of the number of stories.

A total of seven climate locations were selected for the analysis as shown in Figure 2.3, below. One TMY city was selected from each of the IECC climate zones for the contiguous U.S.

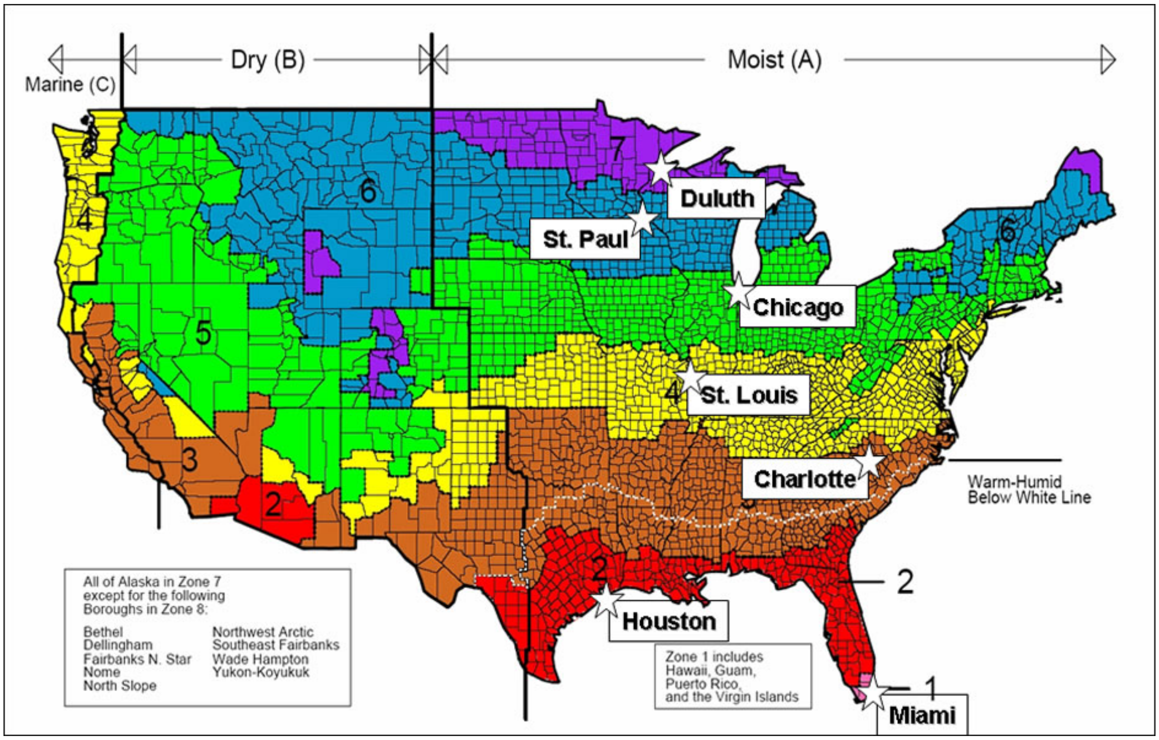

Figure 2.3 IECC Climate map showing the TMY cities selected for the analysis using each of the 7 climate zones within the contiguous U.S.

Once the set of BA homes was selected, the BA Benchmark spreadsheet tool developed by NREL[4] and modified by FSEC was used to determine the appropriate EnergyGauge USA modeling inputs for the benchmark and the prototype homes using the Actual Homes as the basis.

Using EnergyGauge modeling results, the Actual and Evaluated Homes were iteratively adjusted such that the Benchmark spreadsheet tool yielded output results showing BA whole-building energy savings as close to 30% as reasonably possible. Results of this process are presented in detail in Table 2.1 on the following 2 pages.

[4] *Building America Analysis Spreadsheet*, dated 05.03/06 found online at http://www.eere.energy.gov/buildings/building_america/pa_resources.html

Table 2.1 Characteristics of the 30% BA Prototype homes used as the basis for the majority of the analysis (yellow highlighting represents properties that differ).

Climate Location:	Miami, FL	Houston, TX	Charlotte, NC	St. Louis, MO	Chicago, IL	St. Paul, MN	Duluth, MN
Envelope Characteristics:							
Conditioned floor area (ft^2)	2040	2040	2040	2040	2040	2040	2040
no. stories	2	2	2	2	2	2	2
no. bedrooms	3	3	3	3	3	3	3
avg. ceiling height (ft)	9	9	9	9	9	9	9
attached garage	yes	yes	yes	yes	yes	yes	yes
foundation type	slab on grade	slab on grade	slab on grade	slab on grade	slab on grade	slab on grade	slab on grade
slab area (ft2)	870	870	870	870	870	870	870
slab insulation	none	none	R-4.0	R-4.0	R-5.35	R-6.32	R-6.32
slab perimeter (ft)	180	180	180	180	180	180	180
roof type	hip	hip	hip	hip	hip	hip	hip
roof pitch	5:12	5:12	5:12	5:12	5:12	5:12	5:12
roof cover	comp shingles	comp shingles	comp shingles	comp shingles	comp shingles	comp shingles	comp shingles
roof color	Dark	Dark	Dark	Dark	Dark	Dark	Dark
roof solar absorptance	0.92	0.92	0.92	0.92	0.92	0.92	0.92
roof insulation	none	none	none	none	none	none	none
attic type	standard	standard	standard	standard	standard	standard	standard
attic ventilation	1:300	1:300	1:300	1:300	1:300	1:300	1:300
ceiling type	flat	flat	flat	flat	flat	flat	flat
ceiling area (ft2)	1170	1170	1170	1170	1170	1170	1170
ceiling insulation	R-19.0	R-30.0	R-36.0	R-34.0	R-40	R-38	R-30
wall type	Frame-wood	Frame-wood	Frame-wood	Frame-wood	Frame-wood	Frame-wood	Frame-wood
wall insulation	R-11.0	R-13.0	R-22	R-20.0	R-21.0	R-19	R-19
Sheathing R-value	none	3.75	3.1	none	3.75	none	none
wall solar absorptance	0.75	0.75	0.75	0.75	0.75	0.75	0.75
door type	insulated	insulated	insulated	insulated	insulated	insulated	insulated
door area (ft2)	40	40	40	40	40	40	40
window type	double, low-e	double, low-e	double, low-e	double, low-e	double, low-e	double, low-e	double, low-e
size (% CFA)	16.6%	16.6%	16.6%	16.6%	16.6%	16.6%	16.6%
orientation	~40% E & W ~10% N & S	~40% E & W ~10% N & S	~40% E & W ~10% N & S	~40% E & W ~10% N & S	~40% E & W ~10% N & S	~40% E & W ~10% N & S	~40% E & W ~10% N & S
U-Factor	0.57	0.39	0.3	0.4	0.35	0.35	0.35
SHGC	0.45	0.28	0.5	0.5	0.55	0.55	0.4

Climate Location:	Miami, FL	Houston, TX	Charlotte, NC	St. Louis, MO	Chicago, IL	St. Paul, MN	Duluth, MN
Overhang (ft)	1.5	1.5	1.5	1.5	1.5	1.5	1.5
envelope leakage	standard	standard	standard	standard	standard	standard	standard
leakage rate (ach50)	4	4	4	4	4	4	4
Mechanical ventilation	unbalanced	unbalanced	unbalanced	unbalanced	unbalanced	unbalanced	unbalanced
Supply vent rate (cfm)	50.4	50.4	50.4	50.4	50.4	50.4	50.4
Systems:							
cooling type	central	central	central	central	central	central	central
cooling SEER	14	14	14	14	14	13	13
heating type	Heat Pump	Heat Pump	Heat Pump	Heat Pump	Heat Pump	Heat Pump	Heat Pump
heating HSPF	8.2	8.2	8.2	8.2	8.2	8.2	8.2
thermostat schedule	BA Bench	BA Bench	BA Bench	BA Bench	BA Bench	BA Bench	BA Bench
setpoint (htng/cool) (^oF)	71/76	71/76	71/76	71/76	71/76	71/76	71/76
distribution system	forced air	forced air	forced air	forced air	forced air	forced air	forced air
duct insulation	R-6	R-6	R-6	R-6	R-6	R-6	R-6
duct location	Attic	Attic	Attic	Attic	Attic	Attic	Attic
AHU location	Interior	Interior	Interior	Interior	Interior	Interior	Interior
duct leakage	Qn = 0.04	Qn = 0.04	Qn = 0.04	Qn = 0.04	Qn = 0.04	Qn = 0.04	Qn = 0.04
return leak fraction	0.33	0.33	0.33	0.33	0.33	0.33	0.33
hot water type (gal - fuel)	50 - electric	50 - electric	50 - electric	50 - electric	50 - electric	50 - electric	50 - electric
auxiliary elec. EF	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Lighting & appliances:							
% fluorescent	50%	50%	50%	50%	50%	50%	50%
eStar refrigerator	no	no	no	no	no	no	no
eStar dishwasher	no	no	no	no	no	no	no
eStar ceiling fans	no	no	no	no	n0	n0	no
Dryer	electric	electric	electric	electric	electric	electric	electric
Range	electric	electric	electric	electric	electric	electric	electric

2.3.1 BA Rule Set as the Basis for Analysis

The process of accomplishing the analysis using consistent assumptions is complicated by the differences in rule sets that are described above. In general, the BA rule set served as the basis for the analysis and the following assumptions were maintained for the simulations:

- All homes were modeled including mechanical ventilation. For the BA Reference Home, mechanical ventilation is specified by the benchmark analysis procedures as being balanced flow in accordance with ASHRAE Standard 62.2. For Evaluated Homes, the same amount of mechanical ventilation is also used however, the flow is assumed to be unbalanced (supply-only ventilation). This is true even for the cases that are designed to represent the alternative Reference Homes (i.e. HERS and IECC), where mechanical ventilation is added to those Reference Homes for the purpose of comparing with the BA Reference Home.

  Where the Actual and Evaluated Homes are configured as the Reference Home in accordance with the HERS and IECC rule sets, this additional mechanical ventilation is provided as unbalanced, supply-only mechanical ventilation that is in addition to the required SLA for the respective Reference Home. Thus, for configurations corresponding with the HERS Reference Home, the SLA is 0.00048 and for configurations corresponding with the IECC Reference Home, the SLA is 0.00036.

  These additional mechanical ventilation assumptions, which are not required for Reference Homes by either the IECC or HERS rule sets, result in slightly increased energy use in homes that are otherwise configured as HERS and IECC Reference Homes. As a result, cases designated as IECC Standard Design and HERS Reference configurations will not necessarily have the same energy use as the actual IECC or HERS Reference Homes and will result in HERS Indexes slightly greater than 100 and IECC e-Ratios slightly greater than 1.00.

- All homes were modeled using the BA thermostat schedule. Since the BA rule set requires a different thermostat schedule from the other reference home rule sets, the BA thermostat schedule is incorporated into the alternative Reference Home cases for the purpose of comparing the BA Reference Homes with the alternative Reference Homes. It is important to note that identical thermostat settings are used in both the Reference Home and the Evaluated Home in all cases, whether they are from the BA rule set or an alternative rule set.

- All homes were modeled using the BA hot water heater gallons per day (gpd). For the BA Reference Home, the daily hot water use is dependent on both the number of occupants and the temperature of the inlet water. This results in hot water use (gpd) that varies by climate. For the purpose of comparing the BA Reference Home with the alternative Reference Homes, the hot water use was altered in the alternative Reference Homes to match the BA requirement.

- Miscellaneous Energy Consumption is as specified by BA Benchmark. While EnergyGauge automatically generates miscellaneous energy uses in accordance with IECC and HERS Standards, these values are different from the values used in the BA benchmarking analysis procedures. For the purposes of the comparisons presented in this report, only the heating, cooling and hot water energy use results are taken from EnergyGauge results. The remaining energy uses for the homes are as calculated by the *Building America Analysis Spreadsheet* (see footnote 1, above).

2.3.2 Additional Modeling Assumptions for Evaluated Homes

In addition to the above assumptions, which are related primarily to the BA rule set requirements, there are some additional assumptions regarding modeling of the Evaluated Homes in the analysis reported here.

- Windows Orientation. The home plans selected for the Actual Homes in this analysis, were oriented so as to produce the worst case results for the Homes. For example, the 2040 ft^2 homes have a large fraction of their windows on the front and back of the home and only a very small fraction on the sides. The Evaluated Home orientation used for analysis of these homes was with the front of the home facing west and the back facing east, resulting in a "worst case" simulation result.

- Window Area. The Actual and Evaluated Homes generally have less window area than the Reference Homes. For example, the 2040 ft^2 homes have a window to floor area ratio of 16.6% rather than the 18% ratio that is used for the BA and HERS Reference Home standards. However, for the IECC Reference Home, the window to floor area ratio is required to be equal to that of the Actual Home unless the Actual Home ratio greater than 18%, above which point the IECC Reference Home is required to maintain a window to floor area ratio of 18%. These window area assumptions produce modest differences between the HERS and IECC results due to the fact that the HERS rule set results in some credit for the reduced window area in the Actual Home as compared with the Reference Home. On the other hand the IECC rule set requires that the IECC Reference Home have the same window to floor area ratio as the Actual Home for this case.

- Thermostats. It is important to note that thermostat schedules in the Evaluated Home are always maintained at the same settings as for the Reference Home in all cases.

2.3.3 HERS and IECC Figures of Merit

When determining a HERS Index or an IECC Code Compliance figure of merit for homes, the items listed in Section 2.3.1 are treated in accordance with the rule set for the appropriate standard (i.e. either HERS or IECC) rather than as described above. For these purposes, mechanical ventilation fan power in the homes is set to 0.4 watts/cfm of ventilation airflow. This is done so that the HERS and IECC savings are not exaggerated as would otherwise be the case if the fan power were left at 0 as is required by BA procedures for simulations where results are for use in the BA spreadsheet analysis, where mechanical ventilation fan power is added separately through the spreadsheet.

The EnergyGauge figure of merit for IECC Code compliance is called the e-Ratio, which is the result of dividing the total projected energy use for heating, cooling and hot water in the Evaluated Home by the total projected energy use for heating, cooling and hot water in the Reference Home. Thus, like the HERS Index, the smaller the value, the more efficient the home. The e-Ratio, when multiplied by 100, is a very similar figure of merit to the HERS Index, except that it does not consider energy uses other than the code energy uses of heating, cooling and hot water.

3 RESULTS

3.1 Revised Benchmark Incremental Analysis

As part of the analysis, the major differences between the BA rule set and the HERS and IECC rule sets described in Section 2.2.2 were examined on both an individual and a cumulative basis. This was accomplished by revising, one-by-one, the BA Reference Home characteristics to those of the HERS Reference Home for each of the major items that differ, as provided in Table 3.1, below:

Table 3.1 Characteristic Substitutions for Revised Benchmark Analysis

BA Reference Home Characteristic	Current BA Reference Value or Setting	Revised BA Reference Value or Setting
Thermostat Setting	Cool = 76 ^{o}F; Heat = 71 ^{o}F	Cool = 78 ^{o}F; Heat = 68 ^{o}F
Heating, Cooling and Hot Water Equipment	HSPF = 6.8; SEER = 10; EF = 0.86	HSPF = 7.7; SEER = 13; EF = 0.90
Windows: (Miami)	U=1.00; SHGC=0.79	U=1.20; SHGC=0.40
(Houston)	U=0.79; SHGC=0.65	U=0.75; SHGC=0.40
(Charlotte)	U=0.58; SHGC=0.58	U=0.65; SHGC=0.40
(St. Louis)	U=0.53; SHGC=0.58	U=0.40; SHGC=0.55
(Chicago)	U=0.39; SHGC=0.32	U=0.35; SHGC=0.55
(St. Paul)	U=0.36; SHGC=0.32	U=0.35; SHGC=0.55
(Duluth)	U=0.36; SHGC=0.32	U=0.35; SHGC=0.55
Distribution System Efficiency (DSE)	1-story, slab: 100% ducts in attic; 15% air leakage	DSE = 0.80
	2-story, slab: 65% ducts in attic; 9.75% air leakage	DSE = 0.80
	2-story, crawlspace: 65% ducts in crawl; 9.75% air leakage	DSE = 0.80
	Basement: 100% ducts in conditioned basement; no air leakage	DSE = 0.80
Envelope Leakage*	1-story: SLA = 0.00057	SLA = 0.00048
	2-story: SLA = 0.00046	SLA = 0.00048
Mechanical Ventilation*	Balanced system	Unbalanced, supply only**

* Leakage and Mech. Vent treated together as a single "Infiltration" characteristic
** Mechanical ventilation air flow is not actually included in HERS Reference Home

It is also important to point out that for thermostat schedules, identical schedules are used in both the Reference and Evaluated Homes, whether they are the original or the revised schedule. Finally, following the incremental changes, all of the above items were cumulatively changed within a single simulation to represent a "Revised" BA Reference Home containing all of the differences.

Results from the above analysis are quite informative as to the individual contribution of each difference to the total cumulative difference as well as to indicate how climate, foundation type, number of stories and fuel type impact both the individual differences and the cumulative differences. Figure 3.1 below provides an example of results from such an analysis for Chicago, Illinois. Some explanation is helpful. The results are for "30% BA Prototype" homes as compared against the various Reference Home conditions shown by the x-axis labels. With the exception of the BA rules for foundation type and number of stories, the characteristics of the 30% BA Prototype homes are the same for all cases. The 2-story slab-on-grade case is the "calibration" case, which is used to determine the envelope and equipment characteristics for the 30% BA Prototype. These same envelope and equipment characteristics are then used for all other prototype cases so that all the 30% BA Prototypes have identical envelope and equipment characteristics.

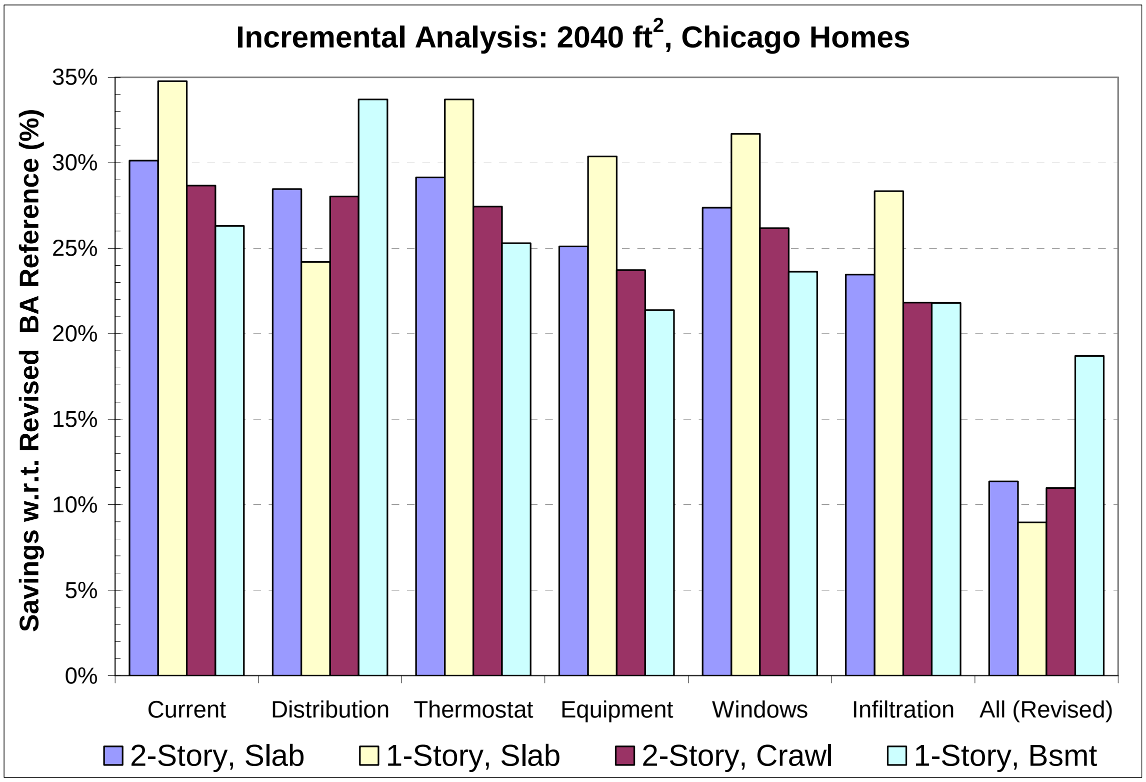

Figure 3.1 Bar chart of "Revised Benchmark" savings for 2040 ft^2 "30% BA Prototype" homes in Chicago, Illinois, using "revised" BA Reference Homes and showing the impact of foundation type and number of stories. The first group of bars [Current] shows the homes evaluated using the current BA Reference Home characteristics with succeeding groups representing individual revisions to this Reference Home and the final bar group [All (Revised)] corresponding to all of the characteristics being changed for the Reference Home. The Evaluated Home (30% BA Prototype) characteristics are not altered in this analysis, excepting for the Thermostat runs where the thermostat is revised in both the Reference and Evaluated Homes, where it produces about a 2% decrease is savings for all homes.

While the crawlspace home tracks the 2-story, slab home rather closely, some significant differences do occur for the other two homes in Figure 3.1. For the 1-story home, the % savings predicted using the current BA reference characteristics are significantly greater than for the 2-story home. Note that this advantage is more than eliminated when the distribution system efficiency is changed to that of the HERS rule set. Also note that when all revisions are included in the Reference Home, this foundation type shows the lowest savings of all the cases shown.

The basement home is also interesting. This home has two floors; one is a conditioned, finished walkout basement with half of its wall area below ground, and the second is directly above the basement. This home had its basement window area reduced by 50% compared to the 1st story of the 2-story prototype so as to equitably correspond with the BA rule set for basement Reference Homes. Again, note what happens when the distribution system efficiency is changed to that of the HERS rule set – the % savings for this case increases dramatically. This fairly dramatic impact also shows up in the final accumulation of the differences with this home showing the greatest % savings when all the revisions are included in the BA Reference Home.

Climate effects can also be examined using this incremental analysis technique. Figure 3.2, below shows how the individual differences in three climates (one cooling dominated, one mixed and one cold) combine to lead to very different combined results.

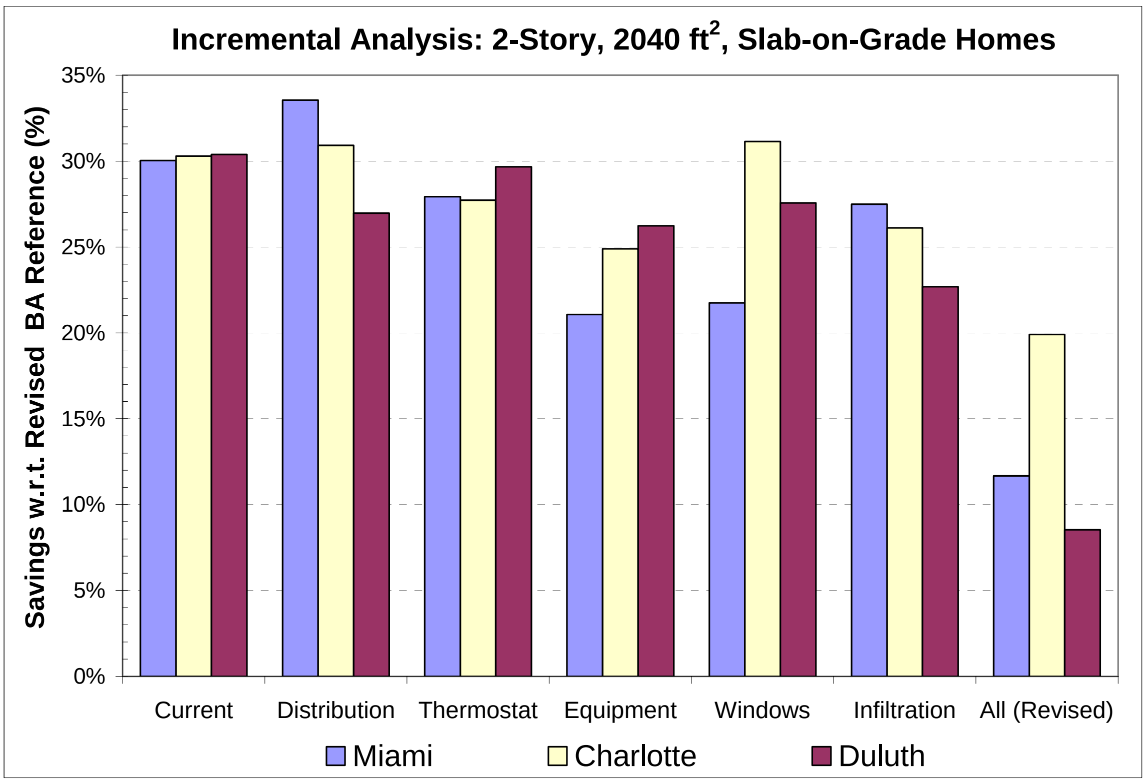

Figure 3.2 Bar chart of "Revised Benchmark" savings for 2-Story, 2040 ft^2, slab-on-grade "30% BA Prototype" homes in cooling dominated, mixed, and heating dominated climates, showing the climatic impacts of revisions to the BA Reference Home characteristics.

It is clear from Figure 3.2 that equipment efficiency and window characteristic changes result in large differences in Miami, where cooling dominates the energy needs. For

Duluth, window differences are also important but infiltration ventilation and distribution system differences cause the largest changes. Charlotte, on the other hand, suffers from the fact that the Current BA window characteristics are more stringent than the 2006 HERS and IECC window characteristics, such that BA 30% Prototype savings increase when the Reference Home is changed to incorporate the 2006 window characteristics.

Finally, Figure 3.3, below, provides summary data for a revised BA Reference Home rule set across all of the 7 climate zones evaluated. It is clear from Figure 3.3 that there are significant climatic differences between the current BA rule set and any revised BA rule set that might be adopted to reduce the differences between BA evaluations and evaluations conducted using current HERS (or IECC) rule sets. Based on these results, there does not appear to be any consistent correlation, which could be used across climates zones, to establish any relationship between BA and HERS (or IECC) projected savings results. In other words, the data show that we can not say what HERS Index is equivalent to the BA 30% Prototype. The HERS Indices for these BA 30% Prototype cases range from a high of 87 in Duluth to a low of 68 in Charlotte.

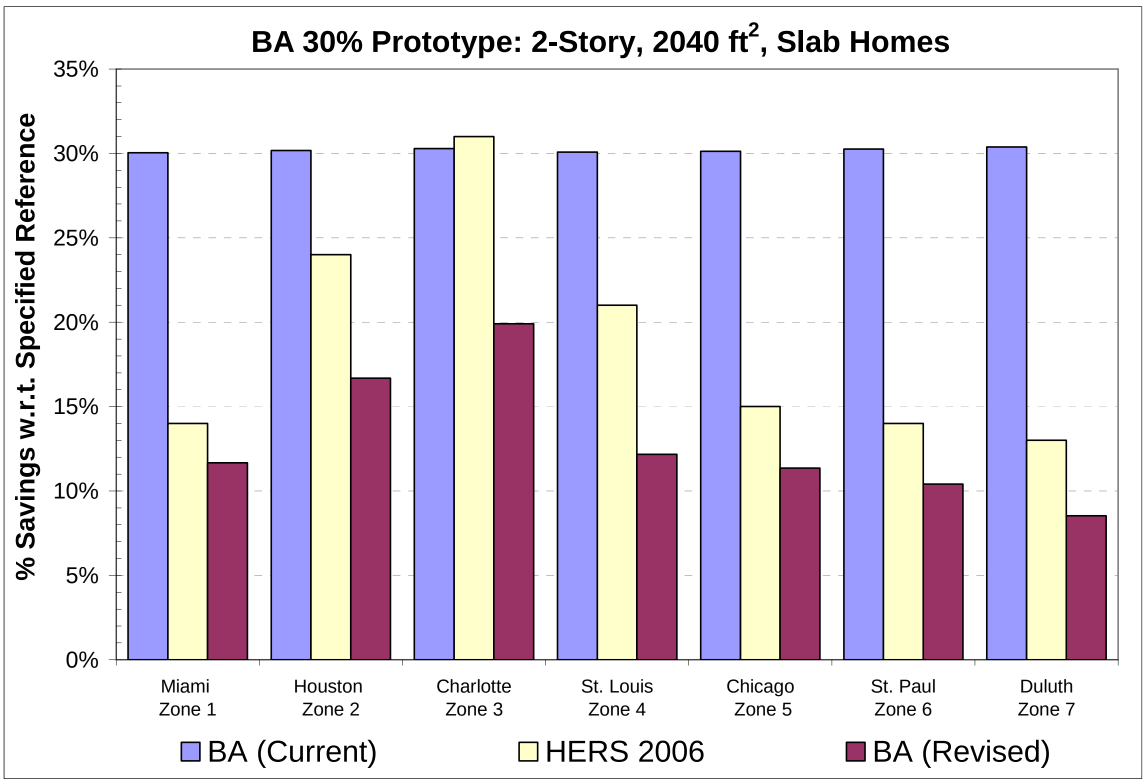

Figure 3.3 Bar chart showing the relationship between the current BA rules set, the HERS 2006 rule set and a fully-revised BA rule set that incorporates all major differences between the current BA rule set and the 2006 HERS rule set.

3.2 Comparisons of BA, HERS and IECC Reference Standards

Another way to look at overall differences between the BA, HERS and IECC rule sets is to compare the % savings results for the 30% BA Prototype against the % savings results for the same home when it is configured to match the Reference Home characteristics of alternative standards. In the previous analysis, the Reference Home characteristics were changed while the Evaluated Home characteristics remained constant. In this analysis, we do the opposite and the characteristics of the Evaluated Home are changed while the Reference Home characteristics remain constant.

3.2.1 Comparisons of the Reference Home Standards

While the previous comparison shows how predicted savings would change if the Reference for the 30% BA Prototype is changed, this analysis shows the energy efficiency of the alternative Reference Homes with respect to the BA Reference Home.

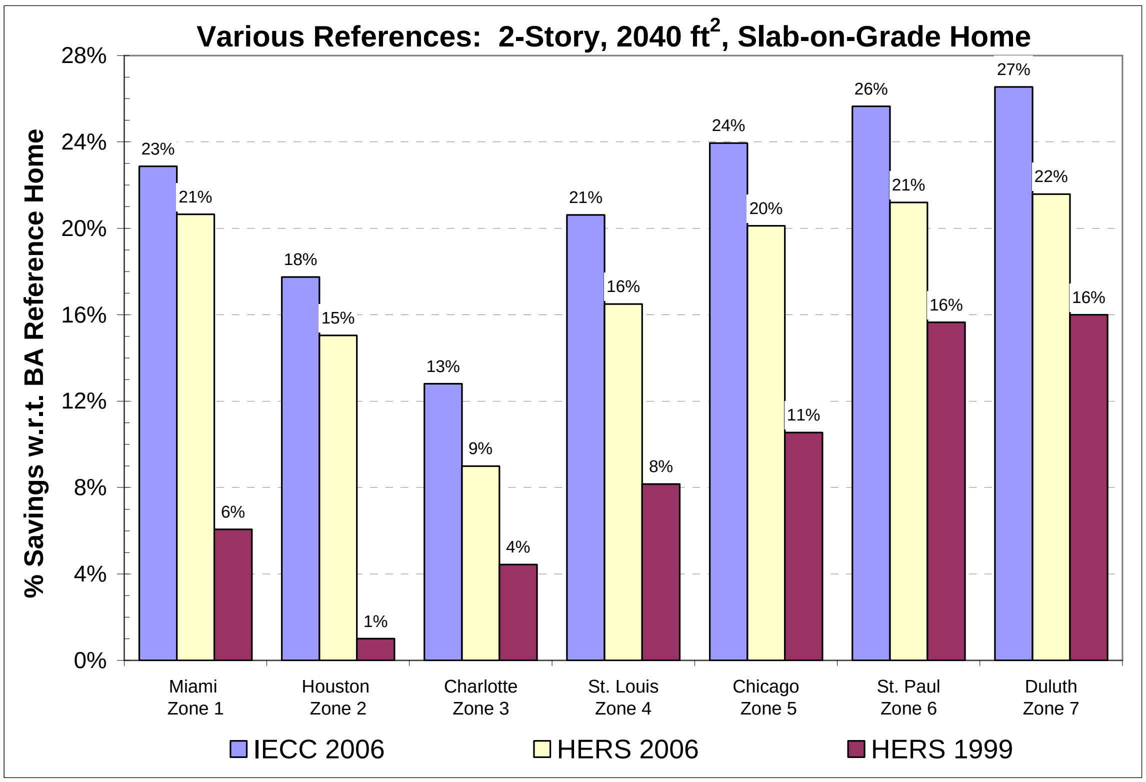

Figure 3.4 Bar chart of the % savings for the 2-Story, 2040ft^2, slab-on-grade home configured to match the characteristics of the IECC and HERS Reference Home rule sets. By definition, the BA Reference Home would produce 0% savings on this chart, so each of the alternative rule sets produce Reference Homes that are more energy-efficient than the BA Reference Home.

Figure 3.4 illustrates a number of interesting facts. First, it is clear from the figure how much more efficient the HERS 2006 standard is compared with the HERS 1999 standard in the south where we see about 15% difference. Only about half that amount occurs in the north. Second, in Miami and in the far north (zones 5-7), the 2006 HERS and IECC Reference Homes are 20-25% more efficient than the BA Reference Home. However, in mid climate zones (2-4), the 2006 HERS and IECC Reference Home standards are much closer to the BA Reference Home efficiency, with a 2006 HERS Reference home low of only 9% more efficient than the BA Reference Home in Charlotte (zone 3).

3.2.2 Comparisons with the 2006 IECC Standard

Yet another way to examine the differences between the BA, HERS and IECC standards is to start with Evaluation Homes that are configured by BA rules to represent the Reference Homes of the alternative standards and calculate the savings with respect to the various Reference Homes. Figure 3.5 makes this comparison for the 2006 IECC Reference Home (Standard Design) configurations.

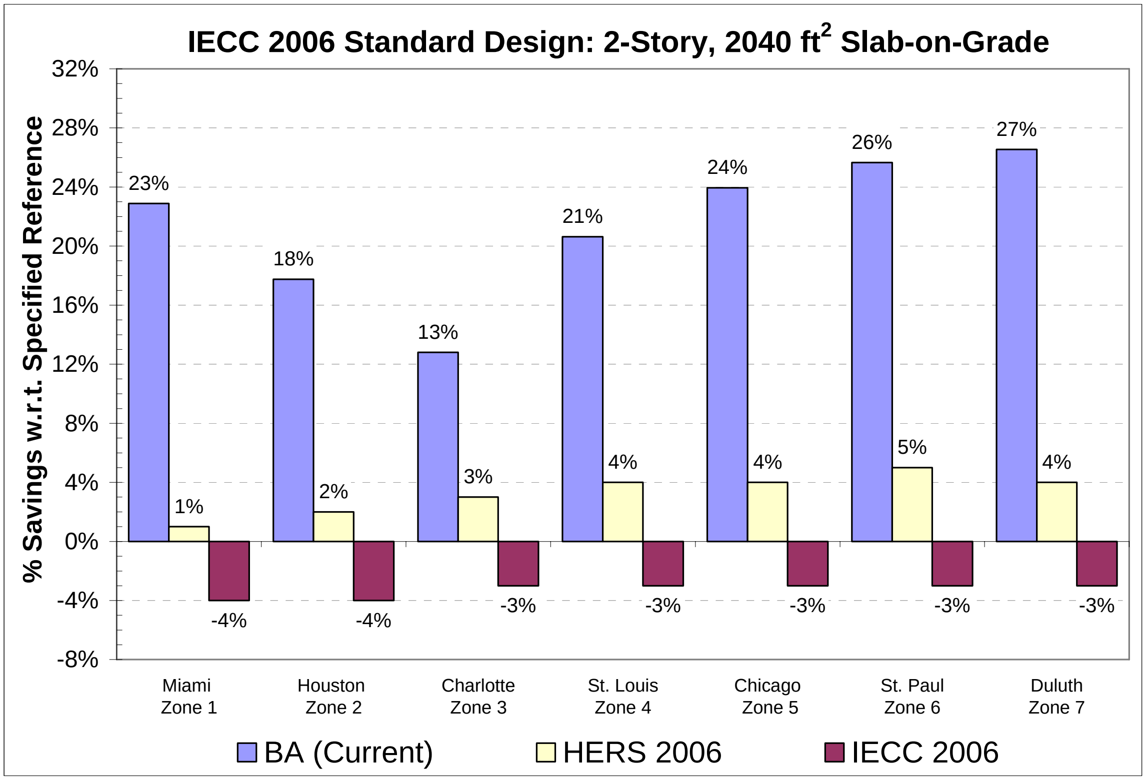

Figure 3.5 Bar chart of % savings for the IECC Reference Home under 3 different Reference Home specifications showing that while significant savings are shown for the current BA rule set, only small to negative savings are shown with respect to the HERS and IECC rule sets.

Figure 3.5 needs some additional clarification. The BA % savings are calculated using standard BA rules, however, the HERS 2006 and IECC 2006 savings use the HERS and IECC rule sets to calculate savings. This means that savings for HERS and IECC are computed using the HERS and IECC figures of merit (the HERS Index and the IECC e-Ratio). Thus, the IECC and HERS Evaluated Homes are not configured "strictly" by IECC and HERS Standards. Where they differ is mechanical ventilation, where neither the IECC nor the HERS rule sets incorporate mechanical ventilation air flow in their Reference Homes. For these Evaluated Homes, mechanical ventilation in accordance with ASHRAE Standard 62.2 specifications, including fan power at 0.4watts/cfm, was added to the Evaluated Homes in addition to the standard envelope specific leakage area required by the HERS or IECC rule set for Reference Homes. The result of this added mechanical ventilation air flow is that the Evaluated Homes are slightly less efficient than their respective rule sets would normally require. As a result, when compared with the IECC rule set standard for Reference Homes, the IECC Standard Design homes given in Figure 3.5 show negative savings where they would normally be expected to show zero savings.

A second item that should be clarified is the difference between the IECC and the HERS results. These differences occur for two reasons:

- The SLA for the IECC Reference Home is 0.00036 and the SLA for the HERS Reference Home is 0.00048, making the IECC Reference Home more efficient than the HERS Reference Home, especially in northern climates where the energy impacts of this envelope leakage area difference is magnified by a much larger indoor-to-outdoor temperature difference and stronger infiltration driving forces.

- The IECC Reference Home rule set does not allow the Evaluated Home to achieve any additional efficiency resulting from reduced window area and, for the cases presented here, the Evaluated Home has a 16.6% window-to-floor area ratio. This means that the home would achieve efficiency "credit" based on the HERS rule set but would not achieve that credits based on the 2006 IECC rule set.

3.2.3 Comparisons with the 2006 ENERGY STAR Standard

A similar comparison can be accomplished with the 2006 ENERGY STAR prescriptive standards[5] where, rather than the 2006 IECC standard, the 2006 ENERGY STAR Builder Option Package (BOP) standard is used to construct the Evaluated Home and the savings from the homes are compared across the various rule sets in the various climate zones. Figure 3.6 presents results from this analysis.

[5] EPA, *Energy Star Qualified Homes: National Builder Option Package*, U.S. Environmental Protection Agency, Washington, DC, July 1, 2006. Online at http://www.energystar.gov/ia/partners/bldrs_lenders_raters/downloads/NatBOPTRK_060206.pdf

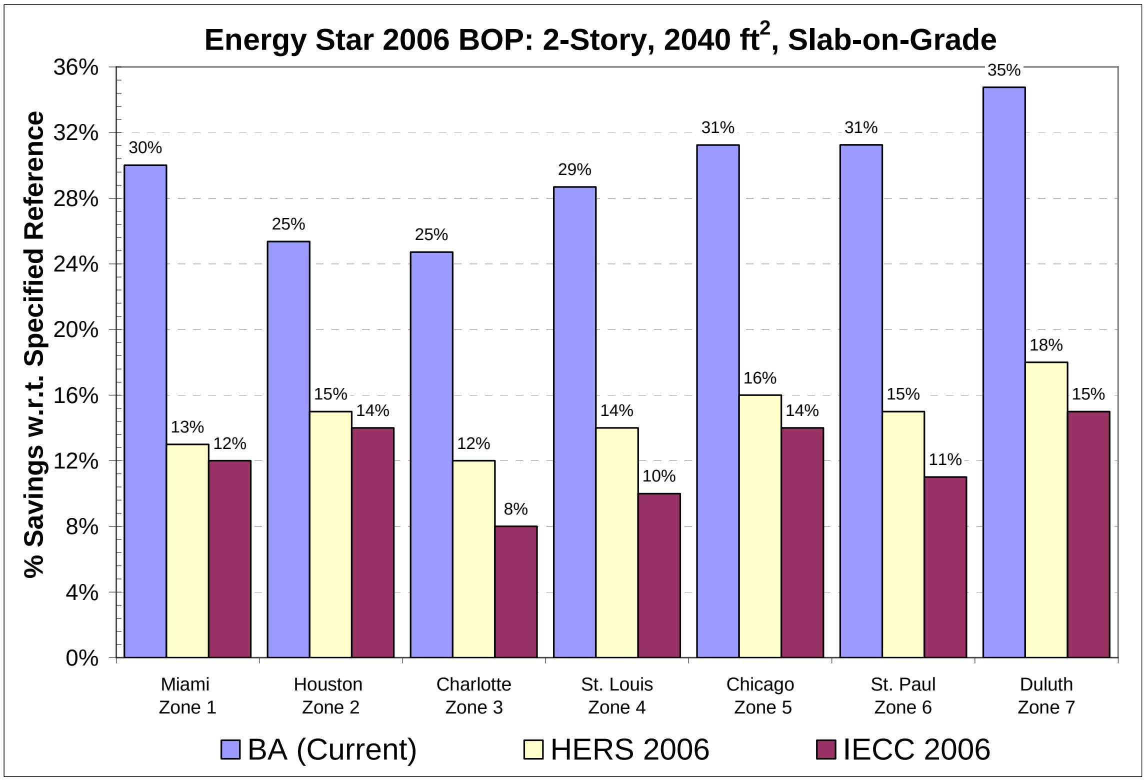

Figure 3.6 Bar chart of % savings for the 2006 ENERGY STAR prescriptive specification under 3 different Reference Home specifications showing that the current BA specification predicts significant savings (=>25%) for ENERGY STAR homes in all climates.

Figure 3.6 shows that the current BA standard produces predicted energy savings between 25% and 35%. These same homes, when evaluated against the HERS 2006 standard produce predicted savings of 13% to 18% and when evaluated against 2006 IECC standards produce predicted savings of 9% to 15%.

It is important to point out that the ENERGY STAR home cases maintain the same mechanical ventilation assumptions that were used in the previous analysis for the IECC Reference Homes. Additionally, they were evaluated using the same procedure, where the savings for the HERS 2006 and IECC 2006 were calculated using the assumptions of those respective rule sets. In other words, the additional mechanical ventilation air flows contained in the ENERGY STAR Evaluated Homes did not exist in the HERS and IECC Reference Homes to which they were compared.

3.2.4 The HERS Index

Another question that arises is how do these cases stack up on the HERS Index? The HERS Index is a relative scoring method with a scale from 0 to infinity. A HERS Index of 0 represents a home with no net purchased energy use and a HERS Index 100 represents the "American Standard Home." HERS Indices greater than 100 mean that the home is less efficient than the HERS Reference Home and Indices of less than 100 mean that the home is more efficient than the HERS Reference Home.

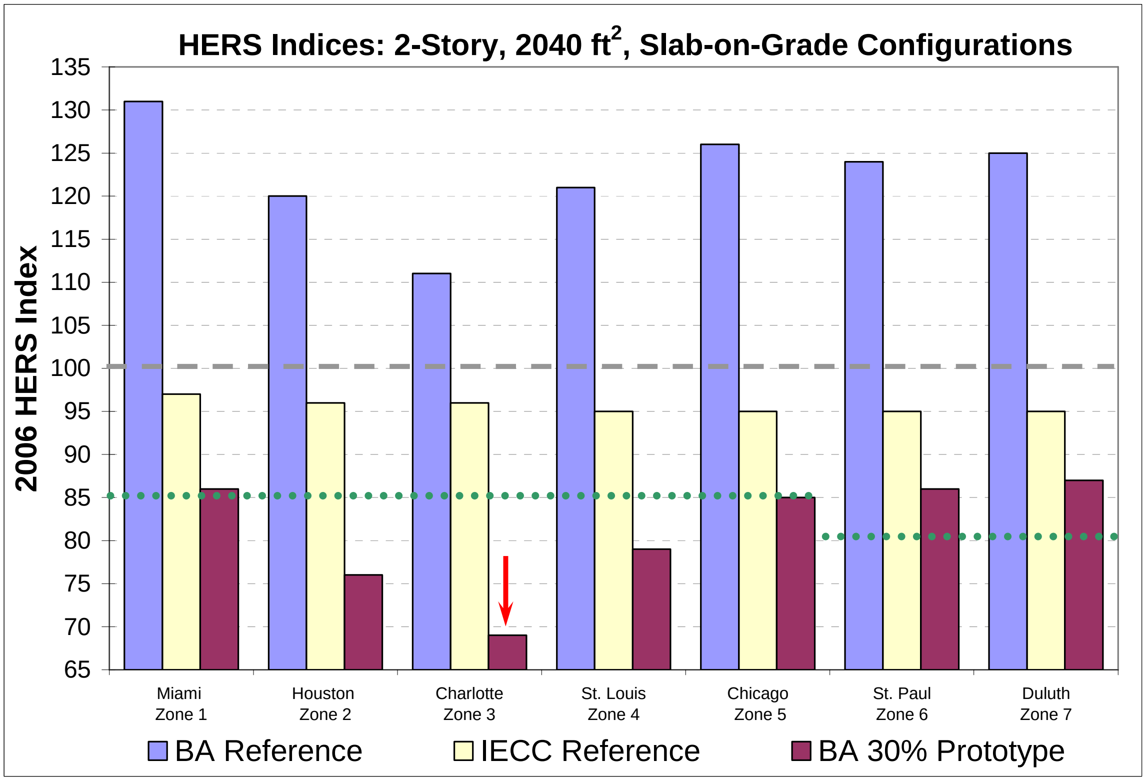

Figure 3.7 Bar chart of the HERS Index for various Evaluated Home cases showing a comparison of the BA Reference Home, the IECC Reference Home and the BA 30% Prototype Home in 7 climate zones.

Figure 3.7 presents the results of a HERS Index analysis showing the relationship between the BA Reference Home, the IECC Reference Home and the BA 30% Prototype Home cases. The green dotted line in the figure shows the performance-based criteria for the 2006 ENERGY STAR program in the 7 climates. Note also that the BA Reference Home cases all have HERS Indices well in excess of 100.

Note also the red arrow above the Charlotte BA 30% Prototype case. The HERS Index for this home is 68, indicating that it saves 31% (100 – 69) with respect to the HERS Reference Home. When evaluated for tax credit qualification, the heating and cooling envelope savings for this case are 39% and the energy savings for heating and cooling are 53%, qualifying this home for the EPAct 2005 federal tax credit. No other BA 30% Prototype case qualifies for this tax credit. In fact, the 30% BA prototype cases in St. Louis and Duluth would not qualify for ENERGY STAR label using the performance criteria shown by the green dotted line on the chart.

3.3 Impacts of Other Home Characteristics

A number of additional characteristics are treated differently by the different rule sets and, therefore, they will also impact the projected energy savings of homes. Among them are: 1) the number of stories in the home, 2) the foundation type used for the home,

3) the fuel type used by the home, 4) the internal gains used for the home, 5) the "other" energy uses of the home and 6) the size (conditioned floor area) of the home.

3.3.1 Number of Stories

The impacts deriving from the number of stories of the home are primarily related to the differences in treatment of the distribution system efficiencies in the Reference Home rule sets. Table 3.1 in Section 3.1 above illustrates these differences. For the BA Reference Home rule set the efficiency of the distribution system is dependent on the number of stories in the Actual Home. For example, for single-story, slab-on-grade homes, 100% of the ducts are assumed to be in the attic in the Reference Home. Additionally, the Reference Home distribution system is assumed to have air leakage to outdoors equal to 15% of the rated fan flow of the air handling equipment.

If this same home is converted to a 2-story structure, with the identical conditioned square footage, window area and other energy characteristics, 65% of the Reference Home ducts are assumed to be in the attic and 35% in the conditioned space. This same 65%-35% ratio is applied to the distribution system leakage, such that 15% x 65% = 9.75% of the rated fan flow is assumed to be leakage to outdoors in the Reference Home. These differences in the BA Reference Home result in differences in predicted energy savings for homes with different numbers of stories but with otherwise identical energy characteristics.

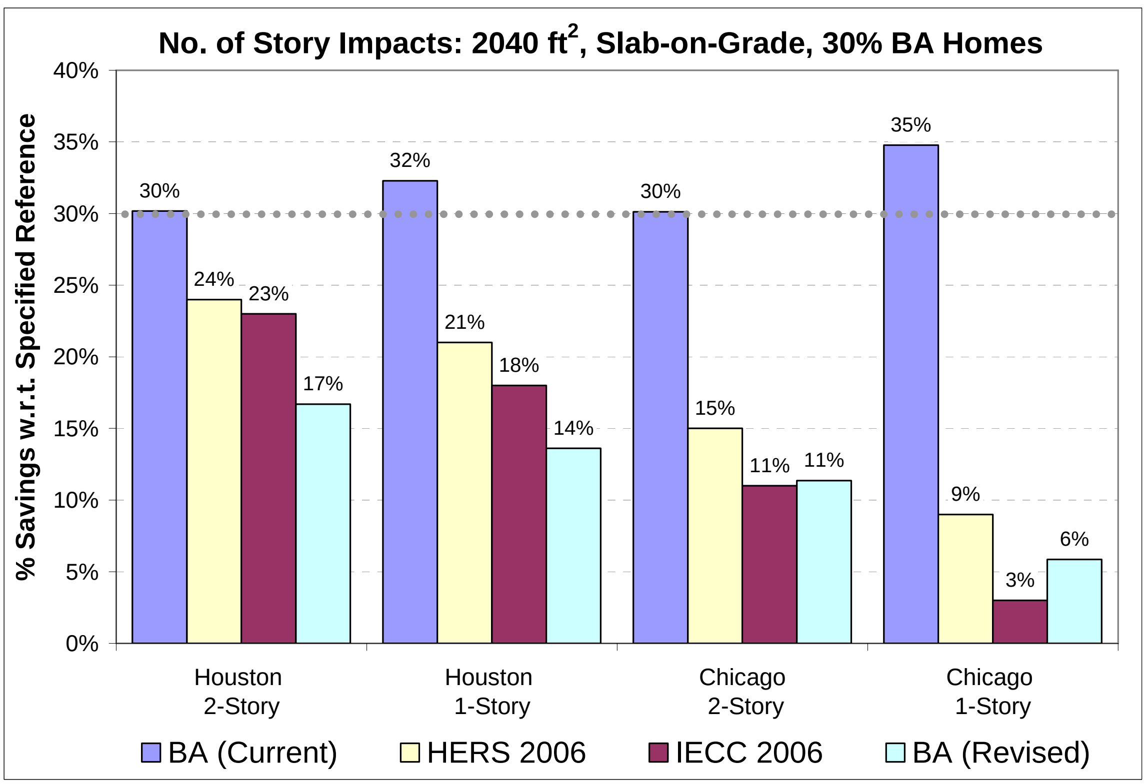

Figure 3.8 Bar chart showing impact of number of stories as a function of the rule set used to determine the savings.

Figure 3.8, above, illustrates how the number of stories of a home impacts the predicted percentage energy savings as a function of the rule set used to calculate the savings. For this figure, all Evaluated Home characteristics are kept identical, except the number of stories, and the homes are evaluated using differing rule sets. For the BA rule set the energy savings increase if the number of stories is increased from 1-story to 2-story. For all the other rule sets, the opposite occurs.

It is also important to point out that the 2-story, slab-on-grade home was used as the basis for analysis. In other words, the 2-story, slab-on-grade Evaluated Home was iteratively modified in each climate until their percentage savings with respect to the BA Reference Home were as close as practical to 30%. Once this was accomplished, the exact same envelope and equipment characteristics were incorporated into the 1-story and alternative foundation home cases.

3.3.2 Foundation Type

Much like the number of stories, foundations are treated differently by the different rule sets. Again, referring to Table 3.1, one can see that the distribution system efficiency in the BA Reference Home is a function of foundation type. For single-story, slab-on-grade construction, the Reference Home characteristics are the most lenient (i.e. they allow the most room for improvement in the Actual Home). And for the basement home, the BA Reference Home characteristics are the least stringent. In fact, they are perfect and allow no room for improvement.

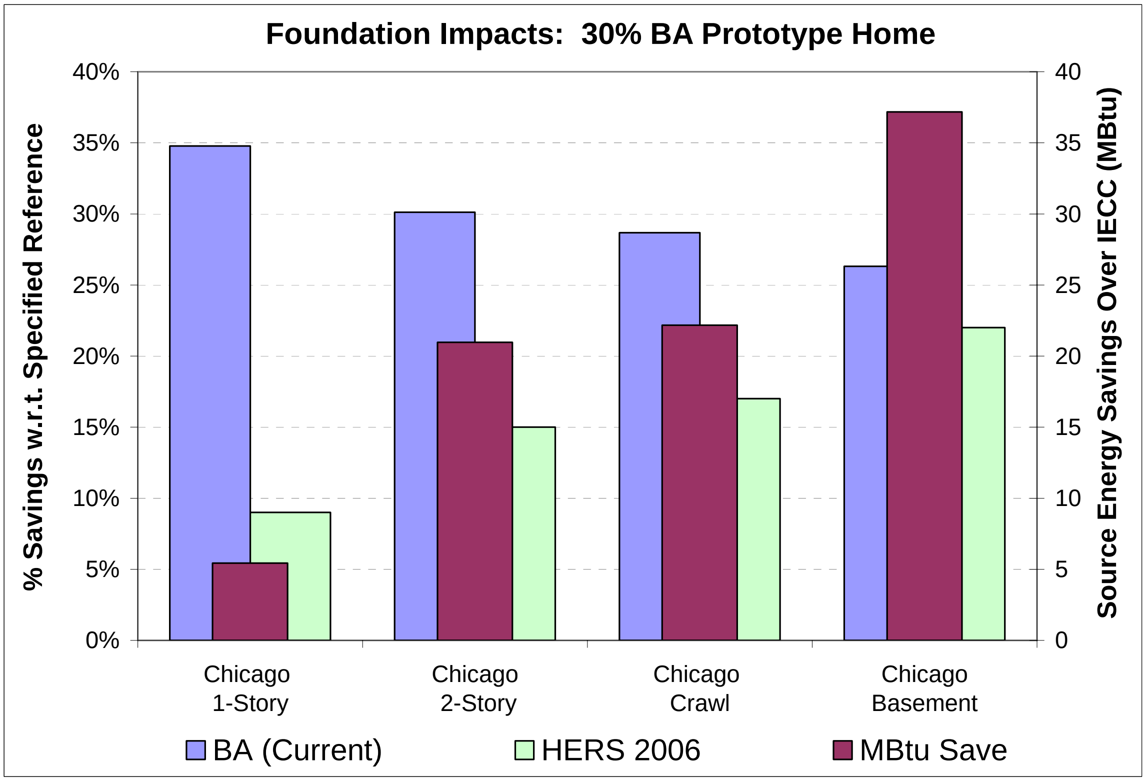

Figure 3.9 Bar chart showing predicted energy savings for the 30% BA Prototype cases as a function of the foundation type in Chicago.

Figure 3.9, above, illustrates the impact of foundation type, showing the predicted percentage energy savings using both the current BA and the HERS 2006 rule sets. Also shown by the magenta bar is the computed source energy savings in MBtu (10^6 Btu) as compared with the IECC 2006 Reference Home. It is clear from this figure that the BA rule set is treating foundations in exactly the opposite manner as the IECC and HERS rule sets.

3.3.3 Fuel Type

Fuel type is treated in three different ways by the BA, the HERS and the IECC rule sets. For the BA rule set, energy use and savings calculations are accomplished using source energy use. For HERS, relative home energy ratings are calculated using the normalized modified loads method,[6] and for the IECC, code compliance is determined using site energy cost rather than either source or site energy use. However, for the purposes of this analysis, all savings (percentage and MBtu) are calculated in accordance with the BA rule set as source energy use savings.

[6] Fairey, P., J. Tait, D. Goldstein, D. Tracey, M. Holtz, and R. Judkoff, "The HERS Rating Method and the Derivation of the Normalized Modified Loads Method." Research Report No. FSEC-RR-54-00, Florida Solar Energy Center, Cocoa, FL, October 11, 2000.

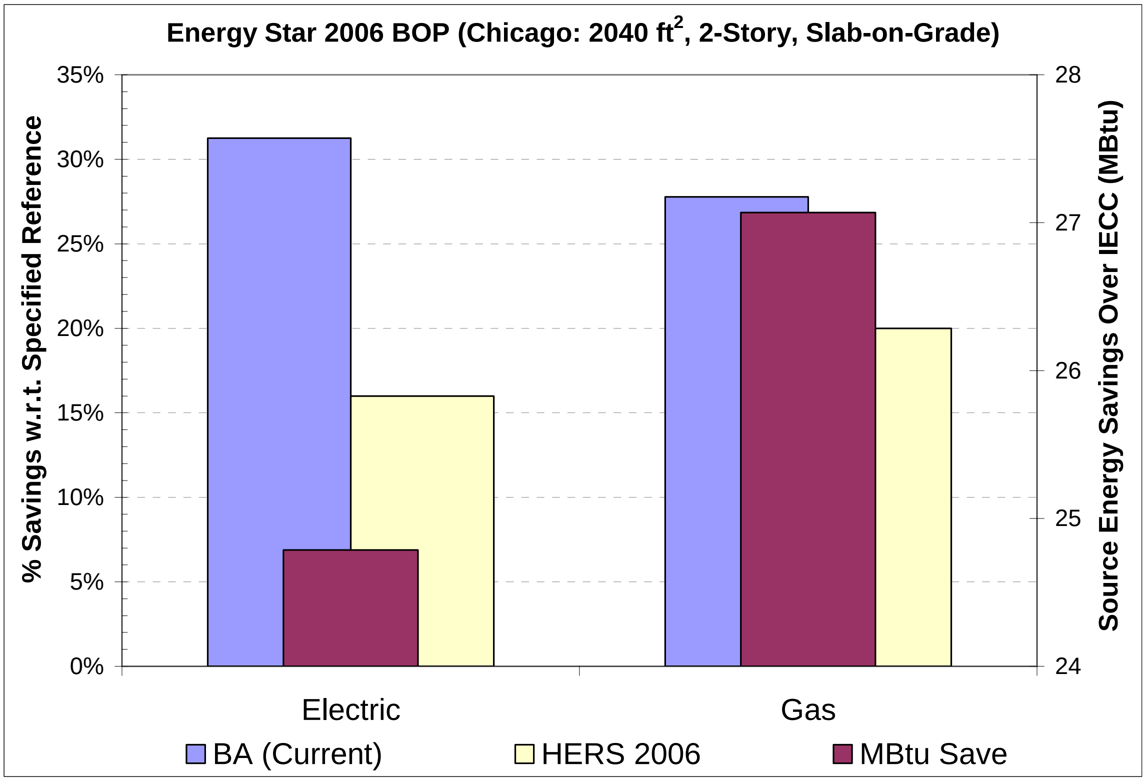

Figure 3.10 Bar chart showing differences between electricity and natural gas energy savings predications for the 2006 ENERGY STAR home case in Chicago.

However, there are other differences in the treatment of fuel type among the different rule sets. They can be generally illustrated using Figure 3.10, above. Using EPA's prescriptive standard for an ENERGY STAR home in Chicago, an all-electric heat pump-heated home and a natural gas furnace-heated home are evaluated. The natural gas home also contains gas-fired hot water, stove and dryer systems. The envelope features of both homes are identical. The results show that the all-electric ENERGY STAR home achieves greater percentage savings using the BA rule set but the gas home achieves greater savings using the HERS 2006 rule set. On the right-hand axis, the magenta bar shows the source energy savings in MBtu for these homes as compared with the IECC Reference Home energy use. These absolute energy savings also show that the gas home is saving more total energy than the all-electric home with respect to 2006 code standards.

3.3.4 Internal Gains

Internal gains (iGains) make a significant difference in the heating and cooling energy consumption of a home. The greater the internal gains the greater the cooling energy use and the smaller the heating energy use. There are differences between the internal gains assumptions in the BA rule set and the HERS and IECC rule sets. For the HERS and IECC 2006 rule sets, internal gains are determined as a function of the conditioned floor area (CFA) and the number of bedrooms (Nbr), as follows:

$$\text{iGains} = 17{,}900 + 23.8 * \text{CFA} + 4104 * \text{Nbr}$$

For the BA benchmark rule sets, internal gains are determined as a function of climate, using climate multipliers for miscellaneous internal gains that vary from 0.77 to 1.11, depending on climate. As a result, internal gains vary by climate for the BA rule set while they are constant for the HERS and IECC rule sets.

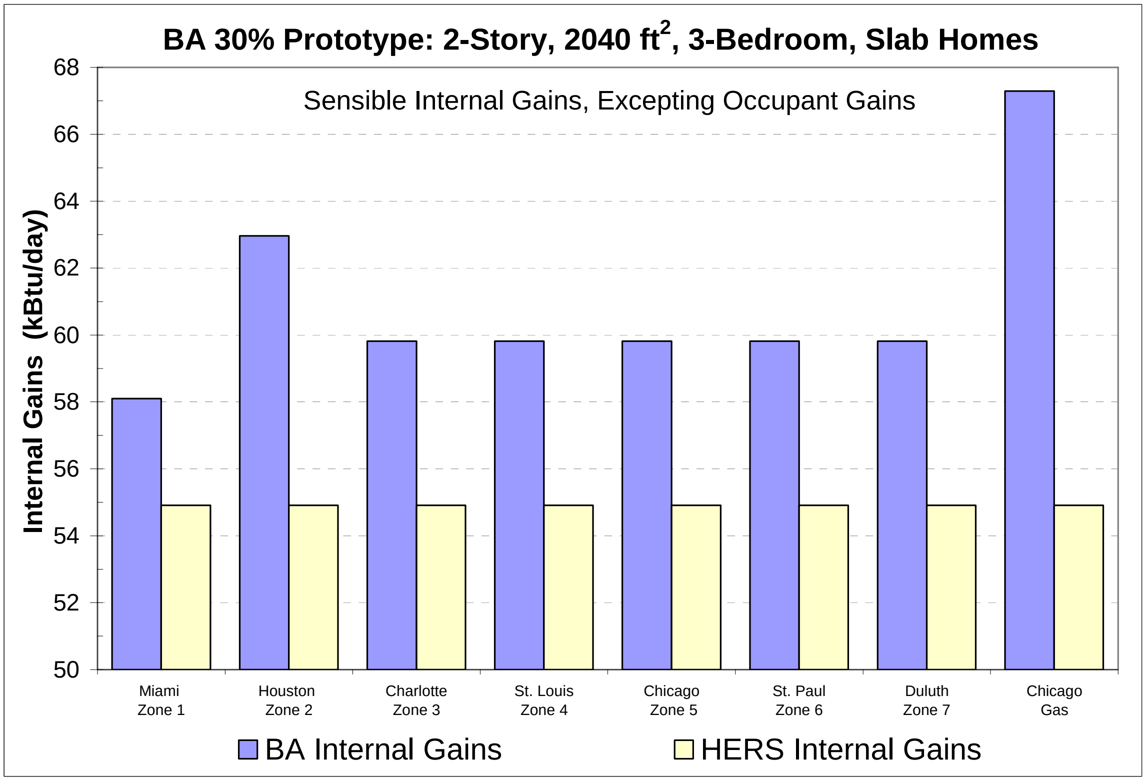

Figure 3.11 Bar chart showing internal gains (less occupant gains) for all electric homes in 7 climate zones and for gas home in Chicago (zone 5).

Figure 3.11 presents the total daily internal loads exclusive of occupant gains for the BA rule set and the HERS rule set. While the HERS rule set is constant across climate zones, the BA rule set varies from state to state. For Miami (and the remainder of Florida) the BA climate multiplier for miscellaneous electric loads (MEL) is 0.94 and for Houston (and the remainder of Texas), the multiplier is 1.11. For California, the multiplier is 0.77 and for New York it is 0.82. In the remaining states, the multiplier is 1.00.

The other item of interest shown in Figure 3.11 is the substantial increase in internal gains for gas homes. Since sensible internal gains offset heating and increase cooling energy uses, this difference results in the gas Evaluated Home being compared against a different standard than the all-electric Evaluated Home. The result of this is to favor gas homes in heating dominated climates but discourage them in cooling dominated climates.

3.3.5 Energy Uses Other than Code Energy Uses

Codes have traditionally addressed only the energy uses associated with heating, cooling and hot water. However, both the BA rule set and the HERS rule set include the lighting and appliance energy uses in homes. For the purposes of this analysis, these “other” energy uses, as defined by the BA rule set, have also been included in the IECC cases for determining % savings so that the IECC rule set could be compared against the BA rule set on a consistent basis. The exception to this is in the calculation of code e-Ratios, where only heating, cooling and hot water are considered in accordance with the IECC rule set.

For the HERS rule set, these “other” energy uses are also incorporated into the rule set, however, they are slightly different that the “other” energy uses included in the BA rule set. To be comprehensive, this report compares these “other” energy uses for the BA and HERS Reference Homes for the 2-story, 2040 ft^2, 3-bedroom, all-electric homes. Table 3.2 below presents the results of this comparison.

Table 3.2 Reference Home Lighting and Appliance Energy Uses for All-electric Homes as Defined by the BA and HERS Rule Sets

"Other" Energy Uses	BA (kWh/yr)	HERS (kWh/yr)
Hard wired lighting	1670	
Plug in lighting	417	
Lighting subtotal	2087	2086
Refrigerator	669	774
Clothes washer	105	
Clothes dryer	835	891
Dishwasher	206	145
Cooking	604	447
Other & plug	3407	3146
OA Ventilation	199	199
Total	8111	7688

Table 3.2 shows that, while there are sometimes significant differences in the individual Reference Home energy uses between the two rule sets, there is a relatively small difference (~5%) in the total lighting and appliance energy uses between the two rule sets.

3.3.6 Home Size

To this point, results have been from only the medium sized home. However, the analysis also considered home size. This home size analysis is accomplished using slightly different homes than were used in the previous results. In order to keep everything identical except the size of the homes, a set of 2-story “boxes” were created. The box sizes were 20 ft x 30 ft, 30 ft x 40 ft and 40 ft by 45 ft. Each box had an 18% window-to-floor area ratio with 40% of the windows facing east and west and 10% facing north and south. Each box also contained identical envelope and equipment energy efficiency features. These features were arrived at through a "calibration" of the 2,400 ft2 home to exactly meet the current BA 30% Prototype requirements.

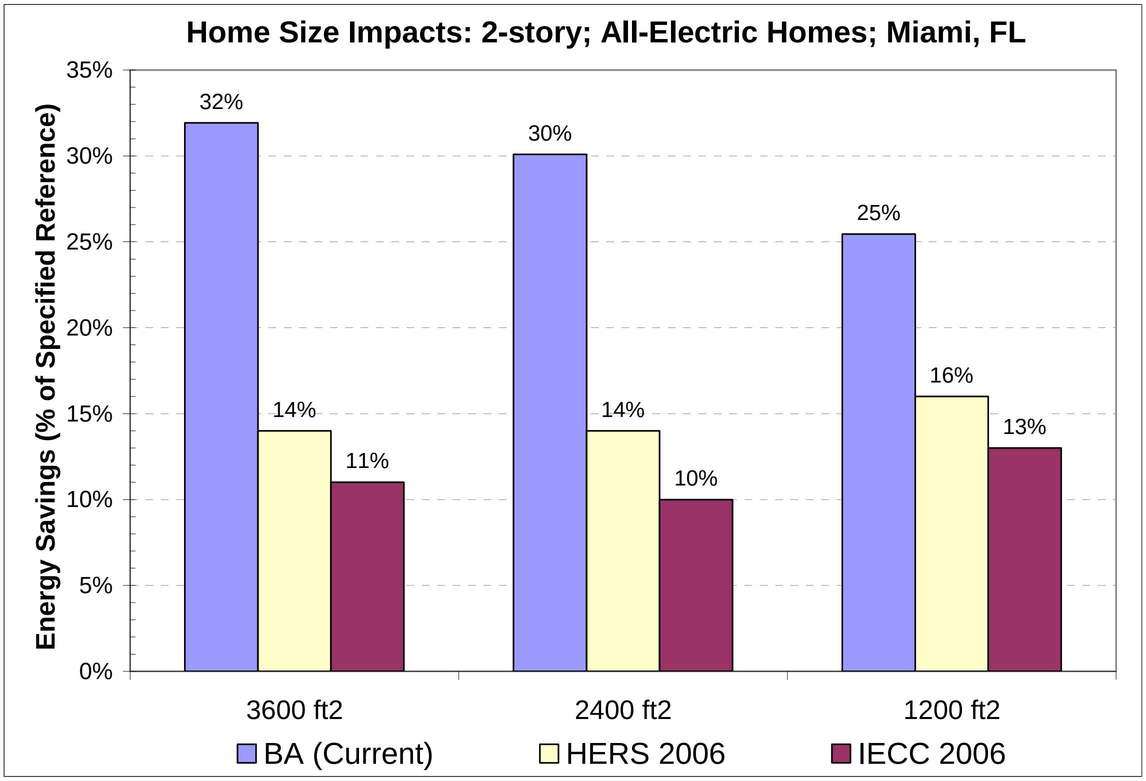

Figure 3.12 Bar chart of percent energy savings as estimated by comparing the BA 30% Prototype with the Reference Homes of the BA, HERS and IECC rule sets.

Figure 3.12 show the results of the home size analysis for homes located in Miami, Florida. It is interesting to note that the BA results and the HERS and IECC results trend in opposite directions. The BA rule set results in smaller savings predictions for smaller homes and the HERS and IECC rule sets result in larger savings predictions for smaller homes.

3.4 Higher Levels of Energy Efficiency (BA-50)

The BA 50% Prototype performance level was also examined in the study. Cooling dominated, mixed and heating dominated climates were selected for this analysis. The homes used were the 2-Story, 2040 ft^2, slab-on-grade cases. They were modified to reach the BA 50% Prototype performance level in each climate and the incremental revised benchmark analysis discussed in Section 3.1 was performed for each case. The projected savings for these homes were then compared across Reference homes.

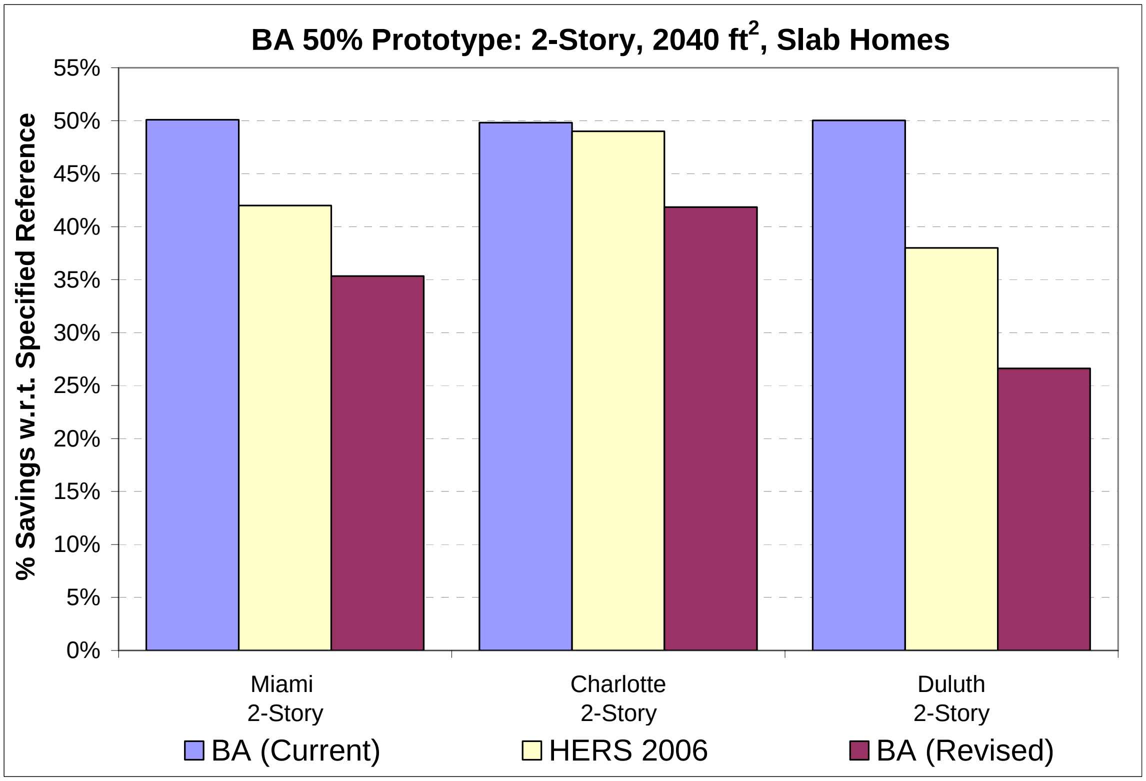

Figure 3.13 Bar chart of BA 50% Prototype homes showing cooling dominated, mixed and heating dominated climate results. The Charlotte home required a 500 peak-watt PV system to reach the 50% goal.

Figure 3.13 provides summary results from this analysis. In all cases the HERS and the Revised BA rule sets showed less savings than the Current BA rule set. For Charlotte, the HERS rule set shows projected savings very near the Current BA rule set, indicating that the trends from the BA 30% Prototype analysis also pertain to the BA 50% Prototype. Again, we see that a Revised BA rule set will result in the lowest projected savings of the rule sets examined.

4 CONCLUSIONS

The conclusions that can be drawn from the analysis are closely related to the major rule set differences presented in Section 2.2.2. These major rule set differences have been examined on an individual basis by substituting each of the HERS Reference Home characteristics, one-by-one, into the BA Reference Home and then evaluating the results with respect to the BA 30% Prototype Homes used in this analysis (see also Table 3.1). Figure 4.1 below presents results from the analysis, where the projected % savings using each alternative Reference Home characteristic value is subtracted from the projected % savings using the current BA Reference Home characteristic value (which is very near 30% for all cases).

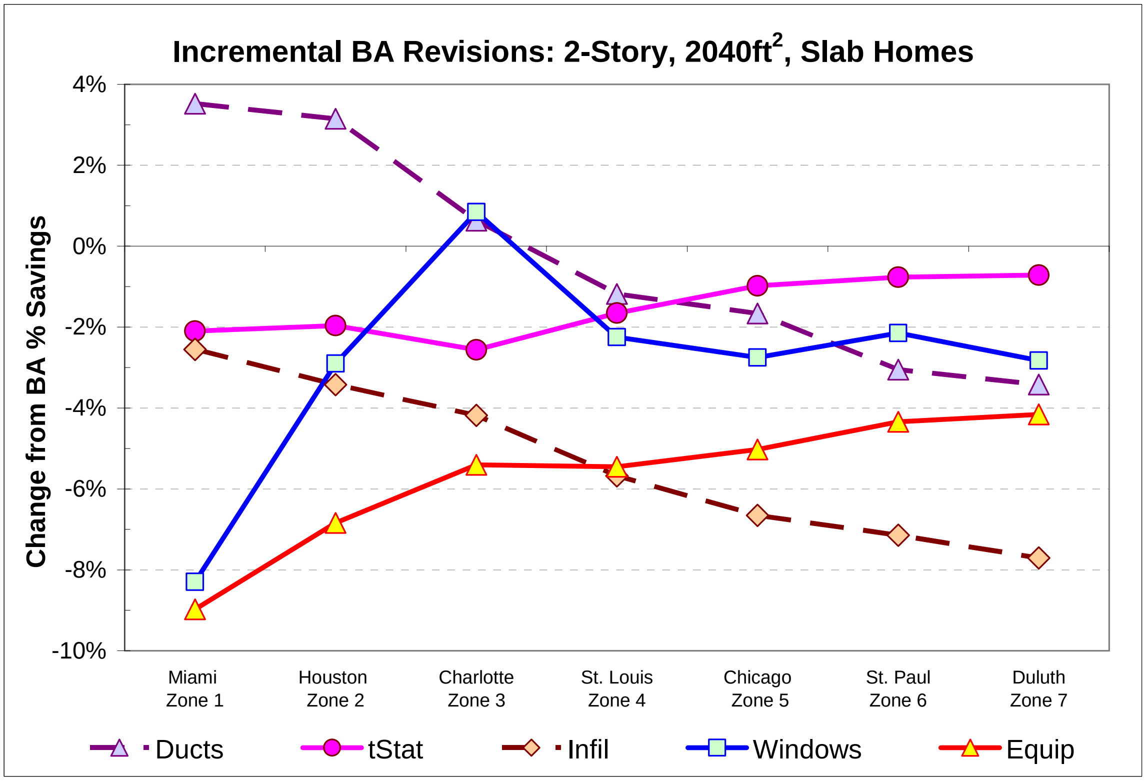

Figure 4.1 Line graph of the change in projected savings for the BA 30% Prototype Home as the characteristics of the BA Reference Home are revised, one-by-one, to correspond with the HERS Reference Home values. A negative % savings value indicates that the revised value for the BA Reference Home characteristic is more energy efficient than the current BA Reference Home value used for the characteristic.

Figure 4.1 shows that differences in the Reference Home characteristics across BA and HERS Reference Home rule sets are not necessarily consistent, either from characteristic to characteristic or across climate zones. Some Reference Home characteristics provide more change in southern climates and less in northern climates and some do the opposite. One Reference Home characteristic, windows, actually changes in a way that causes the mixed climate of Charlotte to stand out as very different from either cooling-dominated or heating-dominated climates.

This study provides additional examples of differences among the standards that are equally disparate. For example, Section 3.3 of the report highlights differences among the standards for number of stories, foundation type, fuel type and home size that illustrate that BA % savings can not be well correlated to the HERS Index, even within the same climate.

A summary discussion of each of these major differences in Reference Home characteristics follows:

- Differences in the treatment of thermostat settings between the rule sets results in the HERS rule set projecting savings that are about 2% less in the south to 1% less in the north as compared with the BA rule set. These differences may at first appears smaller than expected for a 2-3 ^{o}F thermostat revision, however, it is important to again point out that identical thermostat schedules are used in both the Reference and the Evaluated Homes, whether they are the current BA thermostat settings or the revised thermostat settings from the HERS rules.

- The line labeled 'Ducts' in Figure 4.1 shows the impacts of revising the BA Reference Home distribution system efficiency. In southern climates, the revision results in a less efficient Reference Home and in northern climates it results in a more efficient Reference Home. However, these results apply only to the 2-story slab-on-grade homes presented in Figure 4.1. In the BA rule set, distribution system efficiency is heavily dependent on a number of parameters, including the number of stories and the foundation type of the Actual Home and other home and foundation types would achieve different results from those shown in Figure 4.1.

  The complexity of the differences between the rule sets makes it virtually impossible to state with any certainty how results are impacted. In some cases, projected savings are greater using the HERS rule set and in other cases projected savings are greater. The data clearly show that it is much more difficult for BA multi-story and basement homes to achieve large projected savings as compared with single-story slab homes having the same building energy efficiency attributes (see Figure 3.1).

- The differences in Reference Home window treatment result in projected savings that are not well correlated across climate types. For both cooling-dominated and heating-dominated climates, the HERS and IECC Reference Home windows are more energy efficient than the BA Reference Home windows. However, for mixed climates like Charlotte, the BA Reference Home windows are more efficient than the HERS and IECC Reference Home windows.

  The differences are not as much related to window U-Factor as they are to window solar heat gain coefficient (SHGC). For example, in Miami, the BA Reference Home SHGC = 0.79, compared with a HERS Reference Home window SHGC = 0.40. Heating dominated climates in zones 6, 7 and 8 (Chicago, St. Paul and Duluth) are the opposite, with BA Reference Home window SHGC = 0.32 and HERS Reference Home window SHGC = 0.55. The result is that the HERS Reference Home is more energy-efficient in both cooling-dominated and heating-dominated climates. For Charlotte, the opposite is true and the BA Reference Home windows are more energy efficient than the HERS and IECC Reference Home windows.

- Equipment standard differences among rule sets appear reasonably well behaved. There are greater differences in cooling dominated climates compared with heating dominated climates because the increase in Reference Home equipment efficiency is greater for cooling systems than for heating systems. In fact, for gas-fired furnaces, there is no difference in Reference Home heating efficiencies between the various rule sets.

- The treatment of mechanical ventilation and infiltration is different in both Reference and Evaluated Home rule sets. The BA rule set adds the full ventilation air flow to a fairly high infiltration air exchange rate, while the HERS and IECC rule sets for Reference Homes do not. When the Actual Home is mechanically vented, the HERS and IECC Reference Home rule sets add additional fan energy to their Reference Homes but they do not add additional mechanical ventilation air flow because the Reference Home natural infiltration rates are assumed to be sufficient. The fan energy is added so that mechanical ventilation is not penalized in the Evaluated Home, which has the same type of mechanical ventilation as the Actual Home. As illustrated by Figure 4.1, the BA rule set provides substantially more benefit to home tightening and unbalanced mechanical ventilation in heating-dominated climates.

The overall conclusion from the analysis is that, due to the profound differences between rule sets, it is not possible to define a consistent correlation between the BA % savings value and the HERS or IECC figures of merit (the HERS Index or the Code e-Ratio). The changes in projected savings are so significant and their magnitudes so dependent on such a large number of interacting home features (e.g. foundation type, number of stories, home size, fuel type, etc.) that it is not possible to translate any given BA % savings value into a HERS Index and vise versa.

5 RECOMMENDATIONS

It is difficult to make recommendations based on this analysis. There can be pros and cons for any given rule set used to project energy savings. For example, the BA rule set was originally developed to measure progress toward a set of U.S. DOE energy savings milestones called Joules. The intent was to have a consistent standard of performance tied to mid 1990's era home standards. However, in the mid 1990's there were no definitive code standards for windows that are analogous to those that became effective in 1998. In addition, there were no standards or rule sets in the mid 1990's for the evaluation of distribution system efficiency, mechanical ventilation or lighting and appliances in homes.

Since the original objective of this study – to establish a correlation between the BA % savings value and the HERS Index value – could not be accomplished, there appear to be three potential options for moving forward. While options may not be considered recommendations in the conventional sense of the term, they, along with their advantages and disadvantages, are presented below:

1. Maintain the current BA rule set. This option allows BA program milestones to continue to be measured from a constant reference point. While this reference point can not be directly correlated to current codes or to HERS, it does allow program goals to remain consistent with past objectives. However, this advantage also works as a disadvantage. Potential builder partners can not be told with certainty how much better than code there homes will be. Thus, they are left in a bit of a quandary as to how they can advertise these homes in a way that is simply explained to their potential customers.

   Another disadvantage of proceeding with this option is that the current BA rule set appears to significantly advantage certain climates and significantly disadvantage others, at least with respect to current national model building codes and standards. For example, the BA 30% Prototype home in Charlotte, NC qualifies for the EPAct 2005 federal tax credit. At the same time, the BA 30% Prototype home in Duluth, MN, is only 8% more efficient than the IECC 2006 for that climate.

2. Revise the BA rule set. While revising the BA rule set may bring it more in line with alternative, more current rule sets, the analysis presented here did not show that this would result in complete correlation between revised BA % savings values and the HERS Index (or Code e-Ratio). The revised BA rule set examined here consistently resulted in lower % savings values than the HERS rule set (see Figure 3.3). Thus, adopting the revised BA rule set will cause BA program goals to appear significantly more difficult than code-based programs. While this may be true because code-based programs do not include lighting and appliance energy use while BA programs do, it will make achieving the BA 30% savings goal extremely difficult for BA builder partners, especially in heating dominated

climates. Note that the current BA 30% Prototype would only achieve 8% savings under a revised BA rule set in Duluth (Figure 3.3).

3. Migrate to the HERS Index. A large disadvantage of migrating to the HERS Index is that it would change the basis of BA program savings goals and milestones. Of course, the previous option, revising the BA rule set, would do the same. There are, however, some advantages of this option. The HERS Index is widely used as a performance metric. It is used as the basis for the ENERGY STAR new homes program and other emerging national programs like USGBC's pilot LEED-H program. The HERS rule set also forms the basis for the EPAct 2005 federal tax credit for highly efficient new homes. A significant advantage of the HERS rule set is that it is a consensus-based national standard.

   As a metric, the HERS Index includes all of the energy uses of a home. This is one of the basic tenets of the BA program – that whole home energy use is the comparison basis of the program. While changing the BA program standard to the IECC rule set would violate this tenet, changing to the HERS rule set standard would not. The HERS rule set also specifies a methodology to "score" the use of on-site energy production, whether by solar, wind or other "free" fuel resources or by highly efficient on-site conventional fuel technologies like micro-turbines and small combined heat and power plants.

   A disadvantage of the HERS Index is that the "scoring method" used by the rule set does not use energy use as its metric. The metric used by the HERS rule set is called the normalized modified loads method.[7] It was derived as a compromise consensus method of avoiding the fight between site energy use and source energy use. It can be shown to reasonably reflect energy cost in a market where the ratio between site costs for electricity and natural gas are near the ratio of 3 to 1.

   Finally, one advantage of using the HERS Index is that it can be explained fairly simply – the "American Standard New Home" has an index of 100 and a home that uses no purchased energy has an index of 0. In other words, zero is zero and anything greater than 100 probably doesn't meet current minimum energy standards.

[7] Fairey, P., J. Tait, D. Goldstein, D. Tracey, M. Holtz, and R. Judkoff, "The HERS Rating Method and the Derivation of the Normalized Modified Loads Method." Research Report No. FSEC-RR-54-00, Florida Solar Energy Center, Cocoa, FL, October 11, 2000.

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Appendix A

Selected House Plans and Elevations

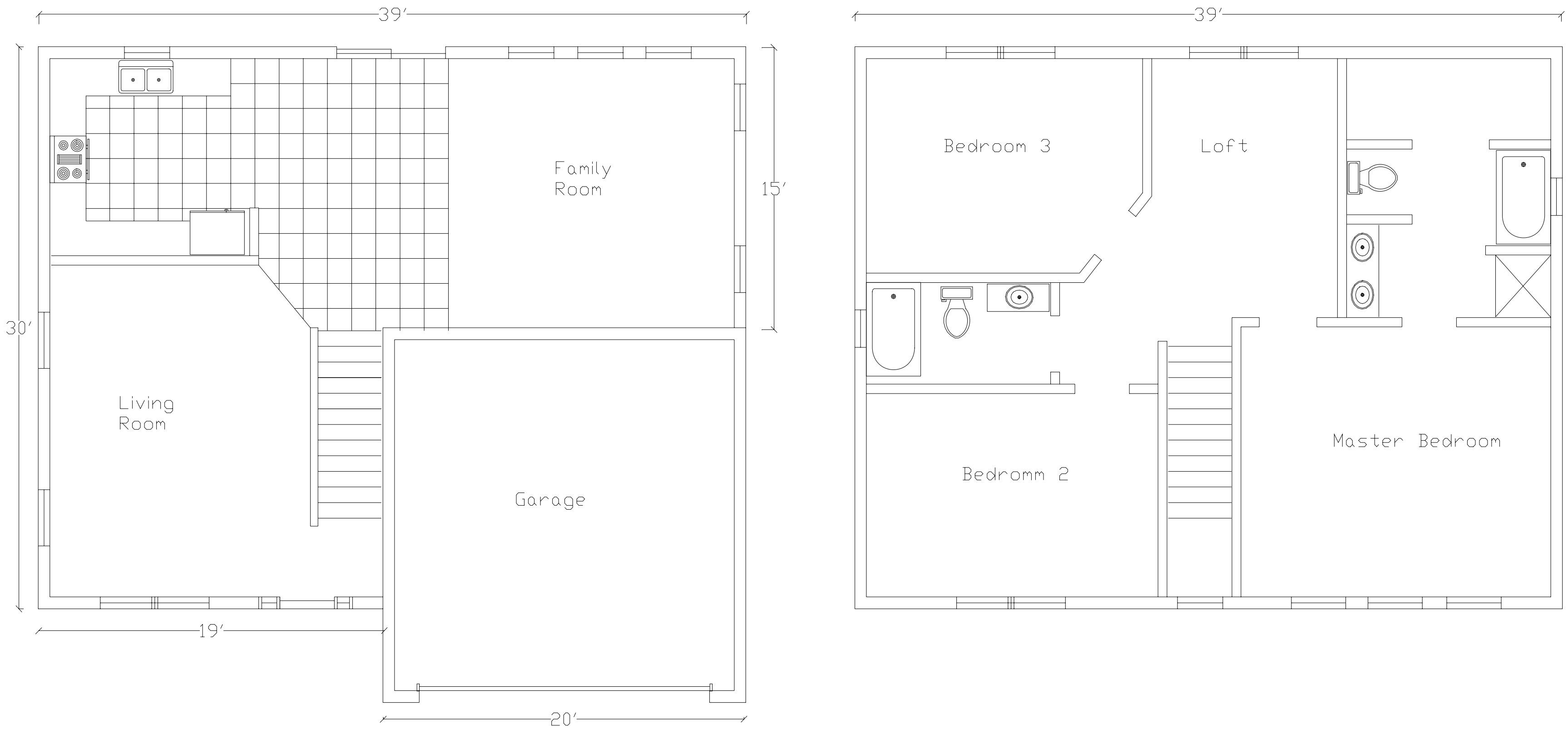


Figure A-1. First (on left) and second (on right) floor plan for 2040 ft^2 home used as the medium-sized model for the majority of the cases in the analysis.

Figure A-2 Front elevation for two-story 2040 ft^2 model home.

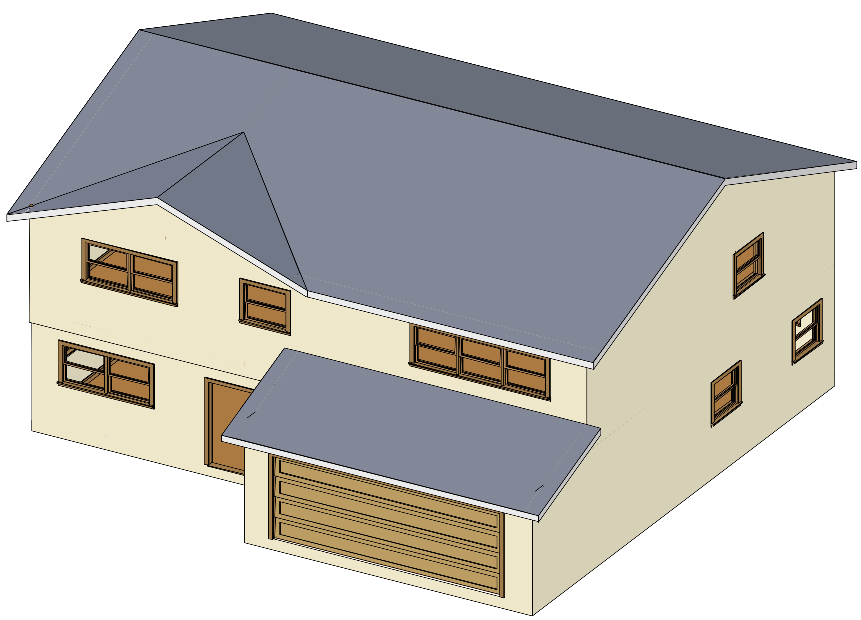


Figure A-3 Three-dimensional rendering of two story 2040 ft^2 model home.

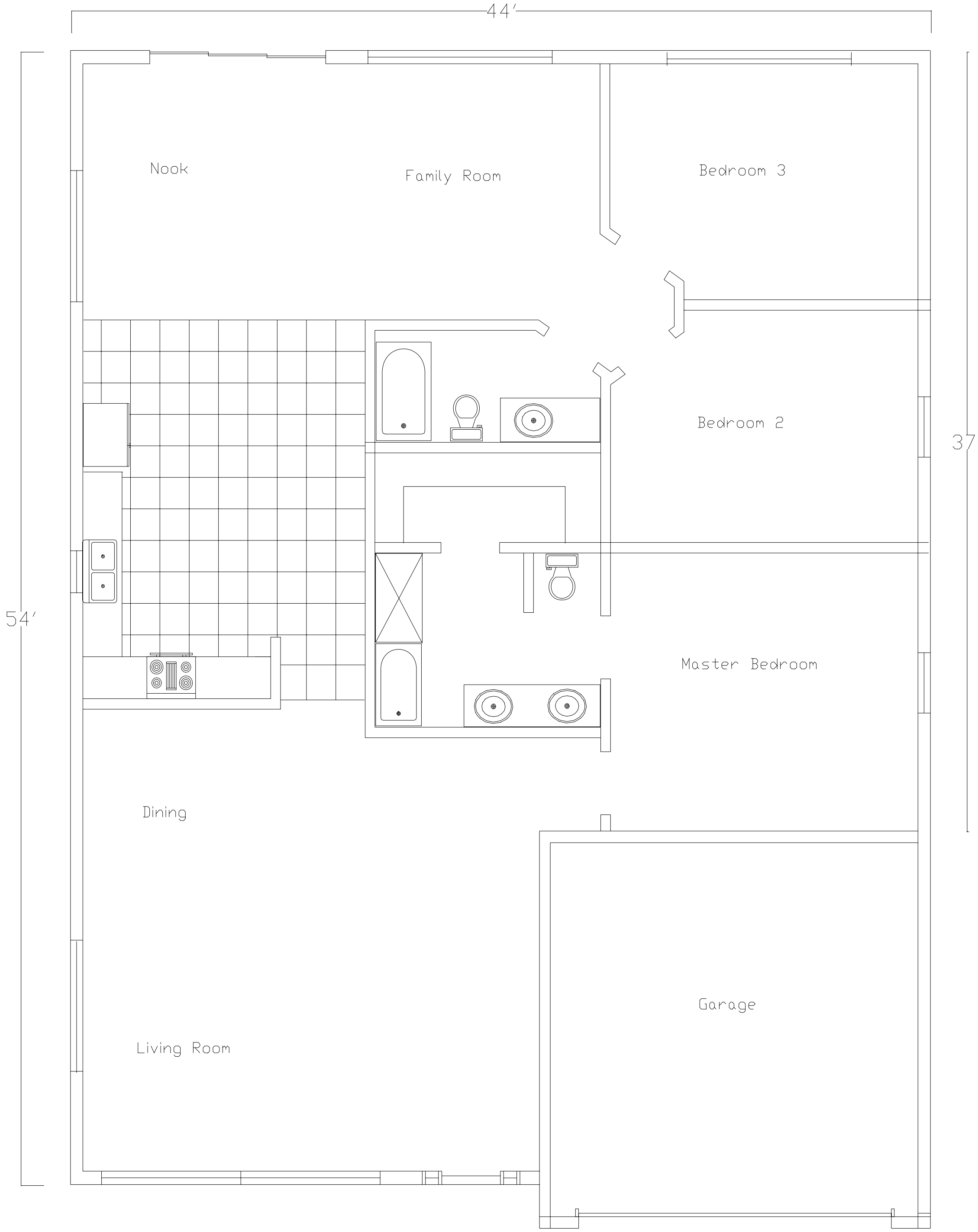


Figure A-4 Floor plan for single-story 2040 ft^2 home.

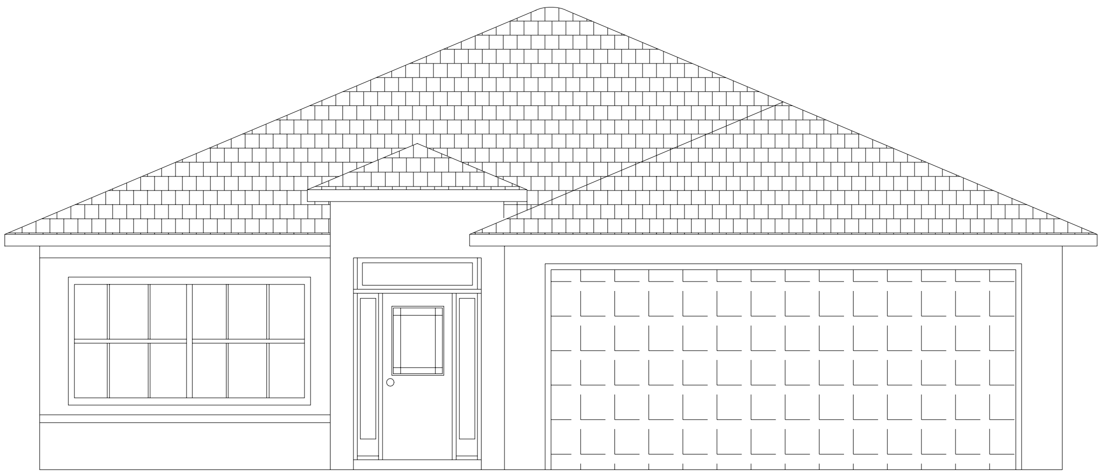


Figure A-5 Front elevation of single-story 2040 ft^2 model home

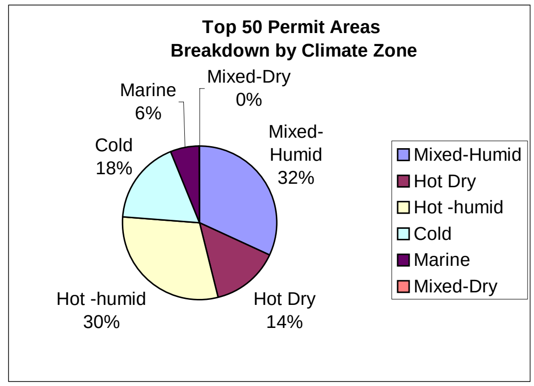
Appendix B

Housing Characteristics

The following building construction data and statistics for finished single-family homes were extracted from the U.S. Census Bureau site (http://www.census.gov/). The data was used to generate the following charts for the one-year period ending in June 2005.

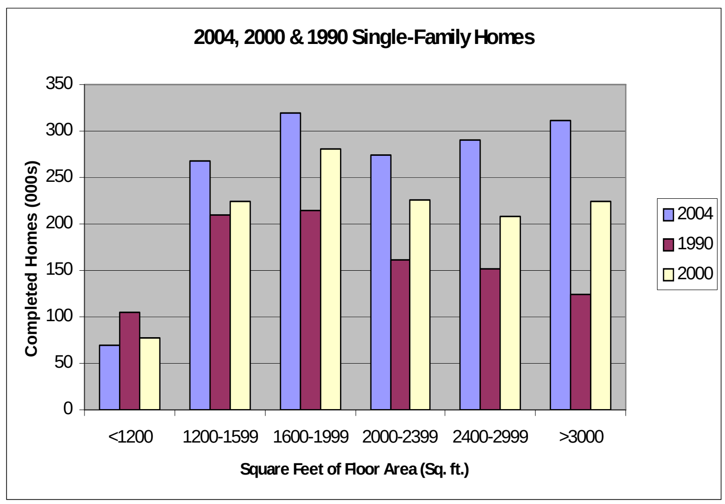
Climate Region Construction Activity

For each of the top 50 metropolitan single-family home construction areas, a climate region was designated based on the county listed under the Building America climate region listing (version 2, Nov. 6, 2003). The resulting percentage breakdown can be viewed in the chart shown at right. Mixed (32%) and Hot-Humid (30%) areas represent the larger regions of construction activity for single-family homes built during 2004-2005

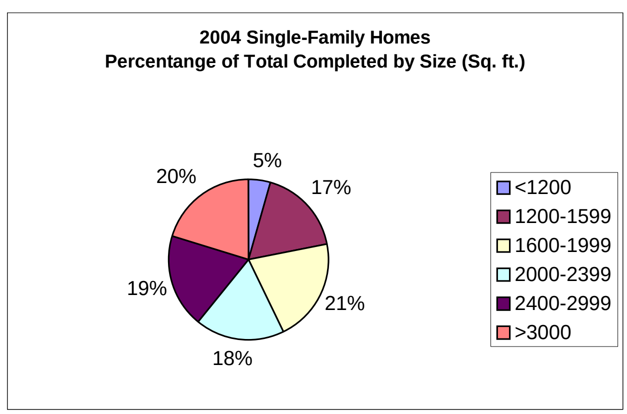


Single-family Home Sizes

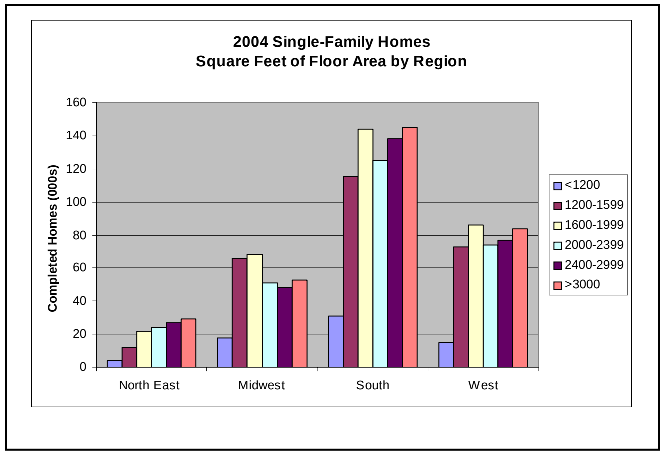
The bar chart at right displays the number of completed homes by size with the right-most range illustrating the amount of homes with conditioned living area larger than 3000 ft^2. The sampled statistics show the difference in the amount of homes built for the respective years, but most notably the increased change of number of homes with square footage larger than 3000 ft^2 when compared to 1990.



The chart to the right displays a breakdown as percentage of home sizes built during 2004-05. Seventy-eight percent of the homes were of at least 1600 ft^2 or larger. Smaller homes including those less than 1200 ft^2 account for 22% of the total built.

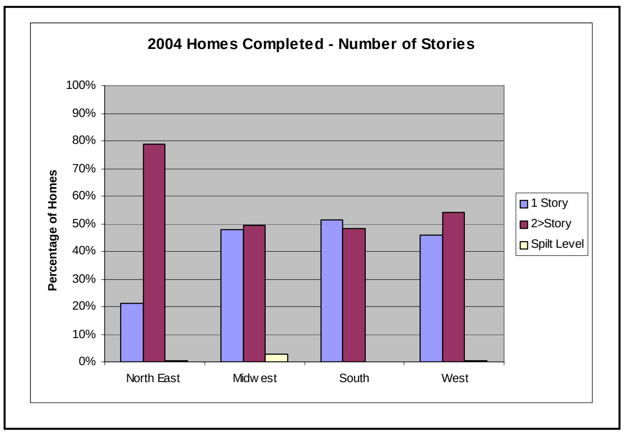


Square Feet of Floor Area by Region



The number of completed homes (by size) continues to be dominant in the South region as shown in the bar-chart figure at right. The amount of completed homes built in the North-East region show the least amount of building activity.

Number of Stories

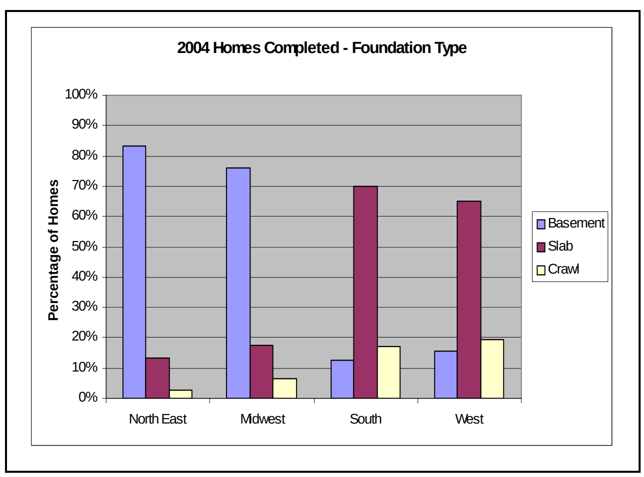


The number of stories for those single-family homes built during 2004-05 appear to be about equal for all regions except for the Northeast region, where the 2-story is the most dominant.

Furthermore, the south region is the only region that shows a slight percentage increase on one-story homes (about 3%) over two-story homes.

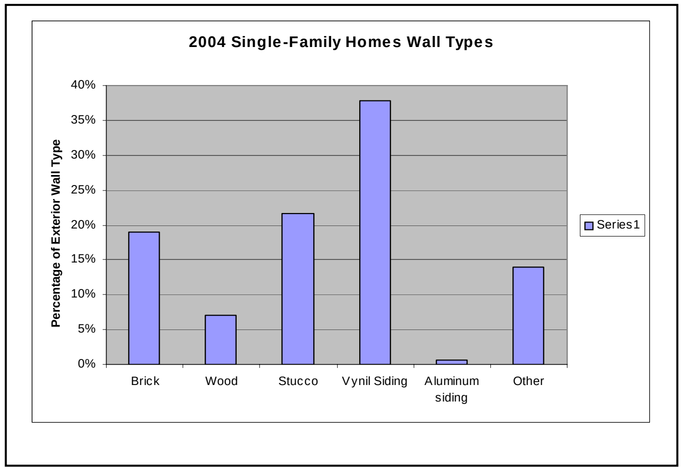
Foundation Types

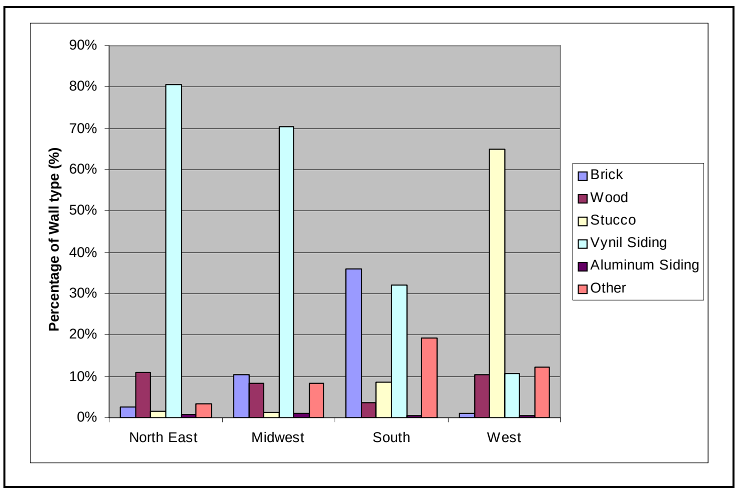
The type of foundation construction for single-family buildings on the four regions of the country can be examined in the side chart. Basement type homes continue to dominate in the Northeast (83%) and Mid-West (76%) regions. Slab foundations are the dominant construction method in the South (70%) and West (65%) regions of the country. Crawl foundation types in the South and the West regions represent 17% and 20% respectively.



Building Wall Envelope Material

Vinyl siding (38%) appears to be the dominant exterior wall material used in today's construction of single - family homes followed by stucco (22%). Brick (19%) follow as the third material utilized in wall construction as can observed in the South region category on the next plot shown below.





Vinyl siding also dominates as the preferred exterior wall material used in the Northeast and Midwest. However, stucco is clearly the dominant exterior wall material utilized in the West.

Heating Fuel

The type of fuel utilized to heat single-family homes constructed during the 2004-05 period can be examined in the chart below. Electric heating (54.3%) dominates in the South region and natural gas represents the majority throughout the rest of the country.